Integrated Environmental Assessment on Eutrophication

A Pilot Study

NERI Technical Report, No. 207

Torben Moth Iversen
Karina Kjeldsen
Peter Kristensen
National Environmental Research Institute
Bronno de Haan
National Institute of Public Health and Environmental Protection
Miel van Oirschot
Institute for Inland Water Management and Waste Water Treatment
William Parr
Tim Lack
Water Research Centre

Ministry of Environment and Energy
National Environmental Research Institute
November, 1997

Data sheet

Title:	Integrated Environmental Assessment on Eutrophication
Subtitle:	A Pilot Study
Authors:	Torben Moth Iversen(1), Karina Kjeldsen(1), Peter Kristensen(1), Bronno de Haan(2), Miel van Oirschot(3), William Parr(4) & Tim Lack (4)
Institutes:	National Environmental Research Institute (NERI)(1), DK National Institute of Public Health and Environmental Protection (RIVM)(2), NL Institute for Inland Water Management and Waste Water Treatment (RIZA)(3), NL Water Research Center (WRC)(4), UK
Serial title and no.:	NERI Technical Report, No. 207
Publisher:	Ministry of Environment and Energy National Environmental Research Institute ©
URL:	http://www.dmu.dk
Year of publication:	November, 1997
Referee:	Niels Thyssen, Keimpe Wiennga
Layout:	Kathe Møgelvang, Juana Jacobsen
Word-processing:	Hanne Kjellerup Hansen, Aase Pedersen
Please quote:	Iversen, T.M., Kjeldsen, K., Kristensen, P., de Haan, B., van Oirchot, M., Parr, W. & Lack, T. (1997): Integrated Environmental Assessment on Eutrophication. A pilot study. National Environmental Research Institute, Silkeborg, Denmark. 102 pp. - NERI Technical Report, No. 207 Reproduction permitted only when quoting is evident
ISBN:	87-7772-347-3
ISSN:	0905-815X
Paper quality:	Cyclus Print
Printed by:	Silkeborg Bogtryk
Circulation:	200
Number of pages:	102 pp.
Price:	DKK 150.- (incl. 25% VAT, excl.postage)

For sale at:

National Environmental Research Institute
P.O. Box 314
Vejlsøvej 25
DK-8600 Silkeborg
Tel. +45 8920 1400
Fax +45 8920 1414

Miljøbutikken
Information & Books
Læderstræde 1
DK-1201 Copenhagen K
Tel. +45 3337 9292 (Books)
Tel. +45 3392 7692 (Information)

Table of contents

1 Introduction

A main objective of the European Environment Agency (EEA) is to provide European information for European policy. Therefore integrated environmental assessment (IEA) has been identified as an area of high priority by the EEA. However, the present experiences with IEA are rather few and the EEA will have to develop its own way in the use of IEA.

Eutrophication of inland and marine waters due to excessive nutrient loading was identified in the Dobris Assessment (*European Environmental Agency, 1995a*) as a major environmental issue in Europe. This also served to highlight that while there is a tradition in many European countries for monitoring the aquatic environment and emissions to water, data quality and comparability may sometimes be questioned.

Eutrophication has therefore been chosen as a subject for this pilot study in IEA. The aim of the study are:

- to identify and test some ways forward for the EEA in the use of IEA;
- to identify gaps in data coverage and knowledge for addressing eutrophication as an environmental issue; and
- to identify appropriate methodologies and policies.

This study is performed as part of the Danish Hosting Agreement with the EEA, with the objective of facilitating the establishment of the EEA in Copenhagen.

We thank Niels Thyssen and Keimpe Wieringa, EEA for contributing valuable ideas and comments to the planning of the project In addition we would like to thank the following colleagues for helpful discussions and contributions to the report: Jørgen Windolf, Henrik Paaby, Ruth Grant, Erik Jeppesen, Jens Peder Jensen, and Dorthe Krause-Jensen all from NERI.

2 Integrated Environmental Assessment

2.1 Definition of IEA

In accordance with the European Environment Agency (EEA/064/95), the concept of Integrated Environmental Assessment in this report is defined as: *the interdisciplinary process of identification, analysis and appraisal of all relevant natural and human processes and their interactions which determine both the current and future state of environmental quality, and resources, on appropriate spatial and temporal scales, thus facilitating the framing and implementation of policies and strategies.*

This definition may look very broad at first hand, but an interpretation of some of the many words may help to focus on the important features of the concept:

- *Interdisciplinary* means, that not only biological and chemical science is needed in order to identify and analyse the problem under study, but also social science, since it is the *interactions* of society and the environment which is the key issue.
- *The appropriate spatial and temporal scales* means, that the information and outcome of IEA must be applicable at the European level and operate on the same timescale as other European policies.
- *Facilitating the framing and implementation of policies and strategies* means that IEA should provide all relevant information in order to be able to make proposals for efficient policies or to assess current policies.

Thus, the primary aims of performing IEA may either be to evaluate different strategies to reduce an environmental problem or to elucidate the relation between structural, technological and economic development in the society, the state of the environment and its implications on human welfare.

In the present case of eutrophication, relevant questions to be answered by the analysis might be, for example:

- What are the relative responsibilities of various human activities?
- What are the prospects regarding eutrophication of recent development trends, e.g. within European agriculture?
- What are the costs and effects following different policy strategies?
- What are appropriate targets to be proposed for sectors or countries following the principle of the cost-efficiency?
- How does society (in its broadest sense) benefit from less eutrophication?

2.2 The DPSIR-framework

The process of IEA may be described within the framework of the DPSIR-concept. According to this framework there is a chain of causal links from **D**riving forces over **P**ressures to environmental **S**tates and **I**mpacts on human welfare, finally leading to political **R**esponses

This framework is outlined in Figure 2.1. The important Driving forces to be identified in the case of eutrophication are the technological processes and the level of production and consumption within agriculture (loss of nutrients), industry, households and aquaculture, and finally the consumption of fossil fuels for energy (traffic and power plants).

The important Pressures are outlets of nutrients to surface waters: waste water, leaching of nutrients from fields and air-borne emissions from energy-consuming processes. An important task in IEA is, therefore, to analyse and quantify the causal links between driving forces and pressures (e.g. fertilisation and leaching of nitrate or transport trends and emissions of nitrous oxides).

Eutrophication shows up as changes in the physical, chemical and biological states of surface waters, but in groundwater, the changes are primarily concerned with the chemical state. The relationship

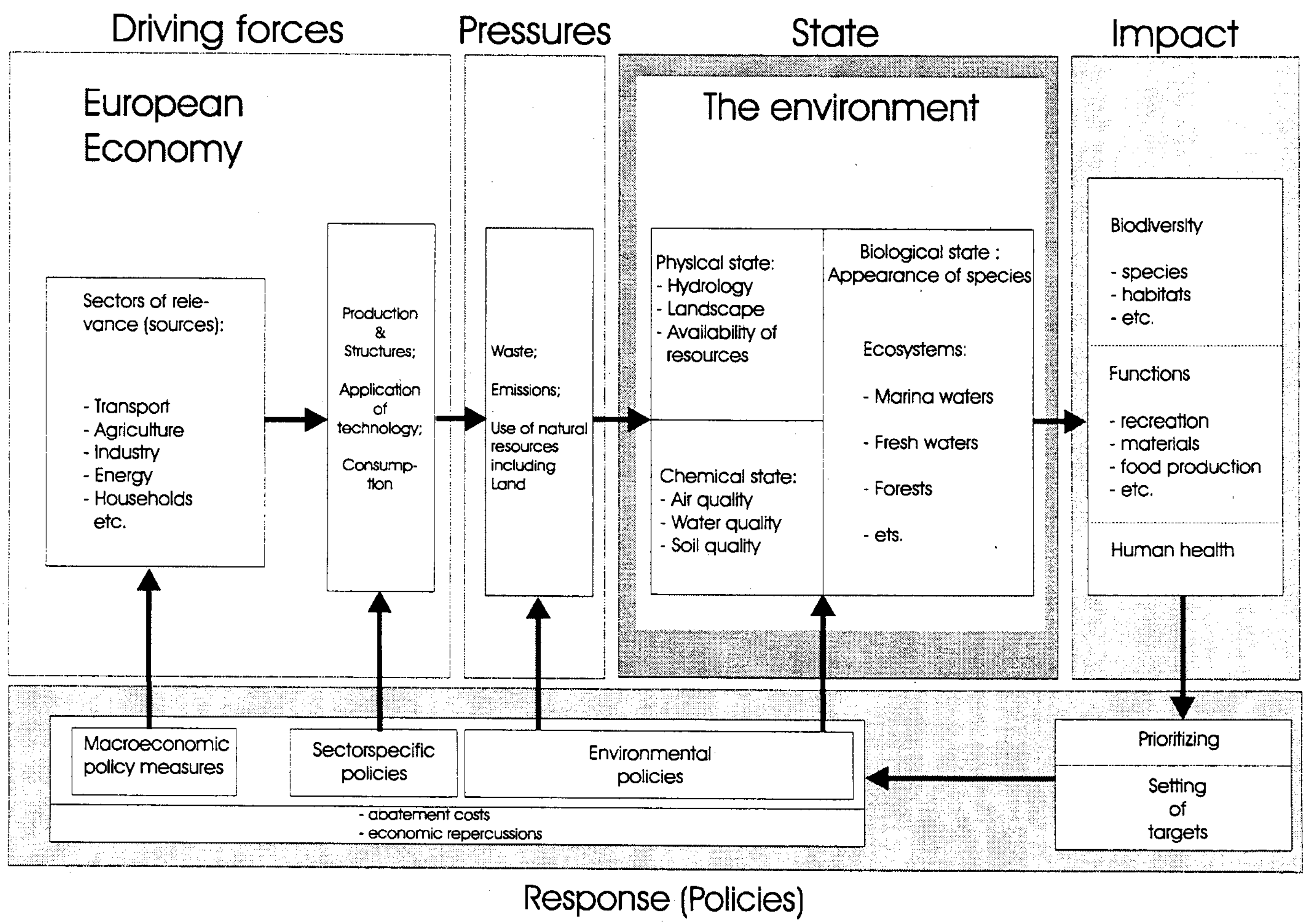


Figure 2.1. The DPSIR-framework (Source: The European Environmental Agency 1995)

between pressures and the state of the environment must be analysed and quantified. Some of these changes may Impact on human welfare (e.g. reducing fish stocks, reducing recreational options etc.). Ideally, these impacts should be assessed, but the information to quantify the impacts on human welfare are often lacking. As such, it is more expedient to stick to the use of target indicators on the ecological quality of surface waters (e.g. the transparency, the concentrations of phosphorus or chlorophyll, or the presence/absence of certain biological species) than to spend years and vast sums of money collecting detailed data.

Deterioration of the state of the ecosystems may cause economic repercussions on society. One example is the contamination of groundwater leading to high expenses for treatment of drinking water. However, abatement policies (e.g. reduced fertilisation in agriculture or waste water treatment) also have costs.

The assessment of all these impacts forms some of the necessary information for prioritising and the setting of targets - the processes of which are political in nature.

The possible Responses to the eutrophication problem - following analysis and assessment - could be general tax-measures, sectoral policy instruments (e.g. set-aside schemes, price policies) or regulation on pressures (e.g. restrictions on land use, fertilisation, revised minimum standards for waste water treatment). These measures to prevent and/or reverse the trend of nutrient enrichment and decreasing biodiversity all have a cost which is dependent on the technology available, and may have far-reaching impacts on sector (industry, agriculture, etc.) activities. Economic models may be required to quantify the costs.

2.3 The appropriate geographical scale

Considering the appropriate geographical scale for IEA of eutrophication, several considerations must be taken into account:

- The spatial extension of the eutrophication-problem: what are the spatial relation between the sources (driving forces) and the impacts?
- The dispersion (transport) of nutrients throughout aquatic ecosystems and ammonia volatilisation and nitrous oxides (airborne).
- The availability of reliable data and models: analysis at a disaggregated level by the use of deterministic models providing very specific data may produce reliable results for a particular region, but it may not be realistic to extrapolate such results to a European scale, because the necessary data are not available.
- The level of political response, i.e. what is the political questions to be answered by the analysis?

3 Eutrophication in rivers, lakes and coastal and open marine areas

3.1 Definition

Inland and marine surface waters are an important part of the European landscape. In recent decades the environmental condition of these areas has deteriorated as manifested by enhanced algal growth, periods of oxygen deficits, fish kills, etc. In many areas the poor environmental condition is attributable to enhanced nitrogen and phosphorus loading of the aquatic environment (eutrophication).

The growth of phytoplankton and benthic algae in the aquatic environment is often controlled primarily by the nutrients nitrogen (N) and phosphorus (P). Under natural conditions both nutrient loading and algal growth are relatively modest, and there is a diverse and stable plant and animal community. With enhanced nutrient loading the production and biomass of algae increase, which significantly affects ecosystem structure. Thus, the function, diversity and stability of plant and animal communities may be changed

Eutrophication significantly affects both the use and the aesthetic quality of surface waters. In cases where inland surface waters are used for domestic water supply, eutrophication may lead to taste and odour problems, and necessitate improved treatment prior to distribution; this is expensive, especially for very eutrophic water.

In this report eutrophication is defined as: *"nutrient-enrichment of the aquatic environment leading to increased primary productivity and related changes in ecological quality, ultimately reducing the utility of the aquatic area"*.

3.2 Nutrient cycling and the impact of various sectors

The environmental conditions in surface waters are greatly influenced by the characteristics of the catchment area. Likewise, climatic conditions affect the water flow. Bedrock geology and soil type determine the mineral content of the water.

Human activity affects the catchment and water quality in several ways, for example, through afforestation or deforestation, urbanization, agricultural development, land drainage, pollutant discharge, and flow regulation (dams, channelization, etc.). The lakes, reservoirs, and wetlands in a catchment attenuate the fluctuation in discharge and serve as settling tanks for material transported. Water flow, water quality and loading are therefore the net result of various characteristics of the catchment.

Point sources

The European population has increased markedly during this century. The urban population has increased at a faster rate during the same period - from less than one-third to more than two-thirds of the population. Sewerage systems have been constructed/upgraded to handle the increased population and both industrial production and household consumption have increased dramatically. This has resulted in extremely large quantities of waste water and hence also of nutrients. Because of the effective sewerage systems in many areas of Europe, the majority of this waste water is discharged into surface waters. The disposal of urban waste water is therefore an important use of surface waters.

In densely populated areas most of the phosphorus loading to surface waters is derived from human waste, phosphorus production being 1-1.5 kg P per individual per year in industrialised countries (*Jones et al. 1979*). The extent to which this is discharged into surface waters depends on the sewage treatment. Mechanical sewage treatment plants (primary treatment) removes only a minor part of the phosphorus from waste water, whereas plants with biological treatment and chemical precipitation of phosphorus may remove more than 95%. Waste water treatment plants incorporating phosphorus removal have been constructed in Europe during the last 15 years, especially in the Nordic and Western European countries. Similarly, many countries have lowered the phosphorus content of detergents, thereby lowering phosphorus loading of surface waters. However, at present the majority of European waste water treatment plants have only limited ability to remove phosphorus.

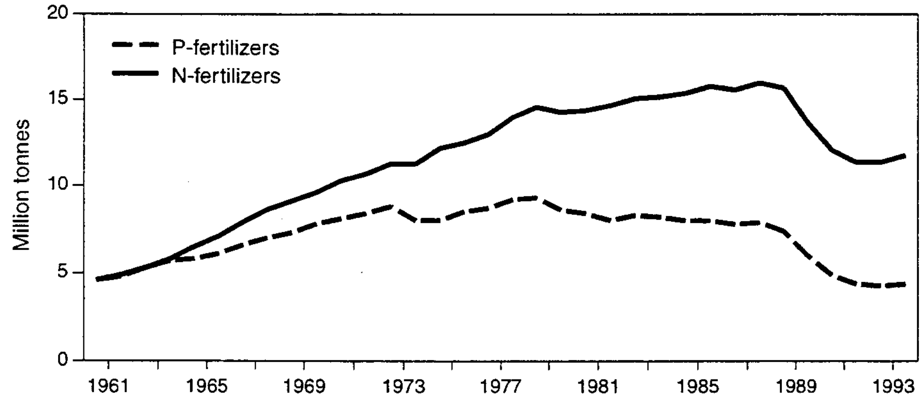
The nitrogen production derived from human waste products 2.2 - 4.4 kg N per individual per year in European countries (*European Environment Agency, 1995b*). Waste water treatment plants incorporation nitrogen removal have been constructed in Europe during the last 15 years, but to a less extend compared to phosphorus removal. Generally nitrogen loads from waste water make up less than half of the total nitrogen load to surface waters

Non point sources

Nutrient application to agricultural land includes fertilizer and manure. Whereas the consumption of nitrogen fertilizer generally has increased since 1970, the consumption has decreased in recent years (Figur 3.1). There are large variations in Europe from about 180 kg N per hectare agricultural land in the Netherlands in 1991 to 30-70 kg N in Southern Europe. The use of phosphorus fertilizer in Northern and Western Europe has generally decreased since 1970 to a level of 20-50 kg P per hectare agricultural land. In Southern Europe the consumption of phosphorus fertilizer has remained relatively stable at a level of 10-30 kg P per hectare.

Similarly, the application of manure to agricultural land varies widely between European countries from >200 kg N and >100 kg phosphate per hectare agricultural land in the Netherlands to <40 kg N and <20 kg phosphate in Southern Europe.

Figure 3.1. Development in the consumption of artificial fertilizer in the EU15 Member States. Source: Eurostat/FAO.



In general, much greater nutrient loads are applied than are harvested with crops. A large part of the nitrogen surplus leaches out of the root zone either to the groundwater and later to surface waters or directly to surface waters for instance through drains. Phosphorus is generally retained in the soil. However, in the Netherlands the high amounts of phosphorus applied for many years have resulted in about 20% of the agricultural land, mainly sandy soils being saturated with phosphorus increasing leaching of phosphorus significantly. Similarly, very high levels of phosphorus (>1 mg l^{-1}) have recently been reported in the major aquifer lying beneath the Po valley flood plain, Italy. Here, the major source of the problem appears to be phosphorus fertilizer applied to overlying rice fields.

The productivity of the agricultural sector has increased markedly in this century. Much land has been drained and many marshes, wetlands, ponds and lakes in Europe have disappeared. This has reduced the capacity of many freshwater ecosystems to retain and metabolise many pollutants including nutrients.

Today more than 30% of the land area of Europe is used for agricultural production, although there are large regional differences in the percentage of farm land, farming intensity, and type of crops grown. For example, agricultural land constitute about 81% of the total land area of Ireland , 65% of Denmark and 8% of Sweden. However, while 60% of the total land area is arable land in Denmark, only 18% is arable land in Ireland; most of the agricultural land being used for grazing.

The significance of different sectors

The relative importance of phosphorus sources to surface waters vary widely in different parts of Europe (Table 3.1).

In sparsely populated areas with very low agricultural activity, such as the Swedish catchment area to the Gulf of Bothnia (including the large rivers Torne älv, Kalix älv and Lule älv), only a small part of the phosphorus loading is related to human activities. The loading is primarily derived from diffuse run-off from undisturbed land.

Table 3.1. Sources of phosphorus discharge to selected catchments. Source: revised from [1)] *Löfgren & Olsson, 1990;* [2)] *BMLF, 1995;* [3)] *Umweltbundesamt, 1994;* [4)] *Italian Ministry of the Environment, 1989;* [5)] *, Oirschot, personal communication;* [6)] *Græsbøll et al. 1994.*

	Catchment area; annual loading; area run-off in kg P $ha^{-1}yr^{-1}$	Point sources (household, industry, etc.)	Agriculture	Natural run-off (forest, mountains etc.)	Atmospheric deposition on surface waters
Swedish catchment area to the Gulf of Bothnia 1982-1989[1]	116,103 km^2 1599 tP yr^{-1} 0.14 $kgPha^{-1}yr^{-1}$	3%	1%	**93%**	3%
Göta älv, Sweden 1982-1987[1]	50,181 km^2 777 t P yr^{-1} 0.15 $kgPha^{-1}$ yr^{-1}	**47%**	12%	**31%**	9%
Austrian part of the Danube catchment 1994[2]	80,731 km^2 5619 tP yr^{-1} 0.7 kgP ha^{-1} yr^{-1}	**71%**	24%	5%	
Germany 1987-1991[3]	356,950 km^2 100,000 tP yr^{-1} 2.8 kgP ha^{-1} yr^{-1}	**52%**	**42%**	6%	
The river Po, Italy 1989[4]	69,400 km^2 23,050 tP yr^{-1} 3.3 kgP ha^{-1} yr^{-1}	**67%**	**32%**	1%	
The Netherlands Catchment area at Rhine and Meuse, 1993[5]	37,000 km^2 14,400 tP yr^{-1} 3.9 kgP ha^{-1} yr^{-1}	**65%**	35%*		
Denmark 1993[6]	43,022 km^2 2,040 tP yr^{-1} 0.47 kgP ha^{-1} yr^{-1}	**51%**	**39%**	10%	

*Includes run-off from natural land (<5%).

Table 3.2. Sources of nitrogen discharge to inland surface waters in selected catchments. Source: revised from [1)] *Löfgren & Olsson, 1990;* [2)] *BMLF, 1995;* [3)] *Umweltbundesamt, 1994;* [4)] *Italian Ministry of the Environment, 1989;* [5)] *Oirschot personal communication;* [6)] *Græsbøll et al., 1994.*

	Catchment area; annual loading; areal run-off in kgN $ha^{-1}yr^{-1}$	Point sources (household, industry, etc.)	Agriculture	Natural run-off (forest, mountains etc.)	Atmospheric deposition on surface waters
Swedish catchment area to the Gulf of Bothnia 1982-1989[1]	116,103 km^2 24,434 tN yr^{-1} 2.1 $kgNha^{-1}yr^{-1}$	3%	1%	**88%**	7%
Göta älv, Sweden 1982-1987[1]	50,181 km^2 21578 tN Yr^{-1} 4.3 $kgNha^{-1}$ yr^{-1}	19%	22%	**33%**	**26%**
Austrian part of the Danube catchment 1994[2]	80,731 km^2 79,987 tN yr^{-1} 9.9 kgN $ha^{-1}yr^{-1}$	**36%**	**46%**	18%	
Germany 1989-1991[3]	356,950 km^2 1,040,000 tN yr^{-1} 29 kgN ha^{-1} yr^{-1}	**39%**	**53%**	8%	
The river Po, Italy 1989[4]	69,400 km^2 243,630 tN yr^{-1} 35 kgN ha^{-1} yr^{-1}	**43%**	**54%**	3%	
The Netherlands Catchment area at Rhine and Meuse[5]	37,000 km^2 140,000 tN yr^{-1} 37 kgN ha^{-1} yr^{-1}	**25%**	**75%**		
Denmark 1993[6]	43,022 km^2 98.000 tN yr^{-1} 23 kgN ha^{-1} yr^{-1}	7%	**87%**	6%	

*Includes run-off from natural land (<10%).

With increasing human activity phosphorus loading from the catchment areas increases, and in the Göta älv catchment area, 60% of the phosphorus loading can be related to human activities, most of this being derived from point sources. The Göta älv catchment includes many large lakes (17.8% of the total area), so atmospheric deposition to inland surface waters is responsible for a relatively high proportion of the phosphorus budget. In the other densely populated areas cited in Table 3.1, 50-96% of the phosphorus load to inland waters is derived from point sources, while agricultural activity generally accounts for 20-40%. If there was no human activity, phosphorus levels would only be 5-10% of the current levels. In these densely populated catchment areas municipal sewage discharge generally accounts for the major part of the point source discharge. However, in the Dutch part of the Rhine catchment industrial effluents account for more than 75% of the point source discharge *(RIVM, 1992).*

The relative importance of different nitrogen sources to surface waters also vary widely in different parts of Europe (Table 3.2)

In those river systems draining catchments in the central and western part of the EEA area 46-87% of the nitrogen load to inland waters is related to agricultural activity (Table 3.2). In some catchments point sources of nitrogen (predominantly municipal sewage treatment plant) also play an important role, accounting for 35-43% of the total discharge. In the two Swedish catchments the differences in percentage of agricultural land and population density are reflected in the nitrogen budgets. In the Göta älv catchment area, where about 10% of the land is cultivated and the population density is about 30 inhabitants per km^2, human activities account for 41% of the nitrogen discharge (some of the atmospheric deposition can also be related to human activities), while in the Gulf of Bothnia catchment area, where about 1% of the land is cultivated and the population density is only 1-3 inhabitants per km^2, most of the nitrogen discharge is related to diffuse run-off from forested and uncultivated areas.

3.3 Nutrient concentrations

As shown in *Kristensen and Hansen (1994)*, nutrient concentrations vary widely in European rivers and lakes.

In most cases, fluvial fluxes are the main nutrient source to lakes and marine areas.

For large rivers in EU a close relationship between population density and river phosphorous concentration has been documented (Figure 3.2). A close relationship also exists between the amount of water available per inhabitant and the river phosphorous concentration. The latter relationship takes into consideration that water availability varies widely in Europe, being particularly low in Southern Europe due to climate and to irrigation.

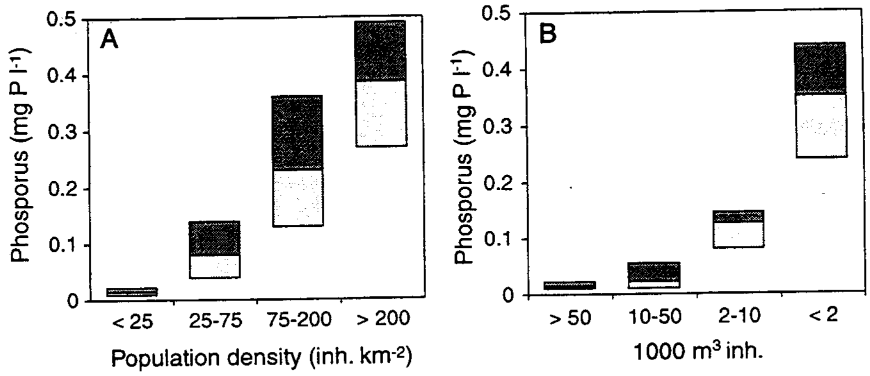


Figure 3.2: Annual average phosphorus concentration in relation to A) population density and B) dilution potential (1000 m^3 per inhabitant). Median, upper and lower quartiles are shown.

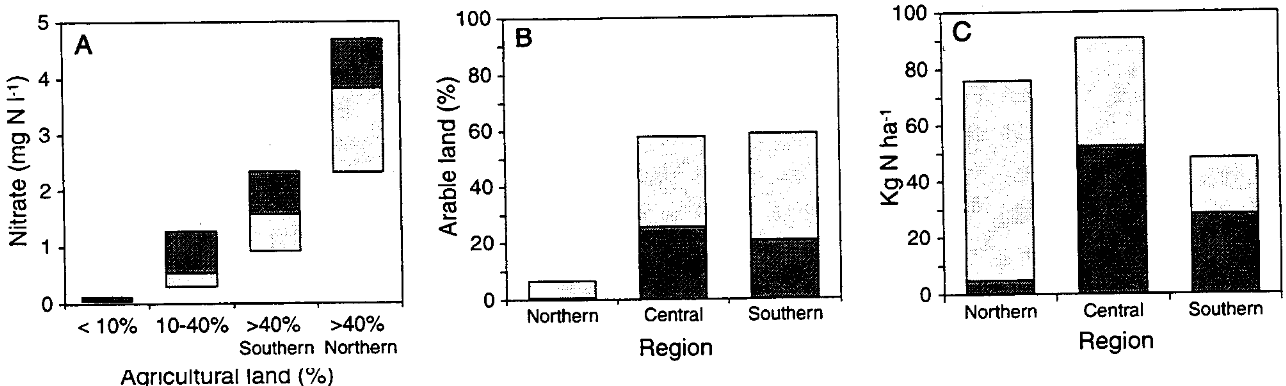


Figure 3.3: A) Annual average nitrate concentration in relation to the percentage of catchment area used for agricultural land. Median, upper and lower quartiles are shown. B) Percentage of total land area used for agricultural purposes (arable land and permanent crops (dark hatched); permanent meadows and pastures (light hatched)). Source: Eurostat (1995). C) Usage of nitrogen fertilizer: light bar: kg N per hectare of total area; dark bar: kg N per hectare of agricultural land. Source: Eurostat (1995).

Similarly, a relationship between percentage agricultural land and river nitrogen concentration has been established for large European rivers (Figure 3.3). The differences in agricultural development between different regions in Europe is clearly reflected in river nitrogen concentrations.

3.4 Ecological effects in aquatic ecosystems

The ecological effects of increased nutrient concentrations vary between different ecosystems.

Small rivers

In small rivers the main primary producers are benthic algae and macrophytes. The main regulating nutrient in small rivers is phosphorus as documented in laboratory and field experiments as well as in field studies (*Gibeau & Miller, 1989; Klotz, 1992*). However, a number of other factors including riparian areas shading, substratum structure and stability, invertebrate grazing etc. often overrules nutrient regulation (*Traaen & Lundstrøm, 1983; Iversen et al, 1991; Rosemond, 1993; Rosemond et al., 1993; Kjeldsen et al., 1996*). There is no evidence that the biomass of rooted macrophytes is regulated by nutrients (*Kern-Hansen & Dawson, 1978*).

Large rivers

When modelling nutrient loading to rivers as part of the IEA protocol, it is total nutrient loads to rivers that are usually modelled. However, not all of this nitrogen and phosphorus is available to algae or higher plants, and only those nutrients which are immediately bioavailable can be used in the short term for plant growth. For reasons of simplicity, the bioavailable N and P fractions are often assumed to be the soluble (or total) reactive phosphorus (SRP) fraction (orthophosphate) and the inorganic nitrogen fraction (nitrate plus nitrate plus ammonium). In most rivers phosphorus is more likely to limit plant growth than nitrogen, so emphasis is placed on phosphorus. The ratio of SRP:total phosphorus (TP) can vary dramatically from <0.01 to 1.0.

Rivers draining agricultural areas tend to have lower SRP:TP ratios (since most of the phosphorus carried into the rivers is adsorbed onto soil particles) than those draining predominantly urban areas (since the phosphorus in sewage effluent is largely bioavailable). Table 3.3 illustrates the range of TP and SRP values found in English and Welsh rivers.

Whilst trophic status remains a primary factor in determining plant growth in rivers, the physical characteristics of rivers are often more limiting to photosynthetic growth, and nutrient availability rarely limits productivity. For example, *Reynolds (1984)* states that "it is impossible to cite phosphorus conditions that are likely to limit algae in their natural environments," but later explains that "while SRP concentrations remain above 5-10 $\mu gP\ l^{-1}$ the probability is that many phytoplankton species will not be simultaneously limited by phosphorus deficiency." He then reviews the literature to demonstrate that a range of freshwater species in culture achieve half of their maximum growth rate (or phosphorus uptake rate) at external phosphorus concentrations of 11-364 $\mu g\ P\ l^{-1}$.

One of the major factor governing the rate of loss of phytoplankton is river velocity: at speeds greater than about 0.5 $m.s^{-1}$ there is little or no potential for even highly productive potamoplankton to reproduce before they are swept downstream (*Reynolds 1988*). Furthermore, in slow flowing rivers and canals other factors, such as turbidity may limit growth, regardless of nutrient levels.

Table 3.3. Minimum, mean and maximum regional SRP:TP ratios in England and Wales (*Mainstone et al 1995*)

National Rivers Authority Region	Mean SRP concentration ($mg.l^{-1}$)	Mean TP concentration ($mg.l^{-1}$)	SRP:TP ratio min	SRP:TP ratio mean	SRP:TP ratio max	No. of samples
Welsh	0.2537	0.2905	0.01	0.87	>1.00	1852
Southern	0.9778	1.1992	0.09	0.82	>1.00	74
Severn Trent	1.1333	1.2629	0.03	0.90	>1.00	573
Thames	2.1578	2.2379	0.03	0.96	>1.00	969
South West	0.1183	0.1804	<0.01	0.66	>1.00	5483
Anglian	0.8263	0.9283	<0.01	0.89	>1.00	1066
North West	0.3927	0.5447	<0.01	0.61	>1.00	378
Yorkshire	0.9012	no TP data				
Northumbrian	0.7750	0.7863	0.01	0.96	>1.00	191
Wessex	0.6179	no TP data				

The majority of macrophytes require sediment for anchorage and are, therefore, found mainly where deposition processes occur in slower-flowing reaches and pools. In faster-flowing reaches, however, where erosion rather than deposition is the main physical process, filamentous algae, such as *Cladophora,* tend to be more abundant because they can utilise rocky substrates for anchorage. *Cladophora* is also associated with high phosphorus concentrations, with maximum standing crops being reported in the literature at concentrations between 60 and >1000 μg P l^{-1} (see reviews by *Cartwright et al 1993,* and *Woodrow, et al 1994*). Other authors (e.g. *Gordon et al 1981, Robinson and Hawkes 1986*) have reported maximal growth rates to be achieved at phosphorus levels of 100-200 $\mu gP\ l^{-1}$ under otherwise non-limiting conditions.

Mainstone et al (1993), following a review of the literature and analysis of unpublished data from UK sites, concluded that there was evidence of changes in macrophyte community status at SRP concentrations above and below 100 $\mu g\ l^{-1}$, but not at concentrations of 100-200 $\mu g\ P.l^{-1}$ and those >200 $\mu gP\ l^{-1}$. *Cartwright et al (1993)* proposed a tentative Environmental Quality Standard of 30 $\mu g\ l^{-1}$ total phosphorus for rivers, while accepting that a lower level may need to be set for slow-flowing rivers.

Thus, there is a range of phosphorus levels within which ecological change occurs in riverine plant and planktonic communities, but such values assume steady-state or worsening conditions. This does not necessarily imply that reducing the total phosphorus levels in a river from 300 to 50 $\mu gP\ l^{-1}$ would bring about a dramatic improvement in ecological status in the medium- to long-term, especially bearing in mind that many macrophytes appear to derive nutrients primarily from the sediment, rather than the water column itself. British rivers were classified according to their flora by *Holmes (1983),* but this classification divides plant communities into four major categories and 45 sub-categories, indicating that trophic status is only one of many chemical factors affecting community status.

The invertebrate fauna of river sediments are used extensively for biological monitoring, but unlike the use of epipelic diatom indices, the distribution of invertebrates is largely determined by physical characteristics (particle size distribution) and sediment oxygen demand which, in turn, is directly related to the organic content of sediment. Invertebrates are, therefore, affected to a greater extent by organic loading than by nutrient loading (although, clearly, the two are related).

Very different fish populations live in nutrient poor upland rivers than in nutrient-enriched lowland rivers, but the relationship does not appear to be a cause/effect one as seen in lakes. In rivers, the major factors affecting the distribution of fish appear to physical, with other chemical factors (dissolved oxygen and overall 'pollution status') and biological factors (food availability - see invertebrates, above) also playing a role.

Lakes and reservoirs

Phosphorus is the main limiting nutrient for primary production in lakes and reservoirs, though nitrogen limitation also occurs in some waterbodies.

The environmental quality is especially dependent on the external load of nutrients, but in a transitional period (5-30 years) after external nutrient reduction, internal phosphorus load may have a significant impact on ecological quality.

Phytoplankton abundance measured as the concentration of chlorophyll a, and water transparency (Secchi depth) are important indicators of eutrophication in lakes and reservoirs, but can not be used uncritically. Differences in lake morphometric and biological conditions may have a significant impact on the levels observed. For instance, high biomass of plankti-benthivorous fish such as bream may reduce Secchi depth and increase chlorophyll *a* concentrations by stirring up the sediment when searching for food. This results in turbid water *(Meijer et al., 1990; Breukelaar et al., 1994)*. Resuspension may also increase the release of nutrients from sediment to lake water, thus improving phytoplankton growth conditions. Finally, plankti-benthivorous fish eat zooplankton, thereby reduce phytoplankton grazing. On the other hand high density of submerged macrophytes in freshwater lakes might lead to considerably higher transparency than expected from nutrient input and lake water concentrations (*Canfield et al., 1984; Jeppesen et al., 1990*), this being ascribed to various factors and feed-back mechanisms (*Scheffer et al., 1993)*.

Other ecological variables are also affected by increasing nutrient concentration: e.g. phytoplankton community composition (*Reynolds, 1984*), fish biomass and production (*Quiros, 1990; Hanson & Leggett, 1982; Downing et al., 1990*), fish community composition (*Nümann, 1972; Hartmann & Nümann, 1977; Kitchell et al., 1977; Leach et al., 1977; Persson et al., 1988*), depth limit of submerged macrophytes (*Chambers & Kallf, 1985*) and abundance of periphyton on the plant surfaces (*Phillips et al., 1978*).

The relationship between nutrient loading and in-lake nutrient concentrations, and between nutrients and various environmental variables, roughly follow the same pattern in natural lakes and manmade reservoirs. However, it has been observed that reservoir turbidity is higher than that of natural lakes due to the fact that large quantities of silt are transported to the reservoirs (*Thornton & Rast, 1993; Lind et al., 1993; Hoyer & Jones, 1983*). Thus in reservoirs, and in particular in the areas adjacent to inflowing rivers (*Lind et al., 1993*), Secchi depth per unit of chlorophyll *a* is often considerably lower than in corresponding natural lakes (*Thornton & Rast, 1993*). However, in reservoirs where retention times are short (typically <5 days) phytoplankton are washed out before they can reproduce. Transparency is, therefore, higher than in otherwise comparable natural lakes (*Søballe & Threlkeld, 1985; Komárková, 1994*).

A number of simple, empirical and more complex dynamic models have been developed to describe the relations between nutrient loading and the ecological quality of lakes. Such dynamic models are data-hungry but, following calibration, are usually able to describe the biological status and nutrient dynamics of individual lakes. However, if a broad spectrum of lakes is to be covered, major recalibration is necessary. Furthermore, they are often not able to predict future states if major changes occur, for instance in nutrient loading. This type of model will not be discussed further here.

Empirical models are much simpler and can be applied to a wide range of lakes, but the predictions for a particular lake may be imprecise. However, for IEA empirical models are the most relevant. Empirical eutrophication models typically consist of two sub-models: one describing the relationship between nutrient loading and lake concentrations, and the other describing the relationship between lake concentrations and environmental quality parameters (Figure 3.4). The latter type of sub-model may itself consist of further sub-models, e.g. one describing the relationship between lake water nutrient concentrations and algal biomass, and subsequently one relating predicted algal biomass to water transparency (Figure 3.4).

The models give the impression that changes in biological structure with increasing nutrient input take place gradually, this is a simplification. Stepwise changes are often observed, particularly in shallow lakes in which three different stages are generally found (*Scheffer et al., 1993*): nutrient-poor lakes in equilibrium are always in a clear-water state and very nutrient-rich lakes are always turbid. However, at intermediate nutrient levels two alternative stable states seem to exist: a clearwater state dominated by submerged macrophytes and a turbid state dominated by phytoplankton. Both states have a number

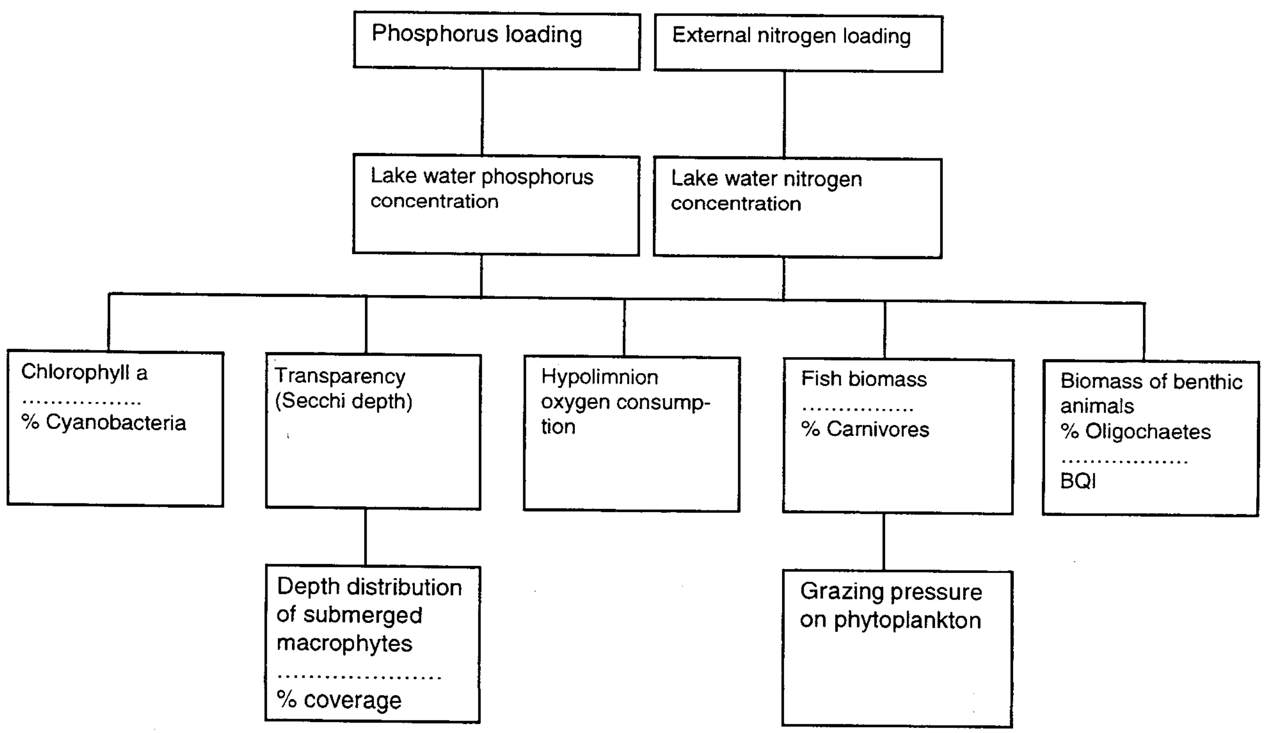


Figure 3.4. Empirical relationships between nutrient supply and the ecological status of lakes.

of stabilizing feedback mechanisms, implying that within this nutrient range higher perturbation is often needed for a change of state. This means that an increase in nutrient loading to a clearwater lake leads to resilience towards a shift to the turbid state, and, conversely, that nutrient loading reductions not necessarily lead to a clearwater state without a high (possibly artificial) perturbation within the system.

In summary empirical models exist which, from the level of nutrient loading, can predict lake nutrient concentrations and ecological status when in equilibrium with the external loading.

Coastal waters

In this report we defined coastal waters as shallow marine areas (depth<10m).

Most temperate coastal systems are apparently nitrogen limited (e.g. *Boynton at al., 1982; Graneli et al., 1986*), some switch seasonally between nitrogen and phosphorus limitation (*McComb et al., 1981; Malone et al., 1996*), and others are limited by nitrogen and phosphorus in combination (*Eppley et al., 1973*). Tropical and sub-tropical lagoons are often considered to be phosphorus limited (e.g. *Smith, 1984*).

Coastal waters are relatively open ecosystems, and their nutrient status is therefore influenced not only by the magnitude of nutrient loading from land, but also by mixing with surrounding waters. The degree of mixing varies widely with tidal amplitude, wind and river flow. Relatively open estuaries with a short freshwater residence time tend to be less affected by a given nutrient loading from land than more enclosed bays with a longer residence time, and differences in freshwater residence time also significantly affect estuarine nitrogen retention due to denitrification (*Nielsen et al., 1995*).

With increasing nutrient loading of coastal ecosystems the composition of primary producers is changed. Ample historical data have documented a shift from dominance of slow-growing seagrasses and large macroalgae at low nutrient loading towards dominance of fast growing macroalgae and epiphytes at intermediate nutrient loading and phytoplankton dominance at higher nutrient loading (*Sand-Jensen & Borum, 1991; Duarte, 1995*). The shift in community composition of primary producers along a eutrophication gradient greatly affects the biological structure and relationships between ecosystem components higher up the food chain (*Sand-Jensen and Borum, 1991; Duarte, 1995*).

Several attempts have been made to model these interactions in individual water bodies (e.g. *Bendoricchio et al., 1994; Madden and Kemp, 1996; Boynton et al., 1996*), but predictive models are scarce due to the differences in freshwater residence time, biological structure, the complexity of the interactions, and a lack of knowledge on the time scale of recovery of coastal ecosystems following reduced nutrient loading. Nevertheless, a eutrophication model has been developed, which describes simple relationship between increasing nutrient concentration, increasing chlorophyll concentration, decreasing Secchi depth and decreasing depth limit of the benthic vegetation (*Nielsen et al., 1989; Sand-Jensen et al., 1994*). Being empirical the model is similar to previous models developed for benthic vegetation in lakes (*Chambers and Kalff, 1985; Duarte and Kalff, 1987*).

Chlorophyll-a concentration is strongly coupled to the total-N concentration, whereas the relationship between chlorophyll and total-P is much weaker and mainly due to co-variation between total-P and total-N. Secchi depth transparency can be predicted with good precision from chlorophyll and suspended matter, and the depth limits for eelgrass and macroalgae increases linearly with transparency. This cascade effect of increasing total-N concentrations on chlorophyll concentration, Secchi-depth and macrophyte depth limit was used to demonstrate relationship between total-N and macrophyte depth limits. Thus this relatively simple model allows predictions of the areal loss of seagrasses and benthic macroalgae upon eutrophication-derived reduction in water transparency and may provide useful tools for coastal managers. The study was based on data from Danish coastal waters but similar studies in other systems indicate that the patterns have a general value (*Gallegos and Kenworthy, 1996*). Examinations of the depth limit of seagrass communities distributed worldwide confirm the statement that differences in seagrass depth limits are largely attributable to differences in the underwater light climate (*Duarte, 1991*). It should be noted, however, that in some water bodies, a major part of the light attenuation is due to factors other than chlorophyll, i.e. resuspended sediment or dissolved organic colour, and for such areas, a reduction in total-N may only result in a minor improvement of water clarity (*Gallegos and Kenworthy, 1996; Olesen, 1996*). Thus, the model is not applicable to all waters, especially not to those in which phytoplankton constitute a minor proportion of the turbidity budget. For example, in English and Welsh tidal waters, chlorophyll-a concentrations account for less than 5% of the variability in light transmissivity (turbidity) levels (Environment Agency, unpublished data).

In summary, coastal water quality cannot be predicted from information on external loading, as mixing with open marine waters differs between coastal areas. However, empirical models have been developed, which from water nutrient concentration can predict ecological quality.

4 Relevant EU-legislation

4.1 The Urban Waste Water Directive

The Urban Waste Water Directive (91/271/EEC) defines standards for the collection, treatment and discharge of urban wastewater and waste water from some industrial sectors.

The Directive states that (with a few exceptions) all wastewater discharges >10,000 PE to coastal waters and >2,000 PE to freshwater and estuaries will be subject to secondary treatment by the year 2005.

Before 1994 the Member State had to classify part of their national water-bodies as sensitive or less sensitive areas. Freshwater cannot be classified as less sensitive. In sensitive areas, discharges shall be subject to more stringent treatment with supplementary nitrogen and/or phosphorus removal, whereas in less sensitive areas less stringent treatment than generally prescribed is accepted. However primary treatment is the minimum requirements in less sensitive areas.

All municipalities smaller than the lower threshold of 2,000 PE/10,000 PE shall also be subject to appropriate treatment by the year 2005. However, no specific criteria are given in the Directive.

The Directive specifies the limit values connected with secondary treatment (BOD, COD and suspended matter) and with discharges to sensitive areas where nitrogen and/or phosphorus removal is prescribed (table 4.1).

Table 4.1. Requirements for nitrogen and/or phosphorus removal from urban wastewater treatment plants discharging to sensitive areas, (91/271/EEC)

	Concentration	Minimum % reduction
Total P	2 mg P l^{-1} (10,-100,000 PE) 1 mg P l^{-1} (>100,000 PE)	80
Total N	15 mg N l^{-1} (10,-100,000 PE) 10 mg N l^{-1} (>100,000 PE)	70-80

Furthermore, discharges from a list of industrial sectors (>4,000 PE) shall respect above regulations (Remark: uncertain if this also goes for N/P removal)

The full implementation of the Directive has been estimated to cost 100-200 billion ECU (*Hagebro, 1992*)

4.2 The Nitrate Directive

The Nitrate Directive (91/676/EEC) aims to reduce and further prevent water pollution by nitrogen due to the application and storage of fertilizer and manure on farmland.

Due to the Directive each Member State shall not later than 1993 establish codex for Good Agricultural Practice (GAP). The codex is forwarded to the Commission which makes a report (1996). Furthermore Member States have to designate specific vulnerable zones (1993) and for these areas Action programmes have to be decided (1995). Some countries have designated all their territory as vulnerable zones (Netherlands, Denmark, Germany, and Luxembourg) and other countries only consider part of their territory as vulnerable or even not vulnerable at all (Ireland).

The Action Programmes have to be fully implemented not later than the year 1999, and the Directive specifies that the programmes shall include:

- demand for storing capacity (manure)
- restriction of application in relation to expected crop need
- during first 4-years of the Action Programme, the maximum application rate of **manure** will be 210 kg N/ha. During following years the maximum application rate will fall to 170 kg N/ha.
- There is some flexibility for manure application rates above the maximum rates shown above. The Commission has to be informed when this occurs

4.3 The proposed Ecological Directive and the future Framework on Water

The proposed EC Directive on ecological quality of water (COM(93) 680 final) tabled by the European Commission 15. June 1994 is a major new approach, focusing on protecting the aquatic ecosystem as a whole. The proposal is concerned with the adoption of measures to protect all surface waters from point and diffuse source of pollution and from other anthropogenic influences.

The measures adopted must be designed to maintain and improve the ecological quality of waters, with the ultimate aim of achieving good ecological quality. The main requirements of the proposal are to:

- Develop and introduce monitoring and classification schemes for determining the ecological quality of surface waters
- Create inventories of point and diffuse pollution sources and undertake assessments of those sources
- Define operational targets in terms of good ecological quality for all surface waters
- Develop and implement integrated programmes aimed at achieving the operational targets.
- Inform the public about the outcome of the above initiatives

The Commission has initiated two relevant studies:

- The harmonised monitoring and classification of ecological quality of surface waters in the European Union

- Development of technical specifications for the assessment of sources of pollution and other adverse anthropogenic influences in EU surface waters

The proposed Ecological Directive has now been withdrawn by the Commission. However, it has been indicated by the Commission that the concepts will be integrated into the new Framework Directive on Water.

4.4 The CAP-reform

The impacts of agricultural production on the environment are closely related to the common agricultural policy (CAP) in the EC. The EC-policies of agriculture and the environment, respectively, have until now been separated from each other, and consequently there was no coherence between the goals of agricultural and environmental policies. The non-inclusion of environmental considerations in agricultural policy has had serious consequences to the environment, that are only slowly being addressed through national environmental legislation or through EC Directives on the protection of the environment. One can even find examples of the two policies opposing each other in practice. For example, large herds of grazing animals have been built-up in Greece with the aid of EC-subsidies. This has resulted in too high a grazing pressures even in regions, which in accordance with the EC-Directive on the Protection of Wildlife and Natural Habitats (92/43/EEC) should be classified as preserved areas.

However, the reforms of CAP in the late 80s, motivated by the overproduction of some agricultural products and the problems of a growing agricultural EC-budget, involved a gradual integration of environmental considerations in CAP. The adoption of the so-called 'socio-structural measures' in 1986 marked a start of this development, and the reform of CAP in 1992: The MacSharry-reform (EC/1765/92 and EC/2078/92) marks a further step in this direction.

The MacSharry-reform can be divided in two parts:

1. Market measures were aimed against the overproduction of agricultural products in the EC, i.e. a gradual re-adjustment of the subsidies from product-related subsidies towards subsidising land conditioned by the fallowing of a part (15%) of the area under production. The guaranteed prices on grain, oil seed and pulses are reduced over a period of 3 years, starting at the production year 1993/94 and to approach world market prices in 1996. These price-reductions are compensated through the introduction of bounties on hectares of land. The idea is to disconnect the economic incentive to increase production associated by the former system of subsidising production. Furthermore, and initially for 1993, a fallow-scheme has been put into effect, according to which the producers have to fallow 15% of the basic area (the area that had been used for the growing of reform-crops). Besides this, the milk quotas were reduced by 2%, the price on milk was reduced

by 9-10% and the price on beef was reduced 15% over the following 3 years.

2. Structural measures had the aim of protecting nature and the environment, and offered opportunities for the member countries to establish various grant schemes e.g. subsidy schemes to promote less intensive production by a reduction in the applications of fertilizer and pesticides. The measures also promote more environmentally desirable management of nature sensitive areas, increase the adoption of organic farming practices, the taking out of arable land from production for at least 20 years, afforestation of former agricultural land etc. The effect of this reform on the environment will depends on the extent of funding allocated to the purpose. Contrary to the market measures, which are 100% financed by the EC, the structural measures are only 50% financed by the EC, i.e. the individual member countries must contribute the remaining 50% by themselves.

5 Key studies

Numerous scientific papers and regional and national state of the environment (SoE) reports have assessed the relationship between driving forces, pressures and the environmental state; as well as the implication of regulatory measures are evaluated. This review focuses on a detailed description of only a few papers which cover most of DPSIR framework. In addition, an analysis is presented of the similarities and differences in the way the individual authors undertake their assessments. Predominantly European studies describing the relationship between agriculture and N-concentration/N-loads in river catchments as well as relationship between human activities and P-concentration/P-loads are discussed in less detail.

5.1 Studies covering the DPSIR framework

Three studies have been selected to describe models covering most of the DPSIR framework:

- The N&P model *(Paaby et al., 1996a; Paaby, 1996; Paaby et al., 1996b).*
- The CARMEN model (*de Haan et al., 1996; Beusen et al., 1995; Klepper et al., 1995; Meinardi et al., 1994, 1995*).
- The study of Pan (*Pan J., 1994*): Comparative effectiveness of discharge and input control for reducing nitrate pollution.

The models generally focus on driving forces and their pressures (i.e. export/emissions of nutrients), while the state and impact description are more vague (Table 5.1). All three studies assess the relationship between agriculture and nitrogen emission. In the Pan model, only nitrate leaching from the rootzone to groundwater is calculated, while in the N&P and CARMEN models the loading of nutrients into coastal and marine areas is calculated; attempts are made to evaluate ecological effects of the loading in the N&P model. Phosphorus is fully assessed in the CARMEN model and partly in the N&P model. The latter study only includes phosphorus loading from point sources.

Table 5.1. Coverage of the DPSIR concept by the three studies.

Study/model	Nutrient	Driving force	Pressure	State	Impact	Response
N&P model,	N; (P)	X	X	X	(x)	
CARMEN	N; P	X	X	X		
Pan (1994)	N	X	X			

The objectives of the three studies differ: the CARMEN model describes surface water quality based on existing general information on agricultural structure and population density (Table 5.2), while the other two models estimate the effects on the environment of changes in the driving forces and their associated pressures. In addition, cost and cost-effectiveness calculation are included in the Pan and N&P studies. The calculation of cost and cost-effectiveness will not be dealt with in this section. Additional information on the costs of different measures in relation to reduction of nutrient loading can be found in two detailed studies; one by the Swedish Beijer International Institute of Ecological Economics (*Gren et al, 1995*) and the second by a Norwegian agro-economic research group (*Vatn et al., 1996*).

The geographical scale of CARMEN is Pan-European, while the N&P model is restricted to Denmark, and the *Pan (1994)* relates to the land (207 km^2) overlying a single UK aquifer. Both CARMEN and the N&P model involve sub-models for sea compartments and coastal catchments i.e. 41 sea compartments in the CARMEN study and 48 catchments to Danish coastal waters.

Table 5.2. Objectives and geographical scale of selected IEA of eutrophication studies.

	Objectives	Geographical scale
N&P model	The overall aims of the study are: - To quantify the relationship between production patterns and technology (driving force) applied across sectors in various geographical regions (drainage basins) and the environmental quality of Danish marine waters and fjords. - To calculate the cost to society and effects on the quality of waters of various changes in these patterns	The model simulations are based on a geographical division of Denmark's land-area in 48 drainage basins to coastal waters or fjords, and the (inner) marine areas Kattegat, the Belts and the Baltic.
CARMEN	The model aims at describing surface water quality from N- and P-inputs on a European scale.	Pan-European model; with Europe divided into major river catchment and 41 sea compartments.
Pan, UK	The overall objectives is to examine the impact and cost-effectiveness of input and discharge control alternatives to reduce diffuse source nitrate pollution.	A groundwater catchment with an area of 207 km^2 on Cambridge chalk in South Cambridgeshire, England was used for the study.

5.1.1 Driving force-pressure sub-models used

In the three studies, assessment models with the aim of describing the relationship between driving forces and pressures (emissions) have been constructed (Table 5.3). The N&P and CARMEN project include sub-models for agriculture, consumers and industry, as well as for NOx emissions from power plants and transport, while the Pan project only has a single sub-model relating agricultural activity to nitrate leaching from the rootzone.

Agriculture

The relationship between agriculture and nitrate leaching from the root zone is in all three studies calculated by means of simple empirical equations. The equations calculate the leaching of nitrogen (nitrate) as a function of soil type, crops grown, the level and type of applied fertilizer and the utility rate of manure. In the N&P and CARMEN studies, emissions of ammonia to the atmosphere are calculated on the basis of data on livestock numbers and emission factors for each livestock category. In the CARMEN model, phosphorus run-off from agriculture is calculated from estimates of erosion rates, while in the N&P model no estimate is made of phosphorus run-off from agriculture.

Table 5.3. Driving force - pressure (emission) relationship.

	Sectors	Pressure (emissions)
N&P model	**Agriculture**	**Nitrogen leaching from the root zone** is calculated by means of a simple empirical exponential equation. The equation calculates the leaching of nitrogen as a function of soil type, crop type, the level and type of applied fertilizer and the utility rate of manure. **Ammonia emissions** are calculated by means of livestock category emission factors multiplied by livestock numbers.
	Municipal waste water treatment plants	**Emission from WWTPs** are determined from per capita export coefficients multiplied by nutrient retention treatment factors, depending on the purification technology adopted.
	Power plants & traffic	**NOx air emissions** are treated as exogenous inputs.
	Imports	An estimate of **total import of foreign air pollution components** of Nox and NHx is included. An estimate of **total nitrogen loadings imported from boundary marine waters** to the inner Danish marine waters is included.
	Missing:	**P from agriculture; industrial discharge; fish farms and scattered dwellings**
CARMEN	**Agriculture**	**Leaching of nitrate from the topsoil** is estimated by applying empirical relations derived from Northwest European experience and based on land use, texture of topsoil, groundwater depth and groundwater recharge. **Emissions of ammonia** are based on emission factors multiplied by livestock numbers. Only **P export via soil erosion** is included. Erosion rates are estimated using a simplified version of the Universal Soil Loss Equation taking into account rainfall intensity, slope, texture and land use.
	Power plants, transport and industry	**NOx emissions** from power plants, transport and industry are estimated from an air emissions sub-model.
	Consumers & industry	Sewage production is estimated from population density. **N- and P-loads are assumed to be proportional to population numbers.**
	Missing:	**P from leaching; industrial discharges; extent of waste water treatment;**
Pan (1994)	**Agriculture**	**The leaching of nitrate** is estimated using empirical relations between fertilizer uses, management practices and loss of nitrate.
	Missing:	**Only nitrate leaching from agricultural practices is included.**

Consumers and industry

In the N&P model emissions from municipal waste water treatment plants (WWTPs) are estimated from information on the population equivalent which each plant serves and the purification technology adopted (6 different scales of waste water purification). It is possible to run scenarios by upgrading the purification technology employed. In CARMEN, N- and P-loads to WWTPs are estimated from the population density, assuming that in industrialised regions there is a high wastewater production per capita, but that a high level of treatment is applied. Thus, nutrient removal rates are higher than in less highly populated areas. As a first approximation, it is assumed that these two effects cancel out, making N- and P-loads proportional to population numbers.

Power plants and transport

In the N&P and CARMEN models, air emission sub-models are used to calculate NOx emissions from power plants and the transport sector. In the N&P model the NOx emissions are handled as exogenous inputs to the eutrophication model.

5.1.2 Sector information used

A major difference between the three studies is the level of information used to estimate the emission of nitrate from agriculture (Table 5.4). While the CARMEN model uses very general agricultural statistical information and only splits land use into non-agricultural land, arable land and grassland, the two other models operate with detailed information about farm type, area covered by different kinds of crops and livestock density. In addition, the CARMEN model uses per-country averages of input of nitrogen (sum of fertilizer, manure and atmospheric deposition), while in the two other studies the nitrogen input is dependant on the farm type (dairy farms vs. mainly cereals), the type of crop grown and livestock density; as well as different fertilization schemes (autumn or spring application of manure). A major problem in the CARMEN model is the assumption of per-country average nitrogen input; first the level of fertilizer input is very dependent on the crops grown and secondly the spreading of manure is related to livestock farms and in a livestock farm not all fields can be used for manure spreading. Both the CARMEN and N&P models estimate ammonia emissions from agriculture on the basis of livestock statistics and emission factors for each category of livestock.

Point source emissions

In the CARMEN model the only information used to calculate the nutrient emissions from consumers and industry is the population numbers in the different catchments. In the N&P model nation-wide information on all WWTPs (> 30 PE) is used: their size (population connected) and the current purification technology adopted is the basic information input.

Table 5.4. Sector information used.

	Sectors	Information
N&P model	**Agriculture**	**Nitrate leaching:** Agricultural statistics from the 271 Danish municipalities including land-use, crops grown and livestock information are used to calculate agricultural information for each of the 48 catchments. The loading from rural areas is assumed to depend upon: - different crop types (11 categories; spring sown cereals, winter crop, leguminous, roots, grass, permanent grassland, etc.) - livestock density (3 categories; cattle, pigs, others) - Afforested land (2 categories) - the extent of non-production areas and extensively utilized areas (8 categories) - fertilizer applied (total dose; utilization of N in manure)
	Municipal waste water treatment plants	**Emission from WWTPs:** Nation-wide information about WWTPs; their size (population connected) and the purification technology adopted (6 purification technologies).
CARMEN	**Agriculture**	**Nitrate leaching:** **Nitrogen application:** per-country averages based on FAO fertilizer statistics, AMEUR-investigation on manure production and atmospheric deposition. It was assumed that all agricultural land (grassland, arable land, and permanent cultivation) receives the same amount of nitrogen fertilization per hectare, manure was distributed over grassland only. Manure efficiency rate of 0.6. **Soil features:** FAO soil maps of the World split into sandy, loamy, clayey and peaty soils. **land use:** derived from land cover maps split into non-agricultural land and agricultural land **(arable land, grassland)**
	Consumers & industry	**Population numbers.**
Pan (1994)	**Agriculture**	**Nitrate leaching:** Based on county agricultural statistics: 4 farm types (mainly cereals, mixed cropping, mainly dairy and mixed farms) were identified to represent the farms in the catchment. The farm types are described by 8 arable cropping activities, 3 livestock activities and an option of land retirement (e.g. set-aside).

5.1.3 Transport from emissions to loading

The transport from gaseous emissions to atmospheric deposition is handled in similar manner by the CARMEN and N&P models. The atmospheric transport from emissions of NH3 and NOx to deposition is implemented in the models by means of source-receptor matrices, based on the atmospheric transport model TREND (*Asman and Jaarsfeld, 1990*).

The transport from emissions from agriculture (leaching of nitrate) and from point sources and to loading to coastal waters is handled by applying a reduction coefficient to the calculated emission. Based on observed loadings from the catchments (from river monitoring programmes) and model calculated emissions the reduction coefficient is estimated (reduction coefficient=observed load/ calculated load). In the CARMEN model a standard reduction coefficient of 0.12 (0.17) is used, while in the N&P model individual reduction coefficients were calculated for each of the 48 sub-catchments (range 0.09-0.79).

5.1.4 Relationships between nutrient loading and concentration in coastal areas

In the CARMEN model a simple empirical advection-diffusion model for the coastal seas of Europe has been established. Based on the water discharge and nutrient loading (riverine loading and atmospheric deposition) and salinity information from the coastal areas as well a assumption on a background marine nutrient concentration a potential nutrient concentration in the coastal areas is calculated. The term "potential" indicates that all biological transformation and loss rates in the coastal seas are disregarded. A similar approach has been used in the N&P model.

5.2 Studies covering relationship between agriculture and N-concentration/N-loads

Several very detailed dynamic models describing nitrate behaviour in the top soil and leaching of nitrate from the rootzone have been established. Several of these nitrogen models are reviewed in a special issue of Ecological Modelling - Validation of Agroecosystem Models (volume 81, 1995), and their equivalent phosphorus models are reviewed by *Mainstone et al (1994)*. These models are data-hungry on a very detailed level (soil texture, daily precipitation and evaporation data, date of fertilizer application and harvest, etc.) and are poorly suited for regional or large scale evaluation of nitrate leaching. Consequently, these model will not be further described in this report.

In the studies described in the previous section nitrate leaching from the root zone is calculated by means of simple empirical equations. The equations calculate the leaching of nitrogen (nitrate) as a function of soil type, crops grown, the level and type of applied fertilizer and the utility rate of manure. Nitrogen transport from the rootzone to rivers at the downstream end of a catchment area is very complicated and often poorly described. The water flow from the rootzone to surface waters can be described by detailed dynamic models while the calculation of nitrate loss during the transport is even more complicated. Therefore the loading estimates from catchment areas are often based on the simple assumption that a certain part (10-90%) of the nitrate leached from the rootzone is exported to the surface waters.

Another approach is to relate the observed river nitrogen concentration or loads in the catchment area to the agricultural activities going on in the catchments. Numerous studies have shown a close relationship between agricultural activity/intensity and nitrogen levels in surface waters. These studies are usually based on regional river water quality monitoring results and attempt to explain the observed nitrogen levels or loadings in individual sub-catchments by empirical equations related to agricultural activity (e.g. land cover, crops grown, fertilizer use). Information on agricultural activity in the sub-catchments is normally obtained from agricultural census data.

For this review the focus has been on European studies. In total, eight studies have been selected (Table 5.5). The studies are biased towards the north-western European countries with three studies from the UK, one study from the Republic of Ireland, Denmark, Poland and Sweden. In addition a simple relationship between percentage of agricultural land and concentration of nitrate/total nitrogen in European rivers has been included (Figure 5.1).

The way the studies describe the nitrogen levels and the agricultural activities in the catchments are very heterogeneous. Many of the studies describe nitrogen levels by annual average nitrate (NO_3) or total nitrogen (N_{TOT}) concentration, although in one study the maximum annual nitrate concentration (max-NO_3) is used instead (Table 5.6). The loading of nitrogen is generally described by export coefficients of nitrate (L-NO_3) or total nitrogen (L-N_{TOT}) in kg N per hectare per year. The agricultural activities in the catchment are described by the percentage of agricultural land (% agri), the crops grown or the use of fertilizer. Such indicators are not directly related to nitrogen export, so the underlying source or driving factors, e.g. fertilizer and manure application rates may be masked.

In the following section, the eight selected studies are evaluated according to the level of agricultural details used to describe the levels of nitrogen.

Table 5.5. Selected studies covering relationship between agriculture and N-concentration/N-load.

No	Authors	Title	Geographical coverage
1	Neill, 1989:	Nitrate concentrations in river waters in the south-east of Ireland and their relationship with agricultural practices.	6 river catchments S.-E. Ireland
2	Taylor et al., 1986,	Run-off of nutrients from river watersheds used for agricultural purposes	21 Polish river catchments
3	Smith, 1977; Smith et al., 1982	Domestic and agricultural contribution to the inputs of phosphorus and nitrogen to Lough Neagh. Upward trend in nitrate concentration in rivers discharging into Lough Neagh for the period 1969-1979.	6 river catchment to Lough Neagh, Northern Ireland
4	Wright et al., 1991	North east Scotland river catchment nitrate loading in relation to agricultural intensity	11 river catchments in North East Scotland
5	Stribe & Fleisher, 1991	Agricultural production methods - impact on drainage water nitrogen	Catchment area of Laholm Bay, Southern Sweden
6	Kronvang et al., 1995	Non-point-source nutrient losses to the aquatic environment in Denmark: impact of agriculture	77 small Danish river catchments
7	Brooker and Johnson, 1984	The behaviour of phosphate, nitrate, chloride and hardness in twelve Welsh Rivers.	12 Welsh rivers
8	Kristensen, 1996; Kristensen & Hansen, 1994	Quality status and trends of large rivers in the European Environment Agency area; European rivers and lakes	Large European rivers

Figure 5.1: Relationship between nitrate concentration and percentage of agricultural land in large rivers in the EEA area (Kristensen, 1996). Median, upper and lower quartiles are shown. > 40% South = % of agricultural land greater than 40 in southern European rivers; > 40% Cent. = % of agricultural land greater than 40 in central European rivers.

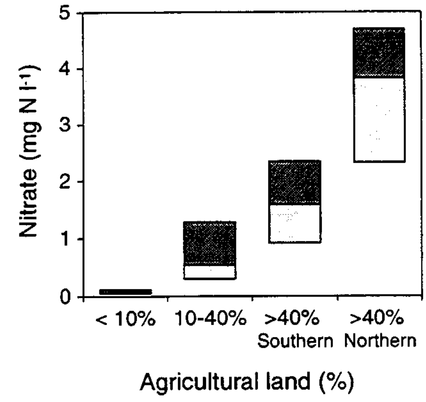


Table 5.6. Abbreviations used to describe nitrogen levels and agriculture activities.

Nitrogen levels	Land-use information
Concentration:	**Percentage of total area**
NO_3 = annual average nitrate concentration (mg N l^{-1})	%agri = % which is agricultural
NTOT = annual average total nitrogen concentration (mg N l^{-1})	%LAP = % land ploughed (the sum of cereals, roots and other crops)
max-NO_3 = annual maximum nitrate concentration (mg N l^{-1})	%arable = percentage arable land
	%ley = percentage of ley
Export coefficients	%pota = percentage of potatoes
L-NO_3 = nitrate export coefficient (kg N ha^{-1} yr^{-1})	%spring = percentage of spring sown crops
L-NTOT = total nitrogen export coefficient (kg N ha^{-1} yr^{-1})	**Area**
	agriculture = area of agricultural land (hectares)
Loading	forest = area of forest (hectares)
tL-NO_3 = total nitrate load in tonnes per year	hill = area of hills (hectares)
tAG-NO_3 = loads from agricultural areas tL-NO_3 - (1.66kg N ha^{-1} * non-agricultural area (hectares))	arable = area of arable land (hectares)
	grass = area of grass land (hectares)
	spring crops = area of spring crops (hectares)
	winter crops = area of winter crops (hectares)

5.2.1 Relationship between nitrogen and land-use

In most of the studies a good relationship between the percentage of agricultural land and the nitrate levels was found (Table 5.7). However, in most of the studies this relationship was even better explained by more detailed land use information such as percentage of arable or ploughed land or the area covered by different kinds of crops (Table 5.8).

On a European scale (8), a positive relationship was found between the percentage of agricultural land and annual average concentration of nitrate. However, a wide variation in nitrate levels was observed in similar agricultural classes. The confidence associated with predicting nitrate concentrations from %agri was markedly improved by a north-south division of the catchment with agricultural areas greater than 40% (Figure 5.1). As expected, the precision of the estimate of nitrogen levels from agricultural activities is generally improved by the use of more detailed land use variables such as arable land or crops grown (Table 5.8).

Table 5.7. Relationships between nitrogen levels and land used for agriculture (no separation of the agricultural land use). Abbreviations see table 5.6.

Study	Equations presented in the studies	Correlation
1)	See land-use	
2)	See land-use	
3)	No significant correlation between annual average nitrate concentration and land-use characteristics in the 6 catchments.	
4)	NO3 = a+b*%agri tL-NO3 = 0.0228*agriculture tL-NO3 = 0.0254*agriculture - 0.0286*forest + 0.00452* hill tAG-NO3 = 0.0216*agriculture	good r^2=0.92 r^2=0.94 r^2=0.92
5)	The were significant positive correlation between annual average NO3 and NTOT concentration and the percentage of agricultural land (P = 0.015 resp. P = 0.010). NO3 =a + b*%agri NTOT = a + b*%agri	
6)	See land-use	
7)	it is not possible to establish relationship between land-use and nitrate concentration (no land-cover data)	
8)	NO3=a+b%agri	good

Table 5.8. Relationships between nitrogen levels and land used for agriculture (separation of the agricultural land use). Abbreviations see table 5.6.

Study	Equations presented in the studies	Correlation coefficient
1)	max-NO3 (1980) = 0.187*%LAP + 0.31 max-NO3 (1986) = 0.276*%LAP + 2.0 L-NO3 = 0.74*%LAP + 1.9	r^2=0.98 r^2=0.99 r^2=0.996
2)	L-NTOT = 0.74*%arable - 1.12 (rivers of Pomeranian region) L-NTOT = 11.05*%arable - 20.8 (rivers of Notec region) L-NTOT = 2.22*%arable - 4.22 (Sucha River) L-NTOT = 5.10*%arable - 8.72 (Piaseczna River)	r^2=0.96 r^2=0.93 r^2=0.99 r^2=0.994
3)	The relationship between annual average nitrate concentration and land-use characteristics in the 6 catchment is not linear.	
4)	tL-NO3 = 0.0564*arable + 0.00293* hill - 0.0127*grass tL-NO3 = 0.0212*spring crops + 0.00270* (hill+forest) tAG-NO3 = 0.0518*arable + 0.00748*grass tAG-NO3 = 0.0285*spring crops + 0.829*winter crops	r^2=0.97 r^2=0.98 r^2=0.97 r^2=0.97
5)	significant (P < 0.05) negative correlation with the percentage of ley L-NTOT = 76.3 - 1.52*%ley significant (P < 0.01 and P < 0.005) positive correlation with the percentage of potatoes and percentage of annual spring sown crops L-NTOT = 44.0 + 1.38*%pota L-NTOT = 0.908*%spring - 9.47	r^2=0.83 r^2=0.86 r^2=0.90
6)	log(L-NTOT) = a(year) + b1*log(R) + b2*%arab + b3*%sand + b4*CA	r^2=0.75
7)	it is not possible to establish relationship between land-use and nitrate concentration (no land-use data)	
8)	*no detailed information about land-use*	

6) R = annual runoff in mm; %sand = percentage of sandy soils; CA = topographic catchment area in hectares; a(year) = a constant for each of the years 1989, 1990, 1991, 1992.

However, in the study of rivers draining into Lough Neagh, N.Ireland (3) the different levels of nitrate (1.7-3.1 mg N l^{-1}) could not be explained by the land use in the catchments. All the river catchment in this study had approximately 95% agricultural land with the percentage of land used for cereals, potatoes and temporary grass varying between 30 and 37%.

In the Polish study (2), no universal Polish relationship between the percentage of arable land and the export coefficient of total nitrogen was found. Instead four different relationships were established by dividing the rivers into regions. The different constants in the four equations are explained by different physiographic characteristics (e.g. soil and soil types) of the four regions.

Only minor improvement in the relationships were observed by going from arable land to more detailed information on the crops grown (4).

5.2.2 Fertilizer use in the catchments

In five of the eight studies the observed nitrogen levels were related to fertilizer use in the catchments (Table 5.9). In the Swedish study (5) the nitrate levels could not be explained by the amount of fertilizer and manure application in the catchments, while in the four remaining studies the nitrate levels were explained by fertilizer application.

Table 5.9. Relationships between nitrogen levels and N application by fertilizer. Abbreviations see table 5.6.

Study	Equations presented in the studies		Correlation coefficient
1)	max-NO_3(1980) = 0.281*Napp - 12.9		r^2=0.97
2)	*no information about fertilizer use*		
3)	NO_3 = 0.803 + 0.016*Napp		r^2=0.91
4)	tL-NO_3 = 0.698*((spring crops*Napp-sc)+(grass*Napp-gr)) + 0.503*(winter crops*Napp-wc) + 0.00240 (hill+forest)		r^2=0.98
	tAG-NO_3 = 0.0868*((spring crops*Napp-sc)+(grass*Napp-gr)) + 0.464*(winter crops*Napp-wc)		r^2=0.98
5)	There were no significant correlation with other land-use parameters; i.e. use of commercial fertilizer and manure, and size and type of livestock		
6)	*no information about fertilizer use*		
7)	Significant (P<0.05) positive trend		
	NO_3 = x1 + a1*Napp	(river Wye)	r^2=0.82
	NO_3 = x2 + a2*Napp	(river Usk)	r^2=0.96
	NO_3 = x3 + a3*Napp	(river Taff)	r^2=0.85
	NO_3 = x4 + a4*Napp	(river Teifi)	r^2=0.94
	NO_3 = x5 + a5*Napp	(river Gwyrfai)	r^2=0.81
	NO_3 = x6+ a6*Napp	(river Dee)	r^2=0.86
	Significant relationships were not detected in the rivers Loughor, Towy or Dyfi.		
8)	*no information about fertilizer use*		

N-application

1) Napp = artificial fertilizer application rates for total area (kg N ha^{-1}) (calculated on the basis of standard application rates to each crop type)
3) Napp = Northern Ireland average rate of fertilization in kg N ha^{-1} for the period 1969-1979 (42-106 kg N ha^{-1})
4) Napp-sc = fertilizer application rates for spring crops (95 kg N ha^{-1}); Napp- wc = fertilizer application rates for winter crops (205 kg N ha^{-1}); Napp-gr = fertilizer application rates for grass (125 kg N ha^{-1})
7) Napp = Welsh average rate of fertilization in kg N ha^{-1} for the period 1967-1981 (30-90 kg N ha^{-1})

In the rivers draining to Lough Neagh (3) and the Welsh rivers (7) time series of annual average nitrate concentrations from the period 1969-1979 and 1967-1981, respectively, were compared with development in fertilizer use. In the N. Irish study one common relationship was established for all six rivers while in the Welsh study the individual trend in nitrate concentration in six out of nine rivers were explained by changes in fertilizer usage.

In the Scottish (4) and Irish (1) studies the fertilizer application rates were calculated for each catchment on the basis of data on the crops grown and standard application rates to each crop type. In these two studies the level of fertilizer application explained most of the observed differences in nitrate levels.

5.2.3 Conclusions

Good relationships were generally found on a regional basis between land-use variables, such as percentage of agricultural or arable land, and nitrogen levels or loads. The different coefficient used in the equations and the European study (8) showed that no universal European relationship between land use variables and nitrogen levels can be established. However, by division of Europe into regions with similar physiographic characteristics (soil and sub soils), it may be possible to establish general equations between land use and nitrogen levels for each of these regions.

5.3 Phosphorus loads related to human activities

In the following section nine European studies describing the relationship between observed phosphorus concentrations/loadings and human activities in the catchments is reviewed (Table 5.10).

Table 5.10. Selected studies covering relationship between agriculture and P-concentration/P-load

No	Authors	Title	Geographical coverage
1	Kristensen, 1996; Kristensen & Hansen, 1994	Quality status and trends of large rivers in the European Environment Agency area; European rivers and lakes	Large European rivers
2	Popovský, 1981	Losses of total phosphorus from watersheds influenced by various human activity.	10 Czech watersheds
3	Taylor et al. 1986	Run-off of nutrients from river watersheds used for agricultural purposes	21 Polish river catchments
4	Smith, 1977;	Domestic and agricultural contribution to the inputs of phosphorus and nitrogen to Lough Neagh.	6 river catchment to Lough Neagh, Northern Ireland
5	Filip & Ceric, 1989	Comparison of measured phosphorus loads with estimated ones in several river basins in Yugoslavia.	River catchment in the former Yugoslavia
6	Moog, 1984	Stream phosphorus exports from prealpine watersheds with respect to geology and land use	13 prealpine watersheds, central Austria
7	Kronvang et al., 1995	Non-point-source nutrient losses to the aquatic environment in Denmark: impact of agriculture	77 small Danish river catchments
8	Brooker and Johnson, 1984	The behaviour of phosphate, nitrate, chloride and hardness in twelve Welsh Rivers.	12 Welsh rivers
9	Vighi et. al., 1991	Phosphorus loads from selected watersheds in the drainage area of the Northern Adriatic Sea.	Northern Adriatic Sea catchment. 13 Coastal watersheds; 2 mountain watersheds

5.3.1 Phosphorus versus population data

Several studies have shown good relationships between phosphorus level and population data for the catchment (e.g. total population and population density) or the load observed in the rivers can be fully explained by the point source discharge in the catchment (Table 5.11).

5.3.2 Phosphorus versus land use in the catchment

Generally the relationships between phosphorus concentration levels and agricultural activities in the catchments are rather complicated because in catchments with high population density the phosphorus levels are dominated by the discharge from point sources (i.e. a function of population number and the degree of waste water treatment); and good relationship between P and agricultural activity/intensity can only be established in catchment without or significant reduced input from point sources. For example, in the *Moog (1984)* study, discharge from point sources has been converted from the catchments or in the *Kronvang et al. (1995)* study relationship between agriculture and phosphorus is established for catchments without point sources (Table 5.12).

Table 5.11. Relationships between phosphorus levels and population data. Abbreviations see Table 5.6.

Study	Equations presented in the studies	Correlation coefficient
1)	PTOT = a+b*pop_den	good
2)	Watersheds without point sources PTOT = 0.017-0.043 mg P l^{-1} Watersheds with point sources PTOT = 0.056 - 0.410 mg P l^{-1}	
4)	tL-PO4 = 0.14+0.56*Tot_pop tL-PO4 = 0.26+0.69*pop_den	r^2=0.95 r^2=0.96
8)	tL-PO4 = 0.112+0.69*pop_den	r^2=0.99
9)	tL-PTOT = tL-PS	r^2=0.98

tL-PS = total load from point sources; pop_den = Population density;

Table 5.12. Relationships between phosphorus levels and land used for agriculture. Abbreviations see table 5.6.

Study	Equations presented in the studies		Correlation coefficient
2)	L-PTOT = 0.35*%arable - 1.14 L-PTOT = 3.59*%arable - 7.55 L-PTOT = 2.08*%arable - 4.12 L-PTOT = 6.60*%arable - 13.0	(rivers of Pomeranian region) (rivers of Notec region) (Sucha River) (Piaseczna River)	r^2=0.88 r^2=0.57 r^2=0.69 r^2=0.95
6)	PTOT = 2.272+1.04*%agri		r^2=0.91
7)	log(L-PTOT) = a(year) + b1*log(R) + 1.10*%arab + 0.43*%sand		r^2=0.68

6 Case studies

Five European catchments have been selected for pilot use of IEA. The following catchments are described: the River Rhine (CH, D, L, F, NL), Odense Fjord (DK), the River Avon (UK), Forfar Loch (UK), and the River Ebro (ES). These catchments cover a wide range of sizes and demonstrate the type of information that is available for undertaking IEA, without undertaking extensive catchment-specific data-gathering and monitoring exercises. Cross-analysis of the catchments is performed and the possibilities for establishment of scenarios concerning responses to relevant legislation are described regarding data availability for each catchment.

6.1 The River Rhine catchment

Introduction

The catchment of River Rhine has a total surface area of 185,000 km^2, covering nine countries: Italy, Switzerland, Liechtenstein, Austria, Germany, France, Luxembourg, Belgium, and the Netherlands. The majority of the catchment is situated in Germany (54% of total area), Switzerland (18% of total area), France (12% of total area) and the Netherlands (12% of total area). For this account only the catchment downstream of Lake Constance in Switzerland to the delta region in the Netherlands is considered, which covers an area of 140,000 km^2. The population in the total catchment of River Rhine is about 50 million (42.6 million for the included area) and the average population density is 269 inh. km^{-2}, ranging from 100 inh. km^{-2} in Luxembourg to 444 inh. km^{-2} in the Netherlands.

Driving forces

Agriculture - Agricultural land covers 43% or 59,500 km^2 of the catchment. Of this area 34,700 km^2 is arable and 24,800 is grassland. Cattle density varies up to 220 heads km^2 in the catchment. More detailed information about land-use (i.e. crop types) and livestock is not available for the catchment, but from IKSR (1992) the agriculture nitrogen surplus is calculated to 805,000 tonnes N in 1985 and that of 1992 to 682,000 tonnes N. The surplus is calculated as the sum of production and imports of all fertilizers and food subtracting the sales and export of agricultural products.

Industry - Information about single activities are not available, but almost all kinds of industrial activities are found in the catchment of River Rhine, with a total effluent of 33,000 tonnes N and 5,100 tonnes P in 1995. This is a reduction for nitrogen and phosphorus of 53% and 69%, respectively, compared to the industrial effluents in 1985.

Waste water treatment plants - Information about single plants was not available for the whole catchment, but the total load of waste water treatment plants from the four main countries in the catchment was 126150,000 PE in 1995 (Table 6.1).Treatment technology has improved since 1985, e.g. the average percentage removal of nitrogen in Germany increased from 30% in 1985 to 56% in 1995 (Table 6.1).

96% of the Swiss population in the Rhine catchment is connected to waste water treatment plants. About 70% of the waste water flow to Swiss WWTPs is treated at tertiary treatment plants, 30% at secondary treatment plants, and less than 1% at primary treatment plants. In the Netherlands, 97% of the waste water discharged to WWTPs is treated at plants greater than 10,000 PE. Of this, 35% is treated by tertiary processes and 65% by secondary treatment technology. In Hessen and Bayern 89% and 38% of the treated waste water, respectively, receives tertiary treatment, and for both regions less than 1% of the urban waste water receives only primary treatment.

Table 6.1. Information of WWTPs of the four main countries in the Rhine catchment.

	Total PE in 1995	Average removal of nitrogen 1985 (%)	Average removal of nitrogen 1995 (%)
Switzerland	5950000	20	31
France	(41000000)*	-	-
Germany	74000000	30	56
The Netherlands	5200000	41	62

* data from 1985

Pressure

In 1985 the nutrient load from diffuse sources to the River Rhine was 18.56 kg nitrogen ha^{-1} and 0.90 kg phosphorus ha^{-1}, with the highest area specific load deriving from the Netherlands (Table 6.2). For the total catchment no changes in diffuse loads to the River Rhine were observed in 1995, but data for single countries was not available for this year.

Table 6.2. Export coefficients of nutrients from diffuse sources from the major countries included in the catchment of River Rhine 1985.

	Area (km^2)	Nitrogen (kg ha^{-1} $year^{-1}$)	Phosphorus (kg ha^{-1} $year^{-1}$)
Switzerland	9500	22.46	0.54
Germany	100000	17.70	1.00
Luxembourg	2500	11.64	1.15
France	22000	12.09	0.41
The Netherlands	6500	50.66	1.51
Total catchment	140500	18.56	0.90

Table 6. 3. Source apportionment of nutrient loads to River Rhine during 1985 and 1995 (percentage of total load given in parenthesis). * no direct information , but assumed to be similar to 1985.

	Nitrogen (Tonnes year^{-1})				Phosphorus (Tonnes year^{-1})			
	1985		1995		1985		1995	
Atmospheric deposition	>16040	(3%)	16040*	(4%)	>990	(2%)	990*	(3%)
Background	>55716	(10%)	55716*	(14%)	1239	(2%)	1239*	(4%)
Agriculture	189000	(35%)	159800	(40%)	10427	(17%)	10200	(32%)
WWTPs	214900	(40%)	139900	(35%)	30600	(51%)	14700	(46%)
Industry	66000	(12%)	33000	(8%)	16430	(28%)	5100	(16%)
Total load	541656		404456		59686		32229	

In 1995 the total nutrient load to the River Rhine was 404,000 tonnes nitrogen and 33,000 tonnes phosphorus (Table 6.3). Compared to 1985 (and mainly due to improved waste water treatment) the nitrogen and phosphorus loads were reduced by 25% and 45%, respectively (Table 6.3). Agriculture and waste water treatment plants contributed some 30-50% of the total nitrogen and phosphorus loads.

Environmental state and development

Downstream of Bimmen/Lobith, the annual average concentration of nutrients in 1993 was 4.9 mg total N l^{-1} and 0.19 mg total P l^{-1}. Phosphorus concentrations have decreased markedly since the early 1980s when typical concentrations were 0.6-0.7 mg total P l^{-1}. No clear trend in nitrogen levels has occurred.

During the period 1965-1980 much effort was placed on reducing the load of organic pollution. This resulted in a great improvement in dissolved oxygen levels in the river, to the point that in recent years no problems have been recorded at any site.

The improved water quality in the river Rhine has let to improved biological status. An increase in numbers of indigenous species has been observed. However, a large increase in numbers of immigrant species has also been recorded, showing that the condition of the river is still far from what can be considered 'natural'.

6.2 The catchment of Odense Fjord

Introduction

The catchment of Odense Fjord is situated on the Danish lowland island Fyn. The total area of the catchment is 1060 km^2, covering about 30% of the total area of Fyn. Seven streams drain the catchment, with the main flow coming from Odense Å. The total population of the catchment is about 260,000 inhabitants.

Driving forces

Agriculture - Information of land-cover in the catchment was obtained from CORINE area mapping and shows that 676 km^2 or 64% of the catchment is agricultural land. No direct information of agricultural land-use was available, but was estimated from agricultural statistics from Fyn Country. In 1994, 605 km^2 (89%) of the agricultural area was arable, with wheat and spring barley as the main crops, 28 km^2 (4%) was permanent grassland, and 45 km^2 (7%) was fallow. While the area of fallow increased markedly between 1990 and 1994, the total agricultural area decreased by 5% during this period.

Numbers of livestock in the catchment were also estimated from statistical information available for Fyn county. In 1994 the total livestock population was estimated to be 58,232 livestock units (LU) or 0.86 LU ha^{-1} agricultural land (Table 6.4). The total livestock increased by 0.1 LU ha^{-1} compared to 1990, mainly due to an increase in number of pigs (Table 6.4).

Table 6.4. Livestock units (LU), and livestock densities in the catchment of Odense Fjord 1990 and 1994.

	No. of livestock units (LU)		Livestock density (LU ha^{-1})	
	1990	1994	1990	1994
Cattle	27086	25649	0.380	0.379
Pigs	25331	31291	0.355	0.462
Sheep	197	220	0.003	0.003
Horses	339	139	0.005	0.002
Poultry	1082	933	0.015	0.014
Total	54035	58232	0.758	0.860

Application of fertilizer and manure to the catchment was estimated based on the land-use data and mean Denmark-application rates to different crop types. In 1994 the total nutrient application was estimated to be 15,000 tonnes nitrogen and 1,700 tonnes phosphorus (Table 6.5). This represents a reduction of 13% for nitrogen and 9% for phosphorus, compared to 1990, due primarily to decreased fertilizer application rates (Table 6.5).

Industry - In 1995 three industrial activities in the catchment discharged effluent directly to surface waters (Table 6.6) while the rest were connected to WWTPs. The total nutrient load was estimated to be 112 tonnes N and 1 tonnes P, with effluent from Stige Ø refuse dump comprising >90% of the total load (Table 6.6).

Waste water treatment plants - 92% of the population is connected to the 38 waste water treatment plants included in the catchment. All waste water treatment plants greater than 330 PE (14 plants) have biological treatment with nitrogen and phosphorus removal, and the three greatest plants (>10,000 PE) also include contact filtering. The total load of these 14 plants was 538,525 PE (Table 6.7), with percentage nutrient removal ranging from 67-95% and 87-98%, respectively, for nitrogen and phosphorus. The remaining 24 plants small plants (<330 PE) operate only mechanical or biological treatment, but these plants export less than 1% of the total nutrient load from WWTPs .

Table 6.5. Nutrient application, harvest, and surplus in the catchment of Odense Fjord 1990 and 1994.

	Nitrogen (Tonnes)		Phosphorus (Tonnes)	
	1990	1994	1990	1994
Application				
Fertilizer	9589	7443	832	641
Manure	5095	4976	1052	1073
Total*	16930	14762	1884	1715
Harvest	9361	7897	1552	1326
Surplus	7569	6865	342	417

* Including N-fixation and atmospheric N-deposition.

Table 6.6. Industrial effluent to Odense Fjord 1995.

	Total N load (Tonnes)	Total P load (Tonnes)
Odense airport	8.2	0.00
Stige Ø refuse dump	103.5	1.08
I/S Fynsværket	0.3	0.02
Total industrial effluent	112.0	1.10

Table 6.7. Information of waste water treatment plants greater than 330 PE in the catchment of Odense Fjord 1995.

Recipient	Size of WWTP (PE)	No of plants	Sum of PE	Reduction (%)	
				N	P
Freshwater	330-2000	2	2477	67-83	87-89
	2000-10000	8	43346	77-95	91-98
	10000-100000	2	61382	81-87	95-97
	>100000	1	429979	89	97
Estuary	330-2000	1	1341	83	94
Total		14	538525		

Scattered dwellings - In 1995 about 7,500 households were without common sewerage. The effluent from 6,700 of these households was treated by sand filtration or septic tanks. The load from these households was estimated to 18,700 PE. The exactly reduction level from the households was not available, but it is assumed that 80% of the waste water reached the surface water. The remaining 800 households had cesspool or waste water tank and it is assumed that they did not contribute to the nutrient load of the Fjord.

Pressure

In 1995 export rates of nitrogen from diffuse sources was 19.69 kg ha^{-1} for the catchment as a whole, but ranged from 13.20-20.91 kg ha^{-1} between the subcatchments (Table 6.8). In terms of phosphorus, the load from diffuse sources ranged from 0.10-0.45 kg P ha^{-1}, with an export coefficient of 0.39 kg P ha^{-1} for the catchment as a whole (Table 6.8).

Table 6.8. Export coefficients of nutrients from diffuse sources from the subcatchments of Odense Fjord 1995.

Sub-catchment	Area (km^2)	Nitrogen (kg ha^{-1} $year^{-1}$)	Phosphorus (kg ha^{-1} $year^{-1}$)
Odense Å	485.86	20.91	0.45
Stavis Å	78.00	18.46	0.34
Lindved Å	64.74	13.20	0.10
Lunde Å	41.60	24.14	0.24
Ryds Å	41.78	18.11	0.42
Vejrup Å	41.48	13.95	0.20
Geels Å	26.68	17.93	0.19
Unmeasured area	279.40	19.89	0.43
Total catchment	1059.54	19.69	0.39

Table 6.9. Source apportionment of nutrient load to Odense Fjord, 1989-1995 mean and 1995. Percentage of total load in parenthesis.

	Nitrogen (Tonnes $year^{-1}$) 1985-1995	Nitrogen (Tonnes $year^{-1}$) 1995	Phosphorus (Tonnes $year^{-1}$) 1985-1995	Phosphorus (Tonnes $year^{-1}$) 1995
Background	571 (20%)	547 (22%)	16 (17%)	15 (22%)
Agriculture	1790 (63%)	1472 (59%)	20 (21%)	12 (18%)
Scattered dwellings		63 (3%)		14 (21%)
WWTPs	230 (8%)	188 (8%)	47 (49%)	15 (22%)
Sewer overflow	37 (1%)	34 (1%)	10 (11%)	9 (13%)
Industry	126 (4%)	112 (4%)	2 (2%)	1 (2%)
Atmospheric deposition on Odense Fjord	75 (3%)	77 (3%)	1 (1%)	1 (2%)
Total load to Odense Fjord	**2829**	**2493**	**95**	**67**

In 1995 the total load to Odense fjord was 2,493 tonnes nitrogen and 67 tonnes phosphorus (Table 6.9). Agriculture was the major nitrogen source but ,in terms of phosphorus, background export, agriculture, scattered dwellings, and waste water treatment plants all had loads of the same order of magnitude (Table 6.9). The phosphorus load in 1995 was 30% lower than the average load for the period 1989-1995, largely due to a marked decrease in the load from waste water treatment plants within this period.

Environmental state and development

Winter concentrations of nitrogen in 1995 were typically about 2 mg total N l^{-1} for the outer part of Odense Fjord and 3 mg total N l^{-1} for the inner part; while the summer concentrations was about 0.7 and 1.2 mg total N l^{-1}, respectively. No trend was observed in concentration of total nitrogen during the period 1977-1995, but the summer concentration of inorganic nitrogen decreased, as expected, in line with improved waste water treatment. In 1995, winter concentrations of phosphorus were about 0.07 and 0.13 mg total P l^{-1} for the outer and inner part of the fjord, respectively; while those in summer were 0.10 and 0.13 mg total P l^{-1}, respectively. The winter 1993-1995 mean concentration of inorganic P was reduced by 60-75% compared to the 1987-1988 mean, but in summer 1995 high concentrations of total P (0.4 mg l^{-1}) were measured in the Fjord, partly caused by phosphorus release from the sediment.

Chlorophyll-a concentrations ranged from 0.5 to 24 µg l^{-1} in 1995. The concentrations in the outer part of the fjord were generally lower than the 1977-1994 median value. Secchi depth results for the outer fjord ranged from 1.0 to 5.5 m in 1995, showing no improvement compared to the 1977-1994 results.

In the 1980s local nightly oxygen deficits were observed in connection with 'blooms' of *Ulva lactuca,* which dominated the vegetation. In 1995 the areas with high *U. lactuca* standing crops were markedly reduced and no oxygen deficits were recorded. The minimum oxygen concentration was 4.1 mg O_2 l^{-1}. With the reduction in *U.lactuca* coverage, a more natural plant community of *Zostera marina* and *Ruppia sp.* has developed, but excessive epiphytic microalgae on the benthic vegetation was still a problem in 1995 and the depth distribution of the benthic vegetation was still reduced compared to the situation in 1900. In addition no improvements in the benthic fauna had been recorded.

6.3 The River Avon catchment

Introduction

The River Avon rises on the Northamptonshire/Leicestershire border, UK, and joins the River Severn at Tewkesbury, 179 km downstream. The river drains an area of 2,900 km^2, largely rural in character but with a number of urban centres included. The catchment contains about 900,000 inhabitants. River hydrology is dominated by rapid-flushing, high flow events in winter and low flows throughout summer.

Driving forces

Agriculture - land-cover information was obtained from satellite imagery data for 1988 and from agricultural census data for 1995. In 1995 the agriculture accounted for some 80% of the catchment area, about half of which was arable and half used for livestock farming 911 km^2 grassland (Table 6.10).

Table 6.10. Land use information for the River Avon catchment 1988 and 1995.

Land Use	1988 Area (ha)	1988 % of catchment	1995 Area (ha)	1995 % of catchment
Cereals	103454	35.8	67706	28.6
Grassland	90673	31.4	91129	38.5
Other crops	57994	20.1	30480	12.8
Woodland	12359	4.3	4493	1.9
Urban	20798	7.2	20798	8.8
Other land uses	3936	1.4	21979	9.4
Total	289214	100.0	236585	100

Inorganic fertiliser application rates for the whole catchment can be calculated from recommended crop-specific fertiliser application rates. For 1988 the whole catchment rates were 21.5 kg P ha^{-1} and 83.3 kg N ha^{-1}, and for 1995 they were 24.1 kg P ha^{-1} and 114.8 kg N ha^{-1}.

Great variation in livestock densities between sub-catchments was observed, but the following mean stocking densities for the whole catchment were calculated:

Table 6.11. Average livestock and livestock density in the River Avon catchment 1988 and 1995.

Livestock group	1988 Density (No.ha^{-1})	1995 Density (No.ha^{-1})
Pigs	0.30	0.23
Cattle	0.48	0.46
Sheep (and goats)	1.08	2.00
Poultry	8.26	3.43

Calculated nutrient application rates to the whole catchment from combined livestock were 9.9 kg P ha^{-1} and 44 kg N ha^{-1} in 1988, and 11.5 kg P ha^{-1} and 46.8 kg N ha^{-1} in 1995.

Industry - An abattoir is the only major industrial unit which discharges effluent to the river Avon. No information is available for the nutrient load from the abattoir, but because of its expected minor contribution to the overall nutrient budget of the river, it is not considered in the source apportionment calculations. Most other industries are connected to WWTPs.

Waste water treatment plants - It is estimated that the sewage from 94% of the population in the catchment is treated at WWTPs. 161 WWTPs are included in the catchment area (minimum size 3 PE) having a total load of 995,375 PE (Table 6.12).

Table 6.12. Waste water treatment plants in the River Avon catchment.

Recipient	Size of WWTP (PE)	No of plants	Sum of PE
Freshwater	3-2000	123	66033
	2000-10000	26	115346
	10000-100000	11	453739
	>100000	1	390257
Total		161	995375

39% of the total sewered PE load is treated at one plant serving a population of 348390 (390257 PE). It has been assumed that all WWTPs involve primary and secondary treatment. The five largest WWTPs in the catchment have been designated under the UWWT Directive as requiring the installation of tertiary treatment, but this upgrading has not yet been completed.

A monitoring study funded by the Environment Agency has measured discharges from 18 plants serving a combined PE of 772,829 (78% of the total sewered PE). Based on this data, export coefficients of 0.63 kg P PE^{-1} $year^{-1}$ and 2.32 kg N PE^{-1} $year^{-1}$ are applied to all WWTPs serving a PE of >10,000, and 0.78 kg P PE^{-1} $year^{-1}$ and 2.34 kg N PE^{-1} $year^{-1}$ for all WWTPs serving a PE of <10,000.

Scattered dwellings connected to septic tanks - the sewage from an estimated 56,892 people is treated by septic tanks. *Per capita* loading rates of 1.16 kg P $year^{-1}$ and 4.5 kg N $year^{-1}$ are applied to this source. It is assumed that the tanks themselves remove 20% of the nitrogen and phosphorus loads, and that 55 % of the remaining P and 35% of the remaining N is removed in the soil prior to reaching the river.

Atmospheric deposition - Annual atmospheric deposition of nitrogen is assumed to be 20 kg N ha^{-1}. Atmospheric deposition of phosphorus is very much more difficult to estimate because this source is very dependent on local land use, as much atmosphere-derived phosphorus is biogenic in origin (pollen, etc.). Moreover, no tracer studies are known to have been undertaken to determine what proportion of atmosphere-derived phosphorus runs off from the catchment. Most atmosphere-derived phosphorus is likely to be adsorbed to soil shortly after deposition. However, estimates of natural phosphorus export are made.

Pressure

Export rates of nitrogen from diffuse sources ranged between 13.41 kg ha^{-1} for the River Leam subcatchment to 37.39 kg ha^{-1} for the River Sowe sub-catchment; and those of phosphorus between 0.09 and 2.43 kg ha^{-1}, indicating great variation in agricultural activities between subcatchments (Table 6.13).

Table 6.13. Export coefficients of nutrients from diffuse sources in the sub-catchment of River Avon 1995 (*Foster et al., 1996*).

Subcatchments	area (km^2)	Nitrogen ($kg\ ha^{-1}$)	Phosphorus ($kg\ ha^{-1}$)
Arrow & Alne	330.55	14.87	0.49
Stour	332.76	24.64	0.27
Leam	360.73	13.41	0.09
Sowe	264.11	37.39	2.43
Upper Avon	213.74	32.59	0.12
Mid Avon	597.09	21.90	0.70
Average for the catchment		**16.49**	**0.47**

In 1995 the total nutrient load to River Avon was estimated to be 13,104 tonnes nitrogen and 1,045 tonnes phosphorus; an increase of 18% and 4% for nitrogen and phosphorus, respectively, compared to 1988 (Table 6.13). In 1995, 73% of the nitrogen load derived from agricultural sources, while in terms of phosphorus waste water treatment plants were the major source of phosphorus, comprising 63% of the total load (Table 6.14).

Environmental state

Eutrophication of the Avon river system has been highlighted as a particular problem by the Environment Agency, particularly the rivers Arrow, Leam, Dene and Bow Brook, in addition to some reaches of the Avon itself.

There appears to be little seasonality in nitrogen concentrations in the Avon at Evesham (typically 10-15 mg l^{-1} total nitrogen in 1994/1995), but phosphorus levels showed a distinct peak in summer (maximum levels of approximately 4 mg P l^{-1}) and a decrease in winter (to levels of >1 mg P l^{-1}) during 1994/1995. The River Leam sub-catchment was designated as a Nitrate Vulnerable Zone in 1995. This designation is intended to reduce leaching of nitrogen from diffuse sources by requiring farmers to take action to prevent the 50 mg NO_3 l^{-1} Nitrates Directive limit from being breached.

Table 6.14 Source apportionment of nutrient load to River Avon, 1988 and 1995. Percentage of total load in parenthesis.

	Nutrient load 1988 (tonnes $year^{-1}$)		Nutrient load 1995 (tonnes $year^{-1}$)	
	P	N	P	N
Atmospheric deposition	57.8 (5.7%)	1790.2 (16.1%)	57.9 (5.5%)	1790.7 (13.7%)
Fertiliser runoff	186.3 (18.5%)	4824.0 (43.3%)	209.5 (20.0%)	6639.9 (50.7%)
Animal waste runoff	86.1 (8.5%)	2164.1 (19.4%)	99.5 (9.5%)	2300.2 (17.6%)
WWTP effluent	654.3 (64.9%)	2239.6 (20.1%)	654.3 (62.6%)	2239.6 (17.1%)
Septic tanks	23.8 (2.4%)	133.1 (1.2%)	23.8 (2.3%)	133.1 (1.0%)
Total	**1008.3 (100%)**	**11151.0 (100%)**	**1045.0 (100%)**	**13103.5 (100%)**

The combination of low summer flows and high nutrient levels has resulted in stretches of the river effectively becoming a series of lakes impounded behind lock gates, within which blue-green algal blooms develop. In some tributaries the chlorophyll-a concentration exceeded 150 $\mu g\ l^{-1}$ in 1995, although the maximum level in the Avon at Evesham was only 20 µg l-1, and more typically >10 µg l-1. The upper Avon has been dredged and/or canalised to allow navigation, resulting in an artificial or very sparse benthic/emergent vegetation.

6.4 The Forfar Loch catchment

Introduction

Forfar Loch is situated in the Tayside region of Scotland, about 20 miles north-east of the city of Dundee and south of the highland region. The lake has a volume of 1.4 million m^3 and a surface area of 0.4 km^2. The catchment covers an area of 15.4 km^2 and is, itself, a sub-catchment to the River Tay, one of the major Scottish rivers flowing into the North Sea. Three streams drain the area of the catchment, with the major inflow to the loch coming from Treacle Burn which carries treated sewage effluent and much of the surface drainage from the town. The total population in the catchment is 13,000 inhabitants.

Driving forces

Agriculture - The catchment has an agricultural area of 11.4 km^2 (75% of the total area), of which 9.2 km^2 is arable and 2.2 km^2 is improved grassland. The arable land is dominated by intensive farming of cereals, grass leys and soft fruit. No data were collated on livestock numbers or estimates of nutrient inputs to the loch from agricultural practices, since the proportion of nutrients derived from this source is low in comparison to that derived from the wastewater treatment plant. Furthermore, the data may be misleading due to poor spatial discrimination over such a small catchment.

Industry - there are no major industrial discharges directly to Forfar Loch, but a major vegetable processing/canning factory in the town produces an effluent with a PE (in terms of BOD) of about 9,000. Data are presented which suggest that this is also a major source of both N and P to the town's waste water treatment plant.

Waste water treatment - The catchment of Forfar Loch include one waste water treatment plant with a total load of 22,000 PE. The plant serves the whole population (13,000 Inh.) and waste water from the vegetable canning factory. At present the treatment plant consists of primary and secondary treatment. Following the designation of Forfar Loch as a 'sensitive area' under the UWWT Directive, the treatment plant will be extensively modified to include tertiary treatment and larger storm water tanks.

Pressure

Export rates of nutrients from diffuse rural sources in the Forfar catchment are 0.1 kg ammonia ha^{-1} and 0.1 kg phosphate ha^{-1}. No information for total N or total P loads was available for Forfar Loch, but the total load of phosphate is estimated to be 16.1 tonnes and that of ammonia to be 49.3 tonnes. The WWTP is the largest source of both nutrients, comprising more than 95% of the total load (Table 6.15).

Table 6.15. Nutrient load to Forfar Loch 1995, with percentage of total load in parenthesis.

	Ammonia (Tonnes $year^{-1}$)	Phosphate (Tonnes $year^{-1}$)
Diffuse rural sources	0.082 (<1%)	0.082 (<1%)
Urban runoff directly into lake via culverts	1.531 (3%)	0.159 (1%)
Sewer overflows	0.567 (1%)	0.227 (1%)
WWTP effluent	47.143 (96%)	15.714 (97%)
Total load	49.323	16.182

Environmental state and development

The mean ammonium concentration in 1995 was 5.43 mg l^{-1} and mean orthophosphate concentration was 1.02 mg l^{-1}. In 1991 the mean orthophosphate concentration was 1.80 mg total P l^{-1}.

In daytime oxygen saturation of surface waters often exceeds 150%. No thermal stratification is observed in the lake, but in the deepest region (8-9 m) a survey in 1974 found that oxygen levels fell to 40-50% during May.

Late summer blue-green algal blooms have been a regular occurrence in the loch, but mean annual chlorophyll levels (12.7 µg l^{-1} in 1991) are low compared to what would be expected from the high phosphorus concentration. The low chlorophyll concentration might either be attributed to high levels of suspended solids/turbidity, which reduce light availability for the algae, or to zooplankton grazing. In 1978 a mean Secchi depth of 1 m was found in Forfar Loch, with a maximum of 4 m in early summer.

The benthic vegetation is dominated by extensive beds of *Enteromorpha, Potamogeton pectinalis* and *Elodea canadensis*. The lake is essentially fish-less because of the high concentration of ammonia and large diurnal fluctuation in dissolved oxygen levels, but contains an abundant zooplankton population.

6.5 The River Ebro catchment

Introduction

The river Ebro, Spain's longest river, rises in north-western Spain and flows south-east before discharging into the western Mediterranean.

Although its catchments is the largest in Spain, 85,000 km^2, the land is arid, poor and generally sparsely populated. About 2.8 million people inhabit the Ebro catchment, of whom 0.6 million living in the city of Zaragoza. Other large cities in the catchment include Pamplona, Lerida, Logrono and Vitoria. The largest tributaries have been utilised for hydroelectric power and irrigation, especially in the middle reaches of the Ebro basin.

Driving forces

Agriculture - Agricultural land covers 48.8% of the catchment (1989), of which 30.8% is arable land. Agricultural land is concentrated in a region running parallel to the main course and the main tributaries approximately, extending approximately 10-20 km from the river shore used for irrigation while other areas used for dry farming. No specific information on the crops grown or livestock densities is provided. However, land use in the north-eastern part of Spain is dominated by cereal production, with low livestock densities.

Industry - CEDEX, Spain provided a map of the catchment showing the location of major industrial categories, as well as information on estimated organic matter discharges by industry per sub-catchment. However, no specific information on nutrient discharge from industry was received. Industry is concentrated in the upper catchment in the cities of Zaragoza, Pamplona, Logrona and Vitoria with food industries, mechanical engineering and textile industries being particularly important. Industry accounts for three quarters of the total discharge of organic matter from point sources with the major industrial centres being responsible for half of the industrial discharge.

Population and waste water treatment plants - The total population in the catchment is 2,742,220 people or 33 inhabitants per km^2. About 55% of the population live in the five largest cities, with about one million inhabitants living in rural areas. Only 10% of the population is connected to WWTPs. Of 488 sewerage networks in the catchment 53% discharge directly to rivers without treatment, 24% discharge to septic tanks and the remaining 23% receive basic treatment. Waste water from the population accounts for 25% of the total organic matter discharged from point sources.

Pressures

No specific information on nutrient loading has been found for the catchment (see the above section with description of the sectors).

Table 6.16. Nutrient levels at upstream, central and downstream sites in the river Ebro. Mean of annual average values for the period 1986-92.

Station name	Catchment area (km^2)	Nitrate concentration (mg N l^{-1})	Total phosphorus concentration (mg P l^{-1})
Miranda de Ebro	5,481	1.57	0.093
Zaragosa	40,434	4.83	0.275
Tortosa	84,230	2.32	0.244

Environmental state and development

At the upstream part of the catchment annual average concentrations of nitrate and total phosphorus in 1986-1992 were approximately 1.6 mg N l^{-1} and 0.1 mg P l^{-1}. In the central part of the catchment at Zaragoza concentrations increased to 4.8 mg NO_3 l^{-1} and 0.28 mg P l^{-1}. Downstream, levels decreased to 2.3 mg NO_3 l^{-1} presumably due to losses in impounding reservoirs. Total phosphorus levels were also slightly lower at the downstream sampling site, with a mean value of 0.24 mg P l^{-1} (Table 6.16)

6.6 Cross analysis

Data availability

Available data in the report is data which was open for the project. Some of the data which in this paragraph is considered as not available for the catchments, may exist at various institutes or by local water authorities, but was not possible to receive for this purpose.

Agricultural data availability differed markedly between catchments (Table 6.17). For all catchments, data for the agricultural area divided into arable land and grassland was available, but information on crops grown and livestock numbers was only obtained for the Odense Fjord and River Avon catchments. Nutrient export was estimated from three of the catchments (only nitrogen in River Rhine), but with different point of references (Table 6.17).

Population statistics were available for all catchments, although the level of information on waste water treatment plants varied (Table 6.18). Information about the total loads to/from WWTPs was accessible for all but the River Ebro , and for three of the catchments information from each plant was available (Table 6.18). Treatment technology of the plants was available for the Forfar Loch plant, for all plants in Odense Fjord, while for the last three catchments this information was only accessible for some of the plants or made by assumptions. (In the case of the River Avon Catchment, this is considered to be an accurate assumption for at least 98% of the sewered population.)

Except for the River Ebro catchment, information on industrial effluents was available, but at different levels of detail (Table 6.18).

Total nutrient loads was available for all case studies, except for the River Ebro. But the level of detail on degree of source apportionment varied between catchments, as does the approach to obtain them (Table 6.19). For example in River Avon the total nutrient budget was calculated by sum of estimated loads from agricultural runoff, atmospheric deposition, scattered dwellings, and point sources (Table 6.19). In contrast the total load to Odense Fjord was measured directly. Agricultural loads where calculated by subtracting measured-/estimated loads from background, point sources and scattered dwellings and from the total measured load (Table 6.19).

Table 6.17. Information of agricultural data availability for the catchments.

	River Rhine	Odense Fjord	River Avon	Forfar Loch	River Ebro
Agricultural area	Data available down to subcatchment level (=main countries in the catchment).	Data available down to subcatchment level.	Data available.	Data available on catchment level.	Data available.
Land- use (area of different crop type)	Agriculture land divided into arable land and grassland on a subcatchment level	Area of different crops in the catchment estimated from regional agricultural census data	Remote sensing data of area of different crops and agricultural census data	Agriculture land divided into arable land and improved grassland	Agricultural land divided into arable land, permanent meadows and pasture, and permanent crops
Livestock density	No information available	Estimated from regional agricultural census data.	Agricultural census data.	No data collected because this source of nutrient input to the Loch was insignificant compared to loads from the WWTP.	No information available
Fertilizer and manure application	No information available	Total nutrient application for each crop type estimated from Danish mean application rates of manure and fertilizer obtained from yearly survey.	Estimated based on mean recommended application rates for different crop type.	No data collected because this source of nutrient input to the Loch was insignificant compared to loads from the WWTP.	No information available
Nutrient export	N-export calculated as the sum of production and imports of all fertilizers and food subtracting the sales and export of agricultural products.	Calculated for each crop type as total nutrient application (including n-fixation and atmospheric deposition) subtracting nutrient harvest (estimated from Danish yearly survey).	No information on surplus, but fertilizer runoff estimated as 20% of nitrogen application and 3% of phosphorus application. That of manure as 17% of produced N and 3% of produced P.	No estimation because this source of nutrient input is insignificant.	No information available
Soil type	No information available	Area of different soil types down to subcatchment level (Danish texture classification system, 7 categories).	No information shown, but recommended fertiliser application rates are based on soil chemistry.	Information about dominating soil types.	Area of different soil types (FAO-UNESCO classification).

Table 6.18. Information on availability of data concerning pressure from waste water

	River Rhine	Odense Fjord	River Avon	Forfar Loch	River Ebro
Population	Data available down to subcatchment level.	Data available for the catchment as a whole and for counties whole or partly included in the area.	Data available for the whole catchment. If required, this could be broken down to subcatchment level.	Data available for the whole catchment.	Data available down to county level.
Number of WWTPs	No total number of plants, but total loads on subcatchment level were known.	Data available.	Data available.	Data available.	Data available from a map.
Connection rate of population	Data available for some areas.	Data estimated from part of PE at WWTPs from municipal waste water and total population.	Data estimated from actual population served and total population.	Data available on catchment level.	Data available for the total catchment.
Size of WWTPs	Data available down to subcatchment level, but not for each plant.	Data available for each plant.	Data available for the single plant	Data available for each plant.	Data available for some areas, but no total figure.
Treatment technology of the WWTPs	Data available for some plants.	Data available for each plant.	Data available for most plants.	Data available for each plant	Data available for some plants.
Discharge of N and P to WWTPs	Available on subcatchment level for nitrogen, not for phosphorus.	Estimated from standard values of N and P in one PE.	No information provided, but could be estimated as for Odense Fjord.	No information provided, but estimates of the sewered human population are provided from per capita loading factors.	No information available
Discharge of N and P from WWTPs	Available on subcatchment level	Available for each plant >330 PE and estimated for smaller plants based on actual PE, treatment technology, and standard values of N and P in one PE.	Available for 18 plants and estimated for the remaining plants based on actual PE of the plants and mean nutrient export coefficient for the measured plants. Divided into plant sizes of <10,000 PE and >10,000 PE.	Ammonium and orthophosphate available for the single plant.	No information available
Percentage nutrient removal from WWTPs	Available on subcatchment level for nitrogen, not for phosphorus	Available for each plant	No information provided, but standard nutrient removal factors could be applied.	No information provided, but standard nutrient removal factors could be applied.	No information available.

(*Table 6.18.* Continued)

	River Rhine	Odense Fjord	River Avon	Forfar Loch	River Ebro
Treated water volume	No information available	Available for each plant.	No information available	No information available	No information available
Annual mean concentration of nutrients in effluent from WWTPs	No information available	Available for each plant.	No information available	No information available	No information available
Industrial effluents of nutrients	Total industrial effluent , but not for single activities	Data available for each activity with direct effluent	No important industry with direct effluent	No important industry with direct effluent	Maps with indication of location of main industries

Table 6.19. Information on calculation of sources of nutrient load from the catchments.

Sources	River Rhine	Odense Fjord	River Avon	Forfar Loch
Background	Estimate based on test-results and monitoring of erosion, runoff and leaching, paying attention to land-use and topography.	Estimate based on discharge weighted concentration of nutrients from five Danish nature catchments.	See below.	Diffuse load calculated by subtracting load from sewer overflow and WWTPs from total load. No further apportionment has been performed.
Atmospheric deposition on land	Estimated based on precipitation data and measured concentrations	Included in the agricultural load	N estimated by standard load to land and export coefficient as percentage of rainfall lost to runoff. P estimated by background export rates from 'natural' catchments	See above.
Agriculture	See above; one of the main criteria also: mineral-balances.	Total measured riverine load subtracting point sources, scattered dwellings, and background load.	Nutrient runoff estimated from a fixed percentage of the estimated nutrient application from fertilizer and manure, respectively.	See above.
Scattered dwellings		Estimate based on information of houses without connection to common sewerage, standard load per house according to type of house and assumption of percentage of the PE reaching surface water.	Estimated based on total PE from unserved population, standard retention coefficients and standard export coefficients.	See above.

(*Table 6.19.* Continued)

Sources	River Rhine	Odense Fjord	River Avon	Forfar Loch
Sewer overflow		Estimate based on Danish standard values of nutrient concentrations in effluents and information of relation between rainfall and discharge in the sewerage system.	Not estimated.	Measured.
WWTPs	In general measured values or estimated based on treatment technology	Measured for WWTPs >330 PE and estimated from actual PE and treatment technology for smaller plants	Estimated from standard export coefficients derived from measured WWTPs in the catchment divided into two size class.	Measured.
Industry	Measured	estimated and measured values	No important effluents discharge directly to river.	Information of total loads of ammonia and phosphate apportion into diffuse rural sources, urban runoff , sewer overflows and WWTP load.
Atmospheric deposition on surface water	see deposition on land	Estimated from coefficients derived from three measuring points in the Fyn County.	Assumed to be negligible.	Assumed to be negligible.

Comparison of catchments

The catchment areas ranged in size between 15.4 km^2 (Forfar Loch) and 185,000 km^2 (River Rhine). The average population density was highest in the catchment of Forfar Loch (844 inh. km^{-2}) and lowest in the River Ebro catchment (33 inh. km^{-2}), while the remaining three catchments contained about 250-300 inh. km^{-2}.

Because of the differences in catchment size, total nutrient loads were markedly different between the three catchments. Where data were accessible, the values ranged from 2,493-404,456 ton N to 67-32,229 ton P, but area-based loads were also different, with highest loads from the Avon catchment and lowest from the catchment of Odense Fjord (Table 6.20). In terms of phosphorus, Odense Fjord received a markedly lower phosphorus load, primarily due to the lower input from point sources. The inter-catchment variability in area-based loads from diffuse sources was much smaller (Tables 6.2, 6.8, 6.13 and 6.20).

Table 6.20. Area specific nutrient loads to River Rhine, Odense Fjord, and River Avon 1995.

	Total nitrogen ($kg\ ha^{-1}\ year^{-1}$)	Total phosphorus ($kg\ ha^{-1}\ year^{-1}$)
River Rhine	28.8	2.3
Odense Fjord	23.5	0.6
River Avon	45.3	3.6

As mentioned above the approaches used for calculating total nutrient budgets in the catchments were very different, so comparisons must be made with caution. However, the relative importance of nutrient loads from point sources was lower in Odense Fjord than for the other catchments, in terms of both nitrogen and phosphorus (Table 6.20). In Forfar Loch the load from point sources was the only significant input and for the last two catchments this source comprised 30-40% for nitrogen and 62-81% for phosphorus (Table 6.21).

Table 6.21. Percentage of total nutrient loads from diffuse and point sources 1995.

	Nitrogen		Phosphorus	
	Diffuse sources (%)	Point sources (%)	Diffuse sources (%)	Point sources (%)
River Rhine	57	43	38	62
Odense Fjord	87	13	63	37
River Avon	70	30	19	81
Forfar Loch	<4 *	97*	<2**	98**

* Ammonium, **Phosphate

6.7 Possibilities for establishment of scenarios to describe the effect of relevant EU-legislation in the catchments

The Urban Waste Water Directive

To determine whether the implementation of the EU UWWT Directive will influence the load of N and P from WWTPs compared to the actual loads in the catchments, the following information is needed:

- Is the water body classified as a sensitive/less sensitive area?
- Treatment technology of each plant (only specific demands for WWTPs >2,000 PE)
- Discharges of PE, total P, total N (N and P might be estimated from national standard values of nutrient contents in one PE) to each size class: 2,000-10,000; 10,000-100,000; and >100,000 PE, classified in treatment technologies
- Discharges of total P, total N from each size class divided into treatment technology or removal percentage (might be estimated from standard coefficient for actual treatment technology)
- Treated water volume for each class (national standard values might be used) and/or nutrient concentration of effluent water.

From this information the requirement to implement better treatment technology in the catchments will be found, and the resulting reduction in nutrient load can be estimated.

As the above list indicates, much of the required information may be estimated from national standard values. Thus, the most important information is the actual discharge of waste water to each plant and treatment technology of the plant, although, even that might be difficult to obtain at a catchment level. For the Rhine, and the Ebro catchment it will be possible to establish the scenario for some of the subcatchments, but not for the catchment as a whole. Anyway, only 10% of the population in the River Ebro catchment is connected to waste water treatment (Table 6.18) and this source may therefore be negligible compared to loads from population without common sewerage. In the Odense Fjord catchment the required information is available and for the Forfar Loch catchment the data is available for phosphate and ammonium (Table 6.18).

The Nitrate Directive

To analyse the effect of the Nitrate Directive (e.g. reduced fertilizer application rates related to expected crop need, and more evenly distribution of manure or reduced manure production) on the nitrate leaching from agricultural land, it would be obvious to use a similar model to those already decribed in Chapter 5 (the Danish NP-model, CARMEN ,and the study of Pan, 1994).

To use the Danish N&P model or Pan's approach, very detailed agricultural information must be available (e.g. information about farm type and field-level information on soil type, crop type, fertilizer and manure application rates). Of the catchment described in this report only the very intensive monitoring in the six Danish agricultural catchments, have such extreme detailed agricultural data. However, for Odense Fjord a very rough estimate might be performed by using agricultural statistics on livestock and crops grown and assuming that soil types are evenly distributed between all crops in the catchment. Mean Danish fertilizer and manure application rates for each crop type could be used. This simplifies the model, but should allow qualitative changes in nitrate leaching at different nutrient application levels to be predicted, even though it will not give any information on the actual values for the catchment.

The standard leaching values are a key parameter for the N&P model, since the results are only valid for condition similar to those from which the experimental data (on which the model is based) were obtained (e.g. crop rotation, cultivation practice). Therefore it would be unwise to apply the model (in its current state) to other areas. Even though relatively detailed agricultural data are available for the River Avon catchment (Table 6.15), and it may be possible to obtain the necessary soil type data, insufficient information is available on farm management practices to apply the model. For the other catchments, the agricultural information is not sufficiently detailed.

The CARMEN model needs less detailed agricultural information, only the areas of arable farmland and grassland. National average fertilizer and manure application rates required are used, with no requirement for information on crop types or farm types. The nutrient content of manure is fixed. This approach gives an indication of nitrate leaching at European and national levels, but the procedure is too simplistic to operate at catchment level.

Several of the studies described in Chapter 5 found a strong relationships between nitrogen application rates and nitrogen concentrations in surface waters. Thus, a rough estimate of the effect of decreased nutrient export (as a consequence of reduced total nutrient application) on N loading from agricultural land, could be made by establishing climate-dependent relationships between nutrients in the catchment and measured nutrient loads in the surface water. This approach would make it possible to indicate the effect of the Nitrate Directive in all but one of the described catchments (the River Ebro catchment).

The CAP-reform

Changes in types of crops grown, livestock composition, and reduced arable area might be some of the consequences of the CAP-reform which, in turn, may influence fertilizer and manure application rates and the amount of nutrients leached from the root-zone. As for the Nitrate Directive, it is often difficult to obtain the detailed agricultural information which is needed to predict the effect of this legislation on the nutrient load. Thus, a simple relationship between nutrient application and nutrient concentration might again give the best description on the effects, and would be accessible for all the catchments but the Ebro catchment.

Conclusion

Even though some information on the sectors and their pressures was obtained from the five case studies, it is very difficult to run scenarios, which evaluate the effects of the EU legislation at such a disaggregated level. Very detailed information is required and the consistency and level of detail of available information differs between countries, catchments and subcatchments.

7 Recommendation for future IEA work on eutrophication

7.1 Introduction

It is important to remark: that in IEA, it is the policy aspects which are in focus - and not the details of the environmental transformation processes. For this reason, simple models that account for the main features of relevance to policy are preferable.

This section reviews the process of integrated environmental assessment of eutrophication on a European scale to identify key issues. The main driving forces and their pressures are analysed to help focus on the important processes. The important relationships on a European scale between pressures and loading into surface waters, as well as the impact on the environmental state are evaluated.

The primary aims of performing IEA of eutrophication are either to evaluate different strategies to reduce the problem, or to elucidate the relationship between structural, technological and economic development in society *(driving forces)* at one hand, and the consequences regarding eutrophication *(state and impact)* on the other; i.e. to evaluate scenarios.

Questions to be answered by the analysis could include:

- What is the contribution of various human activities to the eutrophication problem?
- What are the prospects with respect to eutrophication of recent developmental trends within European agriculture or other societal sectors?
- What are the costs of different strategies to curb eutrophication? This involves comparing technological measures within anthropogenic sources (e.g. waste water treatment), measures directed towards individual sectors (agriculture vs. waste water treatment plants) and measures directed towards different countries or regions (e.g. Switzerland vs. the Netherlands).
- What are appropriate targets to be proposed for sectors or countries following the principle of cost-effectiveness
- What is the effectiveness of current policies on the environment, including assessment of progress of policies achieving targets.

Following the DPSIR framework, IEA of eutrophication involves at least the following steps:

- **The first basic step** in IEA is the identification of the environmental problem.
- **The second step** in IEA is to analyse the relationship between *driving forces, pressures,* changes in the *state* of the environment and *impacts* on ecosystem and society.

- **The final step** in IEA is the appraisal of different policy options which may be taken in response to the environmental problem. The appraisal addresses two main aspects: Target setting and assessing the means achieve reach the target(s).

In the following sections, IEA is evaluated within a European perspective to help focus on key issues.

7.2 Identification of the problem

State and impact

The growth of phytoplankton and other plants in the aquatic environment is mainly controlled by the nutrients nitrogen (N) and phosphorus (P). Under natural conditions both nutrient loading and algal growth are relatively modest, and there is a diverse and stable plant and animal community. Excessive inputs of nutrients (nitrogen and phosphorus) to waterbodies can result in a series of adverse effects known as eutrophication.

This can cause significant ecological changes, and negatively affect the quality of water for human consumption and other uses. In cases where inland surface waters are used for domestic water supply, eutrophication may lead to a host of water treatment problems, such as taste and odour generation, filter blockage, increased chlorination/ozonation rates, etc. These are expensive and time-consuming problems to overcome, especially in the case of very eutrophic water.

The negative effects of eutrophication are generally greatest in lakes and reservoirs, and to a lesser extent in large, slow-moving rivers. Poorly mixed, shallow estuarine and marine areas may also be severely affected. Phosphorus is usually the primary limiting nutrient in freshwater (and so the element to which attention is paid), whereas nitrogen is the major limiting nutrient in coastal areas. In the upper reaches of many estuaries, phosphorus is often said to be limiting, while in the lower reaches, nitrogen is usually said to be limiting. However, in some estuaries, nutrient levels are high enough for neither N nor P to be limiting, yet chlorophyll levels remain relatively low. In such estuaries, light and/or hydrodynamic factors (retention time) are the limiting factors (*Parr, 1996*).

Driving forces and pressures

Nutrient loading generally increases with increasing human activity in the catchment area. Industrial production and household consumption have increased at a rapid rate, producing greater loads of nutrient-rich waste water. The extent to which this is discharged into surface waters depends on the sewage treatment facilities available, as well as the nutrient content of the item(s) produced or consumed. Activities within the agricultural sector have also changed with the result that much more intensive farm management practices are considered normal. Since the 1940s, the use of commercial inorganic fertilizer has increased dramatically. This, in conjunction with increased livestock densities, has resulted in the production and application of much greater loads of manure to and from cultivated land. Higher livestock densities also result in greater emissions of ammonia which, in turn, lead to greater atmospheric deposition of nitrogen to land and surface waters. Changes in arable farming practices have also increased the rate of soil erosion, with a related increase in phosphorus run-off. In many areas, much of the agricultural land is drained and many of Europe's marshes, wetlands, ponds and lakes have disappeared. This has considerably reduced the capacity of freshwater ecosystems to store and break down many pollutants, including nutrients

Most of the phosphorus loading of inland surface waters is attributable to discharges from point sources, especially municipal sewage and industrial effluent, while nitrogen loading is primarily from agricultural activity, especially the use of nitrogen fertilisers and manure. Phosphorus concentrations in most European surface waters have decreased during the last 10-20 years as a consequence of improved waste water treatment and the substitution of phosphorus in detergents. In contrast to phosphorus, the nitrate level in most European rivers has increased during the last 10-20 years, mainly as a result of increasing or high use of nitrogen fertilisers (*Kristensen & Hansen, 1994*).

The nutrient levels in many areas of Europe are too high, and unless major efforts are made to reduce inputs of nutrients, eutrophication is likely to continue to be an important European environmental issue. In many cases, it is essential to remove phosphorus in waste water treatment plants and to reduce the phosphorus content of detergents, as well as to reduce the nitrogen (in particular) and phosphorus loading from agricultural areas.

7.3 Analysis of relationship

The second step in IEA is to analyse the relationship between *driving forces, pressures,* changes in the *state* of the environment and *impacts* on ecosystem and society.

Ideally, it should be possible to analyse the various pressures placed upon the environment in terms of the risks which arise from them; attempting to minimise these risks to the same acceptable level would then form a firm basis for future planning. Unfortunately our understanding of many of the processes is, as yet, insufficient for such an approach to be used. Nevertheless, it should be possible to review the various pressures placed upon the environment at EEA, large catchment and national levels, and to consider the extent to which such pressures are increasing, decreasing, or remaining relatively constant.

7.3.1 Relationship between driving forces and pressures

The pressures on the environment are the result of production or consumption processes which in a macroeconomics context are structured according to economic sectors such as agriculture, energy, industry, transport and consumers. Several economic activities in the society are responsible for substantial loading of nutrients to the environment. On a European scale important antrophogenic sectors are agriculture, consumers and industry, power plants and transport. On more local or small catchment level other antrophogenic factors may be of importance: e.g. tourism or fish farms. In the following section the *driving forces* and their *pressures* are assessed within a European perspective. The basic framework of the driving forces-pressure relationship assessment model is described in Figure 7.1.

The environmental *pressures* from *driving forces* are a function of two types of variables: first the *level* of these activities and secondly the *technology* applied in these activities. The modelling of pressures will therefore require methods that take into account these two types of variables.

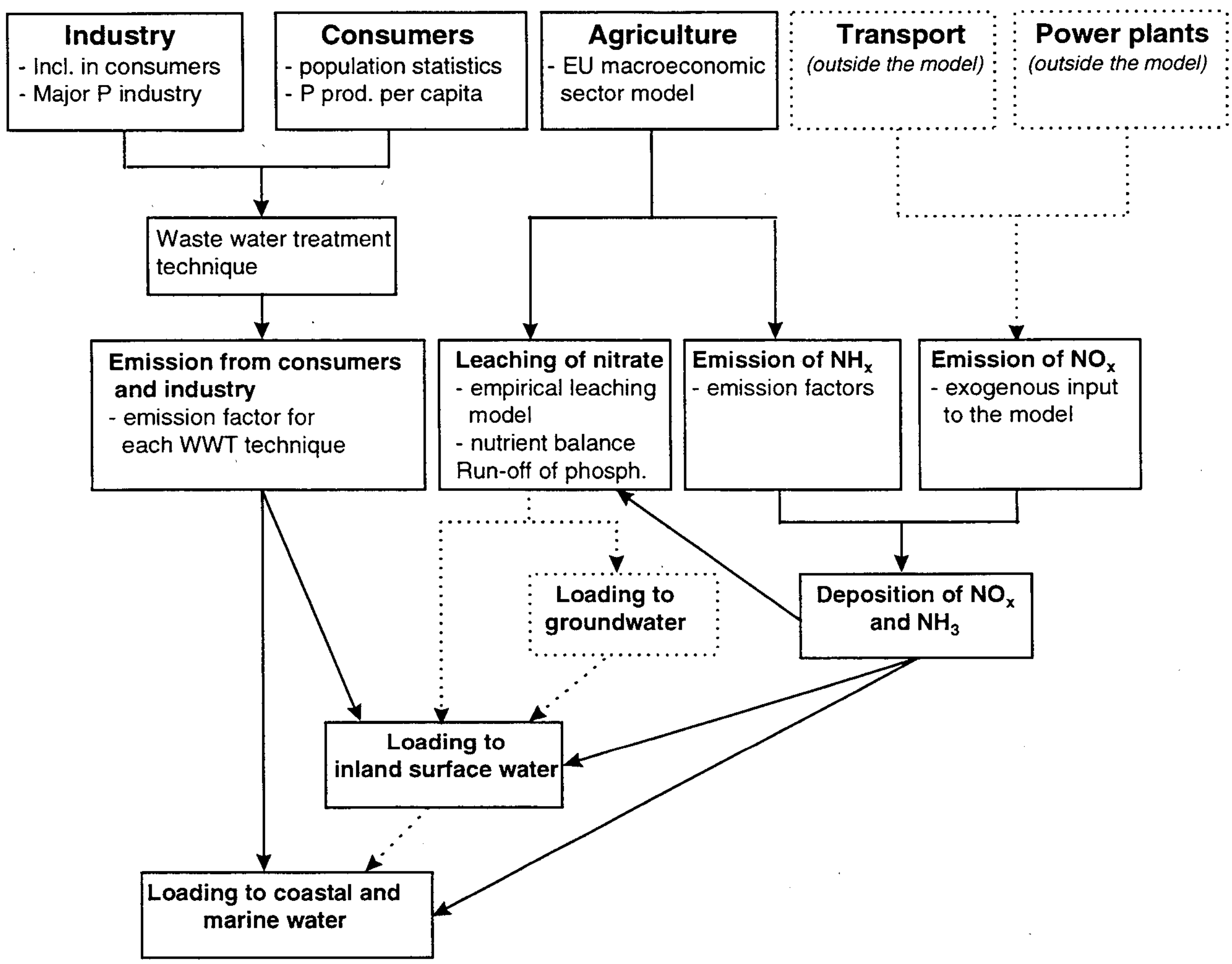


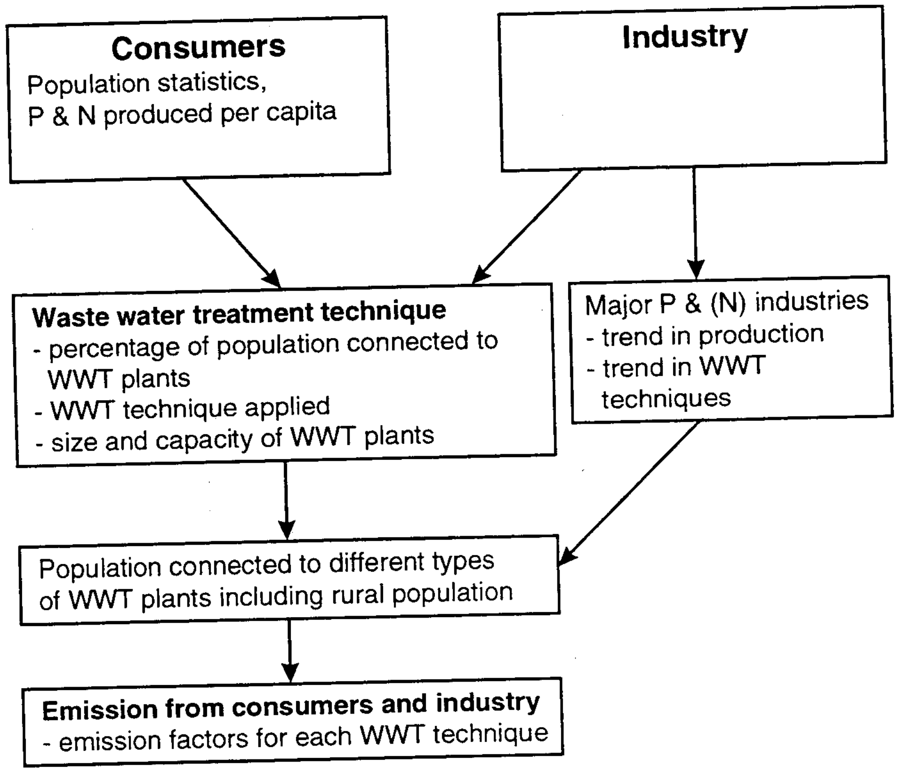
Figure 7.1. Conceptual diagram describing relationship between the main driving forces and their pressures and the loading into surface waters

The variables accounting for the *level* of activities are economic in nature, reflecting the level of production and consumption. The *technology* variables will be reflected by emission factors. For example, empirically estimated relationship between fertilizer application and nutrient leaching or emission factors depend on the purification process applied at waste water treatment plants.

Consumers and industry

Industrial production and household consumption result in waste water containing nutrients. The extent to which the nutrients in waste water are discharged into surface waters depends on the waste water treatment facilities available. Figure 7.2 illustrate the framework for relationship between consumers and industry and their emissions of nutrients.

Figure 7.2. Conceptual diagram describing the main relationships between consumers, industry and their impact on phosphorus and nitrogen emissions into surface water



Level of activity

Industry

Only a small part of the European industrial sector is responsible for the majority of waste water containing phosphorus, in particular the fertilizer industry and other related chemical industries which produce phosphorus containing products (e.g. pesticides). For instance, during the late 1980's in Denmark, phosphorus emissions from two industrial sites (a fertilizer factory and a pesticide production plant) accounted for more than 80% of the total emissions from 58 major industrial plants with direct discharge to surface waters. All remaining industrial works are connected to municipal waste water treatment plants (*Miljøstyrelsen, 1988*). In the Netherlands two fertilizer production plants accounted for the majority of phosphorus emission from industry (*van Oirschot, pers. comm.*). In the two countries a marked reduction in phosphorus emission from these major P industries were observed in the early 1990's due to improved waste water treatment and cleaner technology.

On a European scale focus has especially to be placed on the development of the fertilizer industry and related chemical industries which utilise or produce large loads of phosphorus.

Households

The amount of waste water produced is proportional generally to the population and only to a little extent dependent on the economic development. The nutrient content of waste water from households is primarily determined by excreta from humans and phosphorus from detergents. During the last 10-15 years the most marked change in phosphorus content of waste water in many European countries has been due to nationally-imposed reductions in the P-content of detergents. In many countries phosphate-free detergents today constitute the majority of detergents being sold.

Information requirements: population numbers and phosphorus and nitrogen production per capita per year.

Technology variables

The extent to which the nutrients in waste water are discharged into surface waters depends on the waste water treatment facilities available. The majority of the population in the EEA countries is connected to sewerage systems and municipal waste water treatment plants. However, some regional differences do exist: in north-western countries generally, more than 80% of the population is connected to waste water treatment plants, while the percentage in southern Europe varies between 11% and 60% (Greece and Spain), respectively (*OECD, 1995*). The extent of nutrients removal also varies; generally being highest in Nordic countries and lowest in southern European countries. The construction of WWTPs during the last 10-30 years has of course been prioritised to focus on the catchments of important water bodies with environmental problem, for example, the catchments of many large lakes have WWTPs with high removal of phosphorus compared to national averages.

The total number of WWTPs is very large; in the EU12 countries, for instance, more than 40,000 WWTPs exist (*EWPCA, 1995*) and in the German part of the Rhine catchment their are more than 3000 WWTPs (*Umweltbundesamt, 1994*). The majority of the load to WWTPs is handled by the large plants. In the former West Germany the loading to 243 WWTP (serving >100.000 inhabitants) and 1162 WWTPs (serving> 20,000 inhabitants) were 55% and 84% of the total loading, respectively. The remaining 5179 WWTPs treated only 16% of the total urban/industrial load (*Umweltbundesamt, 1994*). Similar figures can be found for the UK where the waste water from urban centres greater than 15,000 PE in size accounts for 91% of the total load to WWTPs (*DoE, 1995*).

A practical solution for undertaking IEA on a European scale would be to get specific information (size, loading, purification technology adopted) on the WWTPs greater than 15,000 person equivalents (around 4,000 plants in the EU12 countries) and use national *per capita* loading factors to calculate the loading from the populations connected to smaller WWTPs and septic tanks. In addition, information on the waste water treatment process applied at P-intensive industrial sites is necessary.

Agriculture

Agriculture results in export (leaching and erosion) of nutrients from land. In addition, the emission of ammonia to air results in the deposition of reduced nitrogen on surface waters and land which in turn may be washed out into groundwater and surface waters. Figure 7.3 illustrates the framework for relationship between agriculture and the emissions of nutrients.

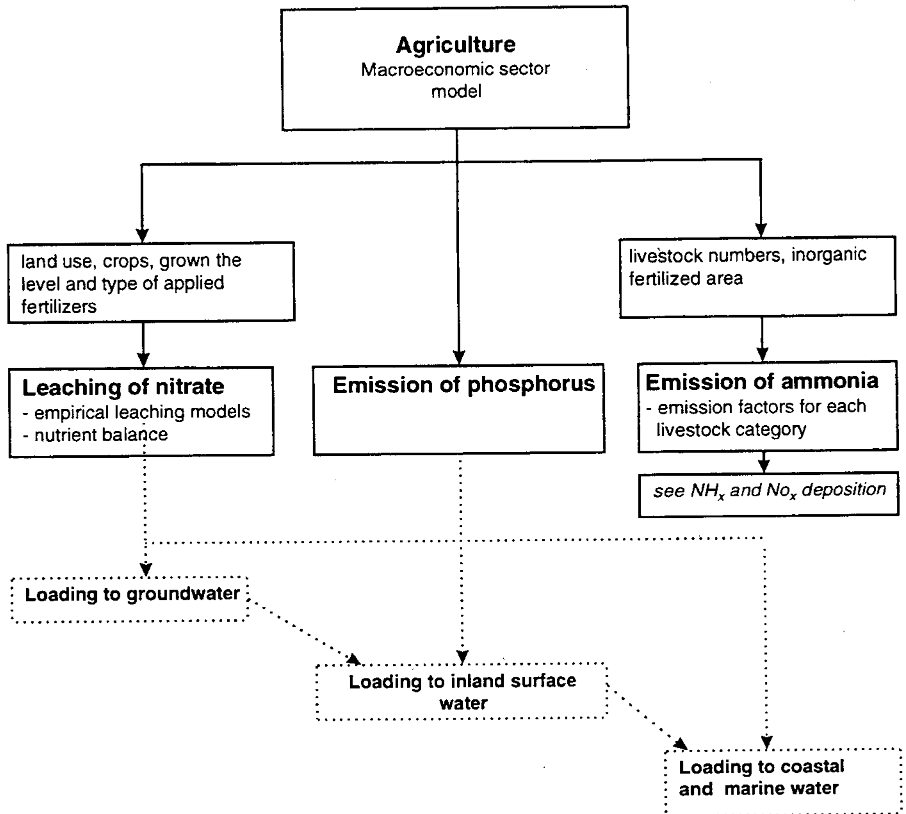


Figure 7.3. Conceptual diagram describing the main parts of the relations between the agricultural sector and loading of nutrients in surface waters

Level of activity

A macroeconomics sector model may be used to define the overall development of agricultural production. More detailed sub-models may be constructed to dis-aggregate this information to a level suitable for environmental purposes. The overall changes in agricultural production (e.g. EU development) has to be divided into the changes which occur in geographical regions and between individual activities. In addition, economic development has to be related to activities affecting the export of nutrients (e.g. development in areas used for various kind of crops, use of fertilisers, development in livestock numbers).

To enable this dis-aggregation of the agricultural development (both spatial and relevant activities) the macroeconomics sector model should provide a detailed breakdown of agricultural production in production activities (crops grown, livestock etc.) and flows of products (e.g. production of crops, use of crops for animal production). The sector model should feed information about structural changes: e.g. changes in crop patterns, changes in animal production, and changes in the geographical distribution of production.

An EU/EEA macroeconomics sector model should be used to define the overall development of agricultural production. Submodels should be established to dis-aggregate this information to a level suitable for environmental purposes (i.e. a regionalisation submodule and sub-modules which relate economic variables to activities affecting export of nutrients.

Technology variables

It is important to have emission factors for the following processes.

Leaching of nitrate

Nitrate leaching from the root zone is generally calculated by means of **simple empirical (exponential) equations**. The equations calculates the leaching of nitrate as a function of soil type, crop type, the level and type of applied fertilizer (commercial fertilizer, manure, and sewage sludge), and the utility rate of manure. Leaching of nitrate can also be estimated based on **nutrient balances**: Leaching = total input - total withdrawal + change in pool where total input = input of (fertilizers, manure, sewage sludge, atmospheric deposition, biological fixation) and total withdrawal = output though (harvested crops, denitrification, volatilisation of manure and fertilizers) .

The information required to calculate leaching of nitrate from agriculture is: land use (percentage of agricultural and arable land), crops grown, the amount and type of fertilizers applied and information on the management of manure.

Run-off of phosphorus

Prediction of phosphorus export from agricultural land is rather complicated. In hilly and mountainous areas most of the phosphorus losses are due to erosion. High loss rates can also be observed in relatively flat lowland areas with high phosphorus application rates. In the sandy regions of eastern, central and southern parts of the Netherlands, for example, around 10% of the area has phosphate-saturated soils from which phosphorus leaches (*Boers et al. 1995*). Likewise, evidence is gradually being presented to support the view that leaching of phosphorus may occur from nutrient-rich soils in the UK, and exceptionally high levels of phosphorus (1-3 mg l^{-1}) have been recorded in groundwater beneath the Po Basin flood plain in Italy. It is unclear what is happening here, since surface water phosphorus levels are considerably lower than groundwater concentrations. It is possible that phosphorus-rich deposits are present in the aquifer, but rice growing is a major land use in the area, the irrigation of which could, in effect, provide a continuous aquatic channel between fertiliser-rich paddy water and groundwaters.

Soil erosion

The run-off of phosphorus by erosion is a function of soil erosion rates and the phosphorus content of the soil. The major tools in soil loss prediction have been the Universal Soil Loss Equation (USLE) and its modifications like the RUSLE (Revised Universal Soil Loss Equation). The original USLE computes the soil loss as a function of a rainfall-erosion factor, a soil erodibility factor, the slope and length of slope, the land cover and a supporting land management practice factor.

The aggregated nature of information on land cover and agricultural management practices on European, country and regional/large catchment levels makes the calculation of soil erosion nearly impossible. For example, fields that are left bare during winter can not be directly related to the very important slope and vegetated buffer strips adjacent to streams, ponds, and lakes could significantly reduce the phosphorus loading into surface waters.

At the moment, soil erosion models like the one used in the CARMEN study can be used to give an indication of areas with high erosion risks and together with information on phosphorus content of the soil estimates of P-losses to surface waters by soil erosion can be calculated. On an European and large catchment scale, however, a relation between agricultural practices and P-losses by erosion is too complex.

Leaching of phosphorus from agricultural soils

The surplus of phosphorus to agricultural soil can be estimated from input-output balances where the input by inorganic fertilizers and manure is important and the output is mainly covered by harvest of plant products. Soils generally have a high phosphorus adsorption capacity. However soils, which are intensively fertilized over long periods, become saturated by phosphorus and high leaching of phosphorus is observed. Dutch studies show a marked increase in soil water phosphorus concentration when 30% of the phosphorus adsorption capacity is left unused (*Boers et al., 1995*).

Long-term phosphorus balances for the surface soil layers of agricultural soils could be estimated from agricultural statistics on crops grown, fertilizer consumption and livestock numbers.

These phosphorus balances could, together with information on the soil type and the phosphorus adsorption capacity of the soil, be used to calculate the European spatial variability in soils saturated with phosphorus. The future phosphorus pool in agricultural soil could be estimated based on predicted change in agricultural practices and areas. This, combined with phosphorus adsorption capacity data (soil types), the risk of phosphorus leaching could be predicted.

Air emissions and deposition

Figure 7.4 illustrates the relationship between driving forces and air emission. In addition deposition is also described.

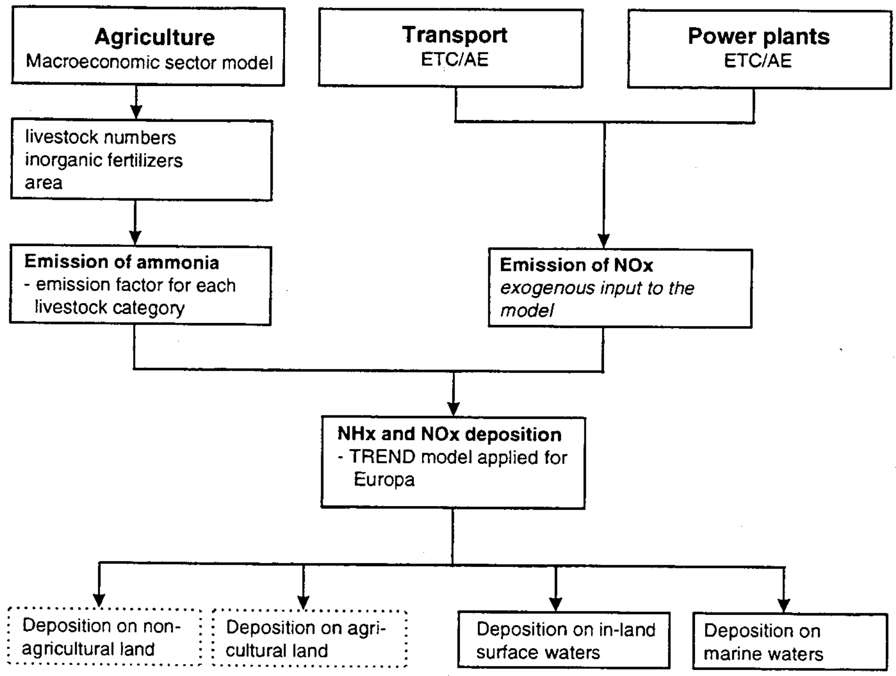


Figure 7.4. Conceptual diagram describing the main processes related to air emission and deposition of ammonia and nitrogen oxides.

Emission of ammonia

Emission of ammonia is calculated by means of emission factor for each livestock category multiplied by the number of animals or animal units in each category. In addition, an emission factor is used to calculate ammonia emission from inorganic fertilizers and crops (1 kg N per hectare arable land).

Emission of nitrogen oxides (NO_x) from power plants and transport

NO_x is formed in combustion processes from both the nitrogen present in the fuel and from the oxidation of nitrogen in air. In most countries, road transport and the production of electricity are the main sources of NO_x emissions. Estimates of European NO_x emissions can be obtained from UNECE/LRTAP and CORINAIR.

Relationship between emission and loading

The transport from emission (i.e. leaching from the rootzone, emission to air and emissions from WWTPs) to loading into surface waters, as well as the transport through inland surface waters generally result in the loss of nutrients (e.g. denitrification and sedimentation). The transport process is very complicated and often poorly described. In the following is briefly described the major obstacles in handling the transport process on a European scale.

Atmospheric transport

The atmospheric transport from emission of ammonia and NO_x to deposition is in most studies implemented by means of source-receptor matrices, based on the atmospheric transport model TREND (*Asman and Jaarsfeld, 1990*). When assessing surface water eutrophication on a European and large catchment scale the deposition on land is generally included into the sum of nitrogen application to these areas. The deposition on surface waters should be taken into account when making loading estimates for these areas.

Transport through soil

The relationship between nitrate leached from the rootzone and the observed loading into surface waters is generally very weak and uncertain. Often, only 10-40% of the calculated leached nitrate from the rootzone was recovered as loading from catchment areas. The problem is generally handled by applying a reduction coefficient to the calculated emission. Based on observed loading from the catchments (from river monitoring programmes) and calculated emissions the reduction coefficient is estimated (C-red=L-observed/E-calculated). It is not realistic on a European and large catchment scale to apply dynamic hydrological models to simulate water flow and loss of nitrate through the soil, because of the large data requirements of such models.

Another approach is to establish relationships between agricultural activities in the catchments and observed nutrient concentrations or loading in the rivers draining the catchment. The review of the key-studies revealed promising results on a regional basis for establishing relationships between agricultural activities and nutrient levels.

Emissions from population and WWTPs

The nutrients export estimated for waste water treatment plants are generally observed as loading to surface waters. In some areas of Europe the majority of the population is not connected to sewerage systems. The waste from the unsewered population is treated by disposal to soil or to septic tank systems; in these cases some of the nutrients are lost before reaching surface waters. The nutrient loading is usually calculated by use of reduction coefficients. Other populations are connected to sewerage systems, but the systems discharge directly to rivers without any treatment measures being employed.

Loss of nutrients in inland surface waters

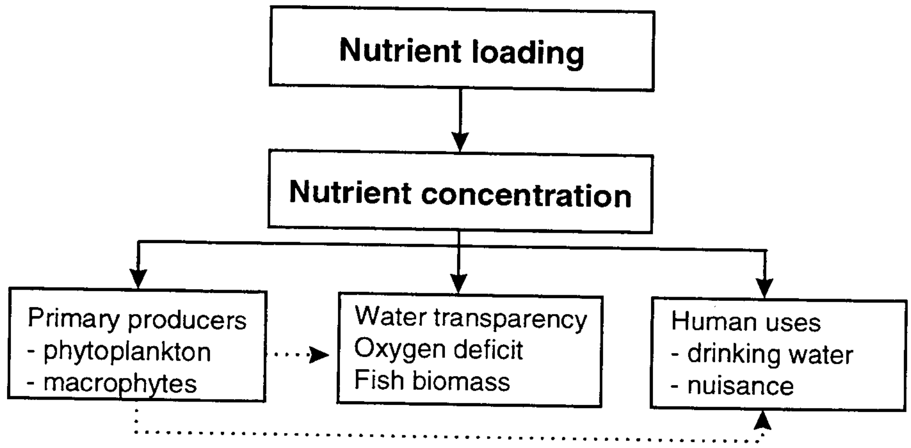
During the transport of nutrients in inland surface waters some of the phosphorus may be lost, especially in large lakes or reservoirs. Nitrogen losses may also be high in lakes and reservoirs, as well as rivers receiving high organic loads which have low oxygen status (thereby promoting denitrification). Large regional differences exist in terms of the areas and volumes of standing waters in the paths of rivers. Typically, over 10% of the catchment areas of large Swedish rivers are occupied by water, and most large Spanish rivers flow through large reservoirs. In contrast, the lowland parts of large rivers in central Europe tend not to include reservoirs and in the UK although lowland rivers are used to supply reservoirs, such reservoirs are sited away from the rivers and the water is pumped to them. Consequently, the rivers do not flow through them.

A first indication of the potential nutrient retention by surface waters in the European catchment could be provided by information on the area of standing waters in the catchments, as well as information on major reservoirs and lakes through which the rivers flow.

7.3.2 Relationship between pressure and environmental state

Empirical eutrophication models typically consist of two-submodels; namely a model describing the relations between nutrient loading and concentration, and a models describing the relationship between nutrient concentrations and various environmental quality variables (Figure 7.5).

Figure 7.5. Relationship between nutrient loading and nutrient concentration as well as relationship between concentration and the impacts.

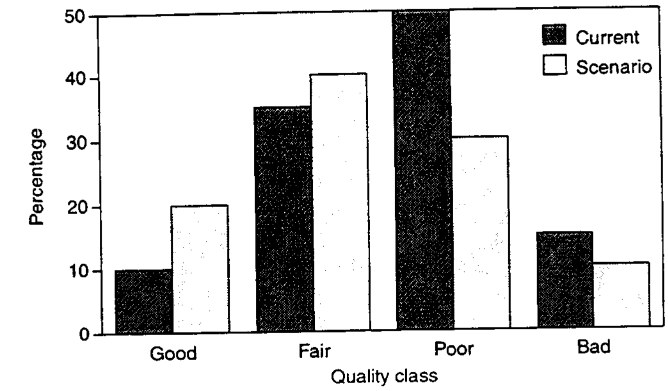


Such models are often good at describing and evaluating the effects of changes in loading to a single water body. For IEA on a European scale, indicators which present information on changes in the environmental state on aggregated level have to be developed. The indicators should present information for a group of water bodies, for example, on the loads of nutrients, annual average nutrient concentration in the water bodies (e.g. small lakes) as well as simple indicators of the environmental state. For example summer mean or maximum chlorophyll a levels, mean annual Secchi disc transparency.

In the proposed EC Directive on ecological quality (which is currently being replaced by a framework Directive on Water) it is the intention that Member States should classify the Ecological quality of their surface waters every 3 years and set operational targets for achieving good ecological quality. The classification schemes proposed for Member States to use for the classification of surface waters include indicators which can be related to eutrophication (*Nixon et al. 1996*)..

Evaluation of the effect of a scenario on the change in the environmental could be based on aggregation of the state information by classification schemes and presenting information on the number of water bodies which is classified with a good, fair, poor and bad ecological quality, respectively (Figure 7.6).

Figure 7.6. Evaluation of the effect of a scenario on the environmental state by use of water quality or ecological classification schemes.



7.4 Policy options

The final step in IEA is the appraisal of different policy options which may be taken in *response* to the environmental problem. The appraisal addresses two main aspects: *target setting* and *assessing the options* for reaching the target.

Target setting

Target setting is basically a political matter. However, it may be qualified by scientific knowledge, e.g. by the setting of critical loads. Targets can be set along the whole chain from driving forces and pressure to environmental state and the quality of ecosystems:

- Driving force targets. Such targets are often used to pin-point explicit responsibilities of specific sectors. The Nitrate Directive obliges Member States to work out codex of "Good Farming Practice"; the Directive on Integrated Pollution Prevention and Control focus on emission from Large Industries.
- Pressure targets. Such targets are used to regulate emissions from specific pressure activities. Targets for the maximum application of fertilizers or nutrients as well as target for outlet concentration from waste water treatment plants are examples.
- Ecological quality targets. Such targets are widely used in water quality management. The proposed Directive on Ecological Quality now part of the framework directive on water

There is of course an inherent interrelationship between these different sets of targets. An important aspect of IEA is to quantify this interrelationship, thereby enabling policy makers to define a consistent set of targets from driving force to ecosystem.

Identification of response options

Response options to reduce eutrophication include structural and technological measures and should also focus on ways to implement them. In the case of eutrophication, the technological and structural measures may be waste water purification, reduced fertilization, setting aside of land in sensitive areas, improved utilization of nitrogen in manure, etc. The implementation instruments may be regulations, economic incentives or taxes, and they may address the *pressures* ("environmental policies"), like the directive on urban waste water, or they may address the *driving forces* ("sector policies"), e.g. a reshaping of CAP integration environmental considerations or a EU tax on the use of nutrients; e.g. commercial fertilizers.

Consumers and industrial measures

Measures to reduce nutrient loading from consumers and industrial activities can be classified into two types:

- improved facilities at Waste Water Treatment Plants (WWTPs) reducing the export of nutrients; and
- a reduction in the amount of nutrients being produced *per capita* or per product being produced.

Agricultural measures

Nutrient leaching

Measures to reduce nutrient leaching from agricultural activities can be classified into three types:

- reductions in application of chemical fertilisers and manure;
- changes in the arable land use towards crops reducing nutrient leakage, and
- changed practices for manure treatment.

The land use measures include increases in the area set-aside, and the area of catch crops, energy forest and extensively used agricultural land e.g. permanent grassland, ley grass. Changes in manure treatment implies a change in the spreading time of manure from autumn to spring. Application of manure in autumn usually implies higher leaching than during the rest of the year since there are no crops available to make use of the nutrients.

Reduction of soil erosion

Conservation tillage is considered to be the best measure to leave more crop or residue cover and thus minimise soil erosion. The establishment of buffer strips along waterways and shorelines is a sensible measure to decrease the velocity of surface runoff, thus reducing transport of eroded material. However, the success of buffer strips is reduced when sited on steeply sloping ground and they are better suited to reducing particulate export during continuous low-level rainfall than if the same amount of rain falls in a series of irregular storm events. Phosphorus runoff by erosion could be further controlled by decreasing the phosphorus surplus from fertilizer and manure application.

Airborne deposition

Atmospheric deposition can be reduced in two ways:

- reduced gaseous nitrogen export at sources (e.g. lower livestock numbers, less use of cars); and
- technologies reducing nitrogen emissions after source (e.g. flue gas equipment).

Nitrogen oxides
Technologies reducing emissions: catalytic converters in cars and ships; and flue gas abatement at stationary combusting sources.

Ammonia emissions
Ammonia emission is dependent on the number of livestock. Consequently, a reduction in the number of livestock can reduce the ammonia exported to air. In addition, the emission of ammonia from fields after spreading as well as volatilisation from manure storage can be reduced by various measures (e.g. tilling after spreading of manure and cover on manure storage)

Restoring wetlands
Wetlands have a high capacity for the retention of nutrients; retention being generally a function of the area of the wetland and the loading. During the last few centuries (and the last century in particular) many wetlands have been drained, thereby reducing their capacity for nutrient retention. Restoration of drained wetlands or construction of new artificial wetlands would promote natural remediation.

7.5 Aggregations

EU/EEA strategies and policies related to eutrophication necessarily have to deal with the problems at a high level of spatial, temporal and sectorial aggregation, even though the effects of those policies may be most pronounced at much lower level of aggregation.

It has to be recognised that the nature of the environment, and the pressures placed upon it, differ spatially. This is in part due to natural environmental features and, in part, due to spatial variations in the controllable (anthropogenic) pressures which arise. Thus, the effects of changes in the sectors (driving forces) and the resulting pressures and the priorities for future management options are not necessarily the same across the EEA area.

7.5.1 Aggregation in time
The driving forces and pressure information is generally presented as annual average values; while the temporal aspect of the environmental state information depends on the media in question. In rivers, for example, nutrient concentration and nutrient loading data can be described in terms of annual average values, but the eutrophication effects (in terms of algal bloom formation) are observed during late spring and summer. Depending on the variable, the most effective form will have to be selected.

7.5.2 Spatial aggregation
Data relating to the pressures placed upon the environment in the EEA area, and its resulting state, are collected by a large number of different organisations, in different ways, in different formats, and

for different reasons. Statistical data for the EU Member States are collated annually by Eurostat, as well as other international organisation such as FAO, OECD and UNECE/LRTAP. Environmental state information is handled by various national, regional and local authorities.

Information on driving forces and pressures

Internationally comparable data

When looking for comparable information on driving forces and their pressures (e.g. agricultural statistics, degree of waste water treatment) on a European/EU scale this information is generally aggregated to country averages. However, European/EU comparable, but less detailed data, can be found for some topics at a more detailed geographical scale. Eurostat and FAO, for example, hold per country average data on year to year development in the crops grown, livestock and fertilizers applied, while the information held by international organisations on nuts3 level (provinces, regions and counties) is less detailed. CORINE land cover data are available for many areas of Europe, this contains about 40 land use classes, albeit not down to crop types.

National data

The most comprehensive data on driving forces and their pressures is generally found at national level. The data available from national statistics and various governmental institutions can often be disaggregated to administrative regional levels. The data held at national level may only be partly comparable at EEA/EU levels.

Consumers and industry

To assess the pressures from consumers and industry on a European and large catchment level, data on the following topics should be available:

- Population statistics including information on the spatial distribution of the population,
- National estimates of phosphorus produced per person equivalent per year, and information on the P-content of detergents,
- Information on large WWTPs (e.g. > 15.000 PE) including data on location, size (PE) and waste water treatment process applied,
- Per country information on the percentage of population (PE) not connected to WWTPs and connected to small WWTPs including per country average information on water treatment process applied at small WWTPs (< 15.000 PE),
- Information on discharges from major P-industries (fertilizer industry etc.)

At **international level** only information on population statistics and per country average data on the percentage of population connected to WWTPs with primary, secondary and tertiary treatment can be found (Source: Eurostat/OECD) (Figure 7.7). In addition, it may be assumed that the development in use of phosphorus in detergent has been rather similar for many countries. It may also be possible to find some general information on the trend in production/sales by the fertilizer industry. However, information on the treatment of waste water from industry is at the very least very difficult and possibly impossible to obtain on a European level.

At **national level**, more comprehensive information on WWTPs, phosphorus produced per capita and changes in export from industrial sources can often be collated, though not for all countries. However, national statistics do not normally include information on the location of point source discharges and national data may not be comparable at an international level (Figure 7.7).

At **regional level** more specific information on WWTPs can be found, however, this information is often hard to obtain because of the large number of organisations involved in producing and handling the data. Again, there may also be problems in terms of data comparability. The review of the information available for the five European **catchments** in section 6 showed that it may be very difficult at the moment to obtain detailed information on the WWTPs in individual catchments.

Agriculture

To assess the pressures from agriculture, data on the following topics should be available:

- Land-use statistics, including information on the area with different crops.
- Livestock numbers, estimates of production of manure and emissions of ammonia.
- Information on the application of nutrients to agricultural areas. Optimally, information will be available on fertilizer application rates to different crops. Mean application rates by different farm types (dairy farms, mainly cereals and mixed farms) can be estimated.
- Nutrient balances.
- Information on soil erosion and P run-off. Where possible, modelled data should be validated against in-river flow/concentration data.

Eurostat and UN/FAO generally have statistical data on changes in agricultural activities. From both sources it is possible to obtain per-country average information on land-use and crops grown, livestock and the application of nutrients to agricultural land (Figure 7.8). FAO has only per country average information, while some regional statistical data can be obtained from Eurostat. A co-operative study with Eurostat using the more detailed agricultural statistical data for IEA on eutrophication appears to offer many advantages, especially when compared to the alternative options available for gathering (often incomparable) data from disparate sources.

At national level the most comprehensive agricultural statistical data can often be found. National data can also provide good information at regional level. The required information on nutrient application rates to different crops, as well as application rates by different farm types (dairy farms, mainly cereals and mixed farms) usually have to be found at national level. RIVM collected per country information on application of fertilizers to specific crops, as well as European Fertilizer Manufacturing Association data on fertilizer application to specific crops for the first Dobris assessment (*Meinardi et al. 1994*). Eurostat has during 1996 made a similar collection of coefficients used by Member States for fertilizer application rates per crop type and manure produced per livestock category.

The geographical regionalization of the different agricultural activities is very important. The EU12 Member States can be divided into around 200 administrative divisions, mainly NUTS2, but for Denmark and Ireland NUTS3, for which it should be possible to obtain agricultural data. These administrative regions have an average area about 13,000 km^2, for which it should be possible to calculate agricultural pressures. Using a GIS, the catchment boundaries of the large rivers and the seas could be laid over these administrative regions to produce information on agricultural pressures and trends within major catchments.

The study on the five catchment revealed that the agricultural data availability differed markedly between catchments. For all of the catchments the area could be divided into different land-use categories, but information was only available for two catchments on crops grown and livestock numbers.

It is recommended that a study on the possibilities for using Eurostat regional agricultural data to calculate pressures from agriculture is performed. This study may also evaluate the possibilities for using Eurostats medium-term forecast model (EU-SPEL) for calculating changes in the pressures from agriculture.

Information on loading and environmental state

The negative effects of eutrophication are generally greatest in lakes and reservoirs, but may also be severe in large slow-flowing rivers, tidal waters and open marine areas. The diagram in figure 7.9 illustrates the spatial level in representing environmental state.

Large European catchments

IEA studies such as the application of the CARMEN and N&P models have focused on calculating the loads of nutrients from relatively large catchments, while the evaluation of environmental state has been more vague. It will be feasible to improve the CARMEN model by including some of the processes and data sources discussed in the previous sections and the experience gained from more regional studies such as the N&P model. An improved CARMEN/European scale model could be used to evaluate IEA on large river and sea catchments.

	Consumers	Industri
International	**Avaiable information** - Population statistics; spatial distribution of population - Categorization of urban - rural population - Percentage of national population connected to primary, secondary, and tertiary WWT plants - P-detergents ban or not **Information which are <u>not</u> available** - The exact number of persons connected to various types of WWT plants - The size of WWT plants (person equivalents connected) - Location of the discharge (inland or marine) - Phosphorus being produced per capita (e.g. trend phosporus content of detergents)	**Available information** - No specific information focused at the development of major P-industries **Information which are <u>not</u> available** - Industries connected to WWT and the purification technique employed - Development of major P industries (fertilizer industri) and the purification technique employed
National	**Available information (optimal)** - Population statistics; spatial distribution of population - Categorization of urban - rural population - The exact number of persons connected to various types of WWT plants - Trend in P-contents in detergents **Information which are <u>not</u> available** - Location of the point source discharge (inland or marine) - Actual information about WWT plants *Problems of aggregation of information at EU level*	**Available information** - No specific information focused at the development of major P-industries - Industries with direct discharge **Information which are <u>not</u> available** - Industries connected to WWT and the purification technique employed - Development of major P industries (fertilizer industri) and the purification technique employed - Location of the point source discharge (inland or marine)
Regional	**Available information (optimal)** - Population statistics; spatial distribution of population - The exact number of persons connected to various types of WWT plants - Location of the point source discharge (inlands or marine) - Actual information about WWT plants **Information which are <u>not</u> available** - Trend in P-contents in detergents *Problems of aggregation of information at EU level*	
Catchment	The information available on catchment level is very variable and heterogenous	

Figure 7.7. Diagram describing the information on consumers and industry available at different spatial levels.

Agriculture

International

Available information
- Spatial information about land-cover/land-use
- National information about the structure of agricultural production (crops grown, livestock numbers, fertilizer use)
- National estimates of emission of ammonia
- Scenarios for the short and medium term development of the agricultural sector

Information which are not available
- The information about crop grown, use of fertilizers, scenarios for the development of the agricultural sector can not be spatial distributed
- Nutrient balances (input - total withdrawal). Eurostat and OECD are currently making attempts to establish national nutrient balances
- No good information on phosphorus emission from agriculture

National

Available information (optimal)
- Spatial information about land-cover/land-use
- Regional information about the structure of agricultural production (crops grown, livestock numbers, fertilizer use)
- National and regional estimates of emission of ammonia
- Scenarios for the short and medium term development of the agricultural sector

Information which are not available
- Regional nutrient balances (input - total withdrawal)
- No good information on phosphorus emission from agriculture

Problems of aggregation of information at EU level

Regional

Available information (optimal)
Similar to the information at national level
In addition, some more detailed may be available

Information which are not available
- No good information on phosphorus emission from agriculture

Problems of aggregation of information at EU level

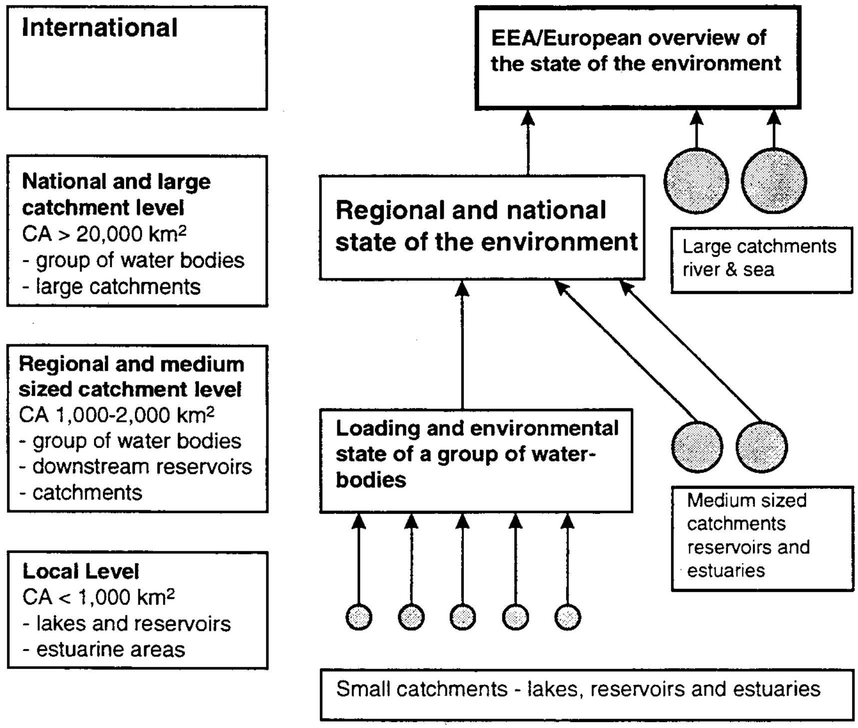
Catchment

The information available for the five studied catchments was generally obtained from national agricultural statistics

Figure 7.8. *Diagram describing the information on agricultural activities available at different spatial levels.*

The EEA and Eurostat will soon begin to produce a GIS catchment map for European water courses at a scale of 1:1,000,000. This map will include all major rivers in the EEA area and further enhance the possibilities for evaluating IEA at a large catchment scale.

Figure 7.9. Diagram describing the different levels in assessment of the environmental state.
CA: catchment area



> It is anticipated that this catchment map will form the basis of EEA reporting on the state of surface waters. Studies relating the driving forces to pressures in these catchments should be initiated as soon as possible, to capitalise on what should become an important tool.
> It is recommended that the CARMEN/European scale model is improved by the processes and data sources discussed in the previous sections to evaluate IEA on large river and sea catchments

Small waterbodies

Eutrophication also affects surface waters which drain small and medium sized catchments. It is therefore vital for the EEA to have information on how different policies and changes in the sectors will affect the trophic status of these waterbodies and the socio-economic status of the catchment populations. It is a complex process to relate the pressure information to the environmental state of lakes, reservoirs and small estuaries so that the effects of changes in pressures can be evaluated. However, all water body types and size must be considered if IEA is implemented on a European scale.

One possible solution could be to select a sub-sample of these water bodies and characterise the various anthropogenic factors in their catchment, and then based on scenarios on changes in the anthropogenic factors try to evaluate the effect on this sub-sample. This approach has been tried in the Danish lake monitoring programme: 37 lakes were selected as a representative sub-sample of all Danish lakes and the lake catchments described in terms of land-use and point source discharges. This allows various 'what if' scenarios to modelled; for example, what is the effect of diverting all point source discharges from the catchments or reducing the area of agricultural land?

The proposed EEA inland surface water monitoring network by the ETC/IW, which is currently being implemented by some countries could be the basis for evaluating IEA on lakes and reservoirs. In this network, Member States select a geographically spread sub-sample of their water bodies which are representative of **the majority of water bodies** in a region. Human activities in their catchments must be consistent with the regional activities. Methods for relating the environmental state of water bodies by region to the pressures still need to be developed.

> It is recommended that methods for evaluating IEA on lakes, reservoirs and estuaries on a European scale are developed. These methods should make it possible to assess the effects of changes in pressures to 'types' of water bodies. For example, what is the effect of changing agricultural practices on eutrophication of lowland lakes?

7.6 Conclusions

Processes

The evaluation in the previous section has identified the following processes for implementation of an EEA scale IEA of eutrophication:

Consumers and industry • Emissions from consumers based on population numbers in the catchment; their production of phosphorus and the waste water treatment applied. • Emissions from large P-based industries related to production estimates, and the waste water treatment technology applied.
Agriculture • Nitrogen leaching from the rootzone. • Erosion and run-off of phosphorus from agricultural areas. If practicable, leaching of phosphorus from P-saturated soils. • Alternatively, simple empirical relations between agricultural activities (e.g. fertilizers application) and state indicator variables (concentration and loads) may be established at regional level and used to estimate the loading from agriculture • Ammonia emission from livestock
Transport and power plants • NO_x emissions
Transport and transformation from emission to loading into surface waters • Retention of nitrogen in soil. • Retention of nutrients in inland surface waters. • Denitrification in surface waters. • Atmospheric transport of ammonia and NO_x.

Environmental state and ecological impacts

- Relationship between nutrient loads to surface waters and nutrient concentration.
- Relationship between nutrient concentration and ecological impacts.

Facing the analytical complexity and the demands for data, IEA on a European scale must be based on simplified relationships, focusing particularly on those processes responsible for the majority of nutrient loading. This would leave out some processes which are important at a regional or local level for example pressures from tourism, and effects of fish farms.

If the necessary information on population numbers and wastewater treatment technology applied is available, the estimation of loads from **consumers and industry** is straightforward.

An EU/EEA macroeconomic sector model should be used to define the overall development of **agricultural** production. Sub-modules should be established to disaggregate this information to a level suitable for environmental purposes. It is necessary to have a regionalisation sub-module and sub-modules which relate economic variables to activities affecting the export of nutrients.

Based on information on crops grown and nitrogen application rates, leaching of nitrate from the rootzone of agricultural land can be estimated. However, the transport from rootzone to loading into surface waters is poorly understood. An approach relating information on agricultural pressure directly to the concentration in surface waters offers advantages in terms of fewer data requirements and overall simplicity.

The process of **phosphorus run-off** due to agricultural activities is rather complicated and at the moment reliable models for predicting the effects of changes in agricultural pressures to run-off of phosphorus are not available. However, information on soil erosion risk together with phosphorus balances for agricultural soil may be useful to determine whether the pressure is increasing or decreasing. **Emissions** of ammonia and nitrogen oxides and their deposition on surface waters may be important in some areas of Europe, notably for coastal and marine areas, as well as for lakes in sparsely populated areas with low agricultural activity. These processes is generally well described and a suitable model exists for calculating emissions and atmospheric transport.

The description of the **transport** from leaching from the rootzone to loading into surface waters as well as the transport through inland surface waters generally result in the loss of nutrients. The transport processes are very complicated and poorly understood. It will be important to develop a better method of predicting losses of nutrients during transport than reduction coefficients which are currently used if this level of detail is chosen to be incorporated into the IEA procedure.

Information needs

To estimate the above mentioned loads it is necessary to use data that are comparable at a European scale: the major information requirements are:

In relation to **consumers** the focus has to be put on the spatial distribution of the population, the amount of nutrients produced *per capita* and the waste water treatment technology employed. On a European scale, the major part of the civil loads is exported from urban agglomeration greater than 15.000 person equivalents. Particularly good information on these large WWTPs is, therefore, needed. Only a small part of the European **industrial sector** is responsible for the majority of phosphorus loading to surface waters. It is important to have good information on changes in production of these industries and the waste water treatment technology applied.

To assess the pressures from **agriculture** data on land-use, including information on the areas occupied by different crops, livestock numbers, and information on the application of nutrients to agricultural areas should be available. Ideally, the information should include nutrient application rates to different crops, as well as the application rates by different farm types (dairy farms, mainly cereals and mixed farms). It is recommended that a study on the possibilities for using Eurostat regional agricultural data (REGIOSTAT and Farm Structure Survey) to calculate pressures from agriculture is performed, the EU Member States can be divided into around 250 administrative divisions (mainly NUTS2, but for Denmark and Ireland NUTS3) for which it should be possible to obtain agricultural data.

Good information on **catchment boundaries and water bodies** is essential to perform IEA on a European scale. In the coming year an EEA catchment map in the scale of 1:1,000,000 will be available and the EEA surface water monitoring network will be established. The catchment map will be a good basis for assessing changes in the environmental state of large European river and sea catchments, while the monitoring network should provide an excellent basis for evaluating the effects on inland surface waters, especially lakes and reservoirs. It is recommended that a study will be undertaken with the aim of relating the driving forces to pressures in these catchments.

Access to data and information

The review of information sources show that data needed for IEA is dispersed amongst international, national, local and sectoral authorities. Also, we found that the organisation of water management, and thus its inventories, varies widely between countries. This handicaps the straight forward and comprehensible access to the level of impossibility.

The UNECE Convention on the Protection and Use of Transboundary watercourses and International Lakes recognised this problem and addresses it in two articles of the Convention (*Helsinki, 1992*). Article 13 furthers the exchange of information between riparian countries. In addition, Article 16 stresses the free access of this information for the general public. The new EU Commission Proposal for a Council Directive establishing a Framework for European Community Water Policy acknowledges the principle of subsidiarity to the management of water bodies by the administration of catchments. The Proposal agrees with the Convention upon articles 13 and 16.

For the sake of IEA, we should take advantage from this Proposal and the Convention and specify the data need and communicate this specification to all inventory holders. This will gear the IEA process and will assist the European Environment Agency in her task of data provision concerning water issues.

Framework and organisational structure for operating IEA on a European scale

At present, no international institution and networks address the full framework of DPSIR on eutrophication. However, several international organisations, such as HELCOM; OSPARCOM and the ETC/IW, address part of the framework, for example collating loading inventories from the catchments of large coastal areas and relating these loads to observed environmental conditions. A framework and organisational structure may be established by the European Environment Agency based on component of the EIONET (Environmental Information and Observation NETwork).

EEA is currently performing a study together with Joint Research Centre, Ispra with the aim of analysis of dataflow for integrated assessment (DAIFA). This study has also selected eutrophication as one of the environmental issues for which the main processes and dataflows are described. The findings of this study will be valuable for structuring the dataflows for performing IEA on a European level.

The IEA framework should be established as a co-operation between several partners, with the EEA being responsible for the overall coordination and the overall integrated environmental assessment while the topic centres as well as other relevant partners should be responsible for assessment of their parts of the DPSIR framework; i.e.

- the ETC on Air Emissions being responsible for data on emissions of ammonia and NO_x as well as relationships between driving forces and changes in emissions
- the ETC on Air Quality being responsible for information on deposition of reduced and oxidised nitrogen
- the ETC on Inland Waters and the ETC on Marine and Coastal waters analysing relationships between pressures and the environmental state of surface waters.

The above structure is missing organisations being responsible for information on sectors (driving forces and changes in their pressures). Eurostat as well as several other institutions have a more sectorial approach and are able to provide information and data at a European level on trends in sectorial activities and may also be able to provide scenarios for future development due to various policies. For example, scenarios for change in agricultural production and activities due to the CAP reform. However, the transformation of these scenarios into meaningful pressure indicators is complicated.

In some areas such as emissions into water from point sources no European overview do exist. Assessment of emissions into water is only weakly included into the work programme of the two water topic centres (ETC/IW and ETC/MC). To be able to perform IEA on European level it is prerequisite that the information on point source is improved. This could be done by extending the responsibilities of the existing ETCs to include emissions into water or by a new topic centre with the task to collect and analyse information on emissions into water.

At the moment, CARMEN is the only model suitable for undertaking integrated environmental assessment at a European scale, but would need further development. Compared to regional models, many simplified descriptors are used in this model and the input of data is very generalised (per country averages). The ideas behind CARMEN should be used as the basis of a coherent modelling framework, upgraded with sub-modules derived from more detailed regional models and the above procedure for deriving nutrient budgets.

A workshop was held by NERI and EEA in March 1997 in Silkeborg. The outcome of the present study was presented for a group of European Experts. One of the aims of the workshop was a discussion of continuation of the work with IEA on eutrophication on European scale including a discussion of the framework and organisational structure.

8 Summary of recommendations from pilot study and workshop

An important general statement is: *in IEA, it is the policy aspects which are in focus - and not the details of the environmental transformation processes. For this reason, simple models that account for the main features of relevance to policy are preferable.*

This pilot project report reviews the process of integrated environmental assessment of eutrophication on a European scale to identify key issues. The main driving forces and their pressures are analysed to help focus on the important processes. The important relationships on a European scale between pressures and loading into surface waters, as well as the impact on the environmental state are evaluated.

Processes

The following processes are identified as potentially important and recommended for implementation of an EEA scale IEA of eutrophication:

Consumers and industry

- Emissions from consumers based on population numbers in the catchment; their production of phosphorus and the waste water treatment applied.
- Emissions from large P-based industries related to production estimates, and the waste water treatment technology applied.

Agriculture

- Nitrogen leaching from the rootzone.
- Erosion and run-off of phosphorus from agricultural areas. If practicable, leaching of phosphorus from P-saturated soils.
- Alternatively, simple empirical relations between agricultural activities (e.g. fertilizers application) and state indicator variables (concentration and loads) may be established at regional level and used to estimate the loading from agriculture
- Ammonia emission from livestock

Transport and power plants

- NO_x emissions

Transport and transformation from emission to loading into surface waters

- Retention of nitrogen in soil.
- Retention of nutrients in inland surface waters.
- Denitrification in surface waters.
- Atmospheric transport of ammonia and NO_x.

Environmental state and ecological impacts

- Relationship between nutrient loads to surface waters and nutrient concentration.
- Relationship between nutrient concentration and ecological impacts.

Facing the analytical complexity and the demands for data, IEA on a European scale must be based on simplified relationships, focusing particularly on those processes responsible for the majority of nutrient loading. This would leave out some processes which are important at a regional or local level for example pressures from tourism, and effects of fish farms.

If the necessary information on population numbers and wastewater treatment technology applied is available, the estimation of loads from **consumers and industry** is straightforward.

A macroeconomic sector model for the EU/EEA area may be used to define the overall development of **agricultural** production. Submodules should be established to disaggregate this information to a level suitable for environmental purposes. It is necessary to have a regionalisation sub-module and sub-modules which relate economic variables to activities affecting the export of nutrients.

Based on information on crops grown and nitrogen application rates, leaching of nitrate from the rootzone of agricultural land can be estimated. However, the transport from rootzone to loading into surface waters is poorly understood. An approach relating information on agricultural pressure information directly to the concentration in surface waters offers advantages in terms of fewer data requirements and overall simplicity.

The process of **phosphorus run-off** due to agricultural activities is rather complicated and at the moment reliable models for predicting the effects of changes in agricultural pressures to run-off of phosphorus are not available. However, information on soil erosion risk together with phosphorus balances for agricultural soil may be useful to determine whether the pressure is increasing or decreasing.

Emissions of ammonia and nitrogen oxides and their deposition on surface waters may be important in some areas of Europe, notably for coastal and marine areas, as well as for lakes in sparsely populated areas with low agricultural activity. These processes are generally well described and suitable models exist for calculating emissions and atmospheric transport.

The description of the **transport** from leaching from the rootzone to loading into surface waters as well as the transport through inland surface waters generally result in the loss of nutrients. The transport processes are very complicated and poorly understood. It will be important to develop a better method of predicting losses of nutrients during transport than reduction coefficients which are currently used if this level of detail is chosen to be incorporated into the IEA procedure.

Information needs

To estimate the above mentioned loads it is necessary to use data that are comparable at a European scale: the major information requirements are:

In relation to **consumers** the focus has to be put on the spatial distribution of the population, the amount of nutrients produced *per capita* and the waste water treatment technology employed. On a European scale, the major part of the civil loads is exported from urban agglomeration greater than 15.000 person equivalents. Particularly good information on these large WWTPs is therefore, needed. Only a small part of the European **industrial sector** is responsible for the majority of phosphorus loading to surface waters. It is important to identify these and to have good information on changes in production of these industries and the waste water treatment technology applied. Assessment of emissions into water is only weakly included into the work programme of the two water topic centres (ETC/IW and ETC/MC). To be able to perform IEA on European level, it is a prerequisite that the information on point source is improved. This should be done by extending the responsibilities of the existing ETCs to include emissions into water.

To assess the pressures from **agriculture** data on land-use, including information on the areas occupied by different crops, livestock numbers, and information on the application of nutrients to agricultural areas should be available. Ideally, the information should include nutrient application rates to different crops, as well as the application rates by different farm types (dairy farms, mainly cereals and mixed farms). It is recommended that a study on the possibilities of using Eurostat regional agricultural data (REGIOSTAT and Farm Structure Survey) to calculate pressures from agriculture is performed, the EU Member States can be divided into around 250 administrative divisions (mainly NUTS2, but for Denmark and Ireland NUTS3) for which it should be possible to obtain agricultural data.

Good information on **catchment boundaries and water bodies** is essential to perform IEA on a European scale. In the coming year an EEA catchment map in the scale of 1:1,000,000 will be available and the EEA surface water monitoring network will be established. The catchment map will be a good basis for assessing changes in the environmental state of large European river and sea catchments, while the monitoring network should provide an excellent basis for evaluating the effects on inland surface waters, especially lakes and reservoirs. It is recommended that a study be undertaken with the aim of relating the driving forces to pressures in these catchments.

Access to data and information

The review of information sources show that data needed for IEA is dispersed amongst international, national, local and sectoral authorities. Also, we found that the organisation of water management, and thus its inventories, varies widely between countries. This handicaps the straight forward and comprehensible access to information.

The UNECE Convention on the Protection and Use of Transboundary watercourses and International Lakes recognised this problem and addresses it in two articles of the Convention (*Helsinki, 1992*). Article 13 furthers the exchange of information between riparian countries. In addition, Article 16 stresses the free access of this information for the general public. The new EU Commission Proposal for a Council Directive establishing a Framework for European Community Water Policy acknowledges the principle of subsidiarity to the management of water bodies by the administration of catchments. The Proposal agrees with the Convention upon articles 13 and 16.

For the sake of IEA, it is recommended to take advantage from this Proposal and the Convention and specify the data need and communicate this specification to all inventory holders. This will gear the IEA process and will assist the European Environment Agency in her task of data provision concerning water issues.

8.1 Recommendations concerning the framework and organisational structure for operating IEA on a European scale

Following the recommendations of the pilot study regarding the content of an IEA activity related to eutrophication, the workshop discussed the importance of forming a network within the organisational framework of the EEA on this matter.

At present, no international institution or network address the full framework of the DPSIR causal chain related to eutrophication. However, several international organisations, such as HELCOM; OSPARCOM and ETC/IW, address part of the framework, such as collating loading inventories from the catchments of large coastal areas and relating these loads to observed environmental conditions.

The Workshop concluded that a broader European IEA-network on eutrophication covering the whole DPSIR chain could play an important role. This network should be set up within the framework of EEA and be based on elements of the EIONET.

In order to perform and carry out the many tasks outlined in the previous section, such a network must be rooted in a firm organisation. The network must have direct reference to the EEA, and should be led by a small group of experts (task force), responsible for coordination, data collection and performing integrated analysis and assessment. The task force must have a close contact to and cooperation with relevant partners covering the DPSIR-chain, i.e.

- the ETC on Air Emissions being responsible for emissions of ammonia and NO_x
- the ETC on Air Quality being responsible for deposition of ammonia and NO_x
- the ETC on Inland Waters being responsible for the loads and effects of nutrients in fresh water systems
- the ETC on Marine and Coastal Waters being responsible for the loads and effects of nutrients in marine areas
- Eurostat and other institutions being responsible for socio-economic information related to the important sectors (agriculture, industry, and house-holds). It is important to involve institutions with expertise in forecasting development in driving forces.

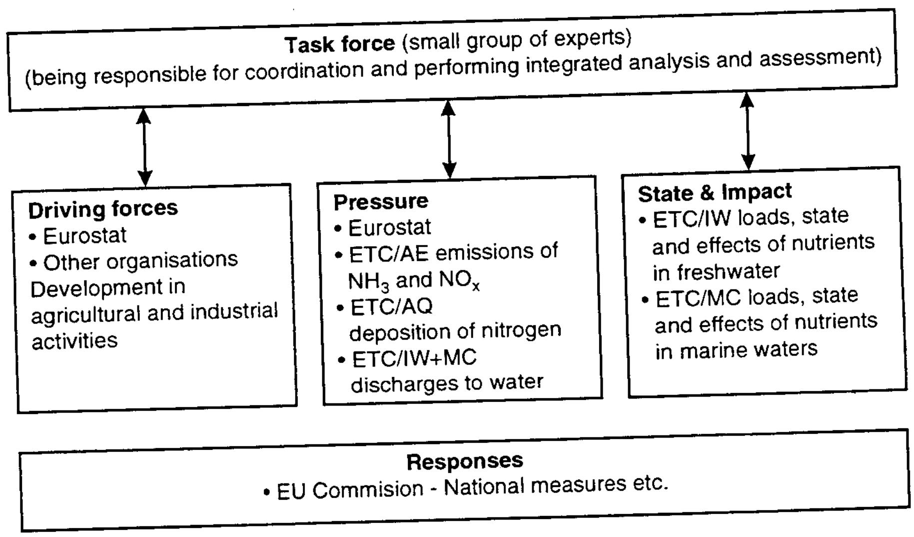


Figure 8.1. Structure of the network to be established for performing Integrated Environmental Assessment on Eutrophication.

The tasks of the network would in the initial phase be to set up a DPSIR information system following the recommendations in the previous section and based on accessible data on a European level. A point of departure in this work could be the CARMEN model, which presently is the only model which can operate on a European scale. This model has to be further refined and developed to be applicable for policy evaluation. Once this information system has been made operational, the primary tasks will concern integrated assessment studies and policy evaluation. Further development of the information system may evolve as a result of these studies.

The IEA-activities related to eutrophication as described above demand a separate financing of the required ETC-related work and of the task force.

9 References

Asman, W. A. H. & H. A. Jaarsveld (1990): A variable-resolution statistical transport model applied for ammonia and ammonium. Report no. 228471007, RIVM, Bilthoven, The Netherlands

Bendoricchio, G., G. Goffaro & C. De Marchi. (1994): A trophic model for Ulva rigida in the lagoon of Venice. Ecological modelling 75/76: 485-496.

Beusen, A.H.W., O. Klepper, and C.R. Meinardi (1995): Modelling the flow of nitrogen and phosphorus in Europe: from loads to coastal seas. Wat. Sci. Tech. **31:** 8 pp. 141-145.

BMLF (1995): Wassergüte in Österreich Jahresbericht 1994. Report from Bundesministerium für Land- und Forstwirtschaft, Wasser Wirtschafts Kataster und Umweltbundesamt. Wien.

Boers, P., W. Laane & L. van Liere (1995): Regional omgaan met landelijke normen. Landschap 1995 12/6 pp. 15-21.

Boynton, W.R., W.M. Kemp & C.W. Keefe (1982): A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production. pages 69-90 in V.S. Kennedy (ed.) Estuarine Comparisons. New York, Academic Press.

Boynton, W.R., L. Murray, J.D. Hagy, C. Stokes & W.M. Kemp. (1996): A comparative analysis of eutrophication patterns in a temperate coastal lagoon. Estuaries 19: 408-421.

Breukelaar, A.W., E.H.R.R. Lammens, J.P.G. Klein Breteler & I. Tatrai (1994): Effects of benthivorous bream (*Abramis brama* L.) and carp (*Cyprinus caprio* L.) on sediment resuspension and concentration of nutrients and chlorophyll *a*. - Freshwat. Biol. **32:** 113-121.

Brooker M.P., and P.C. Johnson (1984): The behaviour of phosphate, nitrate, chloride and hardness in twelve Welsh Rivers. Water Res. **18:**9 pp. 1155-1164.

Canfield, D.E., J.V. Shireman, D.E. Colle, W.T. Haller, C.E. Watkins, & M.J. Maceina (1984): Prediction of chlorophyll a concentrations in Florida lakes: Importance of aquatic macrophytes. - Can. J. Fish. aquat. Sci. **44:** 497-501.

Cartwright, N.G., Painter, H. and W. Parr (1993): An assessment of the environmental quality standards for inorganic nutrients necessary to prevent eutrophication (nuisance growth of algae). WRc report No. NR 2397/1/4226.

Chambers, P.A. & J. Kalff (1985): Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. - Can. J. Fish. Aquat. Sci. **42:** 701-709.

de Haan, B.J., O. Klepper, F.J. Sauter, P.S.C. Heuberger and A.J. Rietveld (1996) The CARMEN status report 1995. RIVM report no. 4615010005.

DoE (1990): Digest of environmental statistics no. 17 1995. UK Department of Environment, London; HSMO.

Downing, J.A., C. Plante & S. Lalonde (1990): Fish production correlated with primary productivity and the morphoedaphic index. - Can. J. Fish. Aquat. Sci. 47: 1929-1936.

Duarte, C.M. (1991): Seagrass depth limits. Aquatic Botany 40: 363-377.

Duarte, C. M. & J. Kalff (1987): Latitudinal influences on the depths of maximum colonization and maximum biomass of submerged angiosperms in lakes. Can. J. Fish. Aquat. Sci. **44:** 1759-1764.

Eppley, R. W., E. H. Renger, E.L. Venrick, M. M. Mullin (1973): A study of plankton dynamics and nutrient cycling in the Central Gyre of the North Pacific Ocean. Limnol. Oceanogr. **18:** 534-51.

European Environment Agency (1995): Europe's Environment - The Dobris Assessment. D. Stanners & P. Bourdeau (Eds.), Copenhagen.

European Environment Agency (1995b): Environment in the European Union 1995. K. Wieringa (Ed.), Copenhagen.

European Water Pollution Control Association (1995): The comparability of Quantitative data on Waste water Collection and Treatment. Final report to the European Commission DG XI B1.

Eurostat (1995): Europe's Environment: Statistical Compendium for the Dobris Assessment. Office for Official Publications of the European Communities, Luxembourg.

Filip, A., & A. Ceric (1989): Comparision of measured phosphorus loads with estimated ones in several river basins in Yugoslavia. River basin management V.

Foster, I.D.L., S. Wade, S. Harrison, and P. Buckland (1996): Eutrophication in controlled waters in Lower Severn Area (analysis of the first 12 months data). Coventry University report to the NRA.

Gallegos, C.L. & W.J. Kenworthy (1996): Seagrass depth limits in the Indian river lagoon (Florida, U.S.A.): Application of an optical water quality model. Estuarine, coastal and shelf science **42:** 267-288.

Gibeau, G.G. & M.C. Miller (1989): A micro-bioassay for epilithon using nutrient-diffusing artificial substrata. Journal of Freshwater Ecology, **5:** 171-176.

Gordon, D.M., P.B. Birch, and A.J. McComb (1981): Effects of inorganic phosphorus and nitrogen on the growth of an estuarine *Cladophora* in culture. Botanica Marina, **24:** 93-106.

Graneli, E., W. Graneli & L. Rydberg (1986): Nutrient limitation at the ecosystem and the phytoplankton community level in the Laholm Bay, soust-east Kattegat. Ophelia **26:** 181-194.

Gren, I.-M., K. Elofson, and P. Jannke (1995): Cost of nutrient reduction to the Baltic Sea. Beijer Discussion Paper Series No. 70. 84 pp.

Græsbøll, P., J. Erfurt, H.O. Hansen, B. Kronvang, S.E. Larsen, Aa. Rebsdorf & L.M. Svendsen (1994): Ferske vandområder - Vandløb og kilder - Vandmiljøplanens Overvågningsprogram 1993 (In Danish). Report from the National Environmental Protection Agency, Silkeborg, 186 pp.

Hagebro, C. (1992): Proceedings of Water Services Association Workshop on the proposed EC directive concerning muniicpal waste water treatment, London, 3-4 May 1990.

Hanson, J.M. & W.C. Leggett (1982): Empirical prediction of fish biomass and weight. - Can. J. Fish. aquat. Sci. **39:** 257-263.

Hartmann, J. & W. Nümann (1977): Percids of Lake Constance, a lake undergoing eutrophication. - Journal of the Fisheries Research Board of Canada **34:** 1670-1677.

Holmes, N. (1983): Typing British Rivers According to their Flora. Nature Conservancy Council.

Hoyer, M.V. & J.R. Jones (1983): Factors affecting the relation between phosphorus and chlorophyll a in Midwestern reservoirs. - Can. J. Fish. Aquat. Sci. **40:** 192-199.

Italian Ministry of the Environment (1989): Report on the state of the Environment.

Iversen, T.M., J. Thorup, K. Kjeldsen & N. Thyssen (1991): Spring bloom development of microbenthic algae and associated invertebrates in two reaches of a small lowland stream with contrasting sediment stability. Freshwat. Biol., **26:** 189-198.

Jeppesen, E., J.P. Jensen, P. Kristensen, M. Søndergaard, E. Mortensen, O. Sortkjær & K. Olrik (1990): Fish manipulation as a lake restoration tool in shallow, eutrophic, temperate lakes 2: Threshold levels, long-term stability and conclusions. - Hydrobiologia **200/201:** 219-227.

Jones, R. A., W. Rast & G.F. Lee (1979): Relationship between summer mean and maximum chlorophyll a concentration in lakes. Envir. Sci. Tech. **13:** 869-870.

Kern-Hansen U. & F.W. Dawson (1978): The standing crop of aquatic plants of lowland streams in Denmark and the inter-relationships of nutrients in plant, sediment and water. Proc. EWRS 5th Symp. on Aquatic Weeds.

Kitchell, J.F., M.G. Johnson, C.K. Minss, K.H. Loftus, L. Greig & C.H. Olver (1977): Percid habitat: the river analogy. -Journal of the Fisheries Research Board of Canada **34:** 1959-1963.

Kjeldsen K., T.M. Iversen, J. Thorup & P. Lund-Thomsen (1996): Three-year study of benthic algal spring bloom development in a small, Danish lowland stream. -Hydrobiologia **335:** 183-192.

Klepper O., A.H.W. Beusen, and C.R. Meinardi (1995): Modelling the flow of nitrogen and phosphorus in Europe: from loads to coastal seas. RIVM report no. 461501004.

Klotz, R. L. (1992): Factors influencing alkaline phosphatase activity of stream epilithon. Journal of Freshwater Ecology, **7:** 233-242.

Komárková, J. (1994): Phytoplankton cycles in the Rimov Reservoir (South Bohemia). - Arch. Hydrobiol. Beih. **40:** 81-84.

Kristensen, P. (1996): Water quality of large rivers. Topic report no 4 Inland waters from the European Environment Agency.

Kristensen, P. & H.O. Hansen (1994): (Eds.) European Rivers and Lakes - Assessment of their Environmental State. - European Environment Agency, EEA Environmental Monographs 1, Copenhagen, 122 pp.

Kronvang, B., R. Grant, S.E. Larsen, L. M. Svendsen, & P. Kristensen (1995): Non-point-source nutrient losses to the aquatic environment in Denmark: Impact of agriculture. Mar. Freshwater Res. 46: pp. 167-177.

Leach, J.H., M.G. Johnson, J.R.M. Kelso, J. Hartmann, W. Nümann & B. Entz (1977): Responses of percid fishes and their habitats to eutrophication. Journal of the Fisheries Research Board of Canada **34:** 1964-1971.

Lind, O.T., T.T. Terrell & B.L. Kimmel (1993): Problems in reservoir trophic-state classification and implications for reservoir management. - Development in Hydrobiol. **77:** 213-288. Kluwer Academic Publishers, the Netherlands.

Löfgren, S., & H. Olsson (1990): Tilförsel af kväve och fosfor till vattendrag i Sveriges inland. Report no. 3692 from Naturvårdsverket, 4 pp.

Madden, C.J. & W.M. Kemp (1996): Ecosystem model of an estuarine submersed plant community: calibration and simulation of eutrophication responses. Estuaries **19:** 457-474.

Mainstone, C.P., R.D. Davis, A. House & W. Parr (1994): A review of methods for assessing and controlling non-point sources of phosphorus. WRc report No NR 3897. NRA Project Record 562/5/W.

Mainstone, C.P., S.J Ashley, A. Gunby, W. Parr, W.J.D. Woodrow, & P. Turton (1995): Development and testing of general quality assessment schemes: nutrients in rivers and canals. WRc report No NR 3866/1.

Mainstone, C.P., J. Gulson, and W. Parr (1993): Phosphates in freshwater: standards for nature conservation. English Nature Research Reports No. 73. English Nature, Peterborough.

Malone, T.C., D.J. Conley, T.R. Fisher, P.M. Glibert, L.W. Harding & K.G. Sellner (1996): Scales of nutrient-limited phytoplankton productivity in Chesepeake Bay. Estuaries **19:** 371-385.

McComb, A.J., R.P. Atkins, P.B. Birch, D.M. Gordon, R.J. Lukatelich (1981): eutrophication in the Peel-Harvey estuarine system, Western Australia. In Nielson B.J., L.E. Cronin (eds.) Eustuarine and Nutrients. pp. 323-342. Clifton, nj: Humama Press.

Meijer, M.-L., M.W. de Haan, S.W. Breukelaard & H. Buiteveld (1990): Is reduction of the benthivorous fish an important cause of high transparency following biomanipulation in shallow lakes? - Hydrobiologia 200/201/Dev. Hydrobiol. **61:** 303-315.

Meinardi, C.R., A.H.W. Beusen, M.J.S. Bollen, O. Klepper, and W.J. Willems (1995): Vulnerability to diffuse pollution and average nitrate contamination of European soils and groundwater. Wat. Sci. Tech. **31:**8 pp. 159-165.

Meinardi, C.R., A.H.W. Beusen, O. Klepper, and W.J. Willems (1994): Nitrate contamination of European soils and groundwater. RIVM Report no. 461501003.

Miljøstyrelsen (1988): Fosfor - kilder og virkninger (in Danish). Report from the Danish Environmental Protection Agency no. 2, 120 pp.

Miljøstyrelsen (1994): Vandmiljø-94 (in Danish). Report from the Danish Environmental Protection Agency, Copenhagen. 160 pp.

Moog, O. (1984): Stream phosphorus exports from prealpine watersheds with respects to geology and land-use. Verh. Internat. Verein Limnol. 22 pp. 1071-1076.

Neill, M. (1989): Nitrate concentrations in river waters in the southeast of Ireland and their relationship with agricultural practices. Wat. Res. 23 (11), pp. 1339-1355

Nielsen, K., L.P. Nielsen & P. Rasmussen (1995): Estuarine nitrogen retention independently estimated by the denitrification rate and mass balance methods: a study of Norsminde Fjord, Denmark. Marine Ecology Progress Series **119:** 275-283.

Nielsen, S.L., J. Borum, O. Geertz-Hansen & K. Sand-Jensen (1989): Marine bundplanters dybdegrænse. Vand og Miljø **5:** 217-220.

Nixon, C., C.P. Mainstone, T. M. Iversen, P. Kristensen, E. Jeppesen, N. Friberg, E. Papathanassiou, A. Jensen & F. Pedersen (1996): The harmonised monitoring and classification of ecological quality of surface waters in the European Union. Final report to CEC, May 1996 from WRc, UK.

Nümann, W. (1972): The Bodensee: effects of expolitataion and eutrophication on the salmonid community. - Can. J. Fish. Aquat. Sci. **44:** 166-170.

OECD (1995):. OECD Environmental data. Compendium 1995. OECD, Paris

Olesen, B. (1996): Regulation of light attenuation and eelgrass Zostera marina depth distribution in a Danish embayment. Mar. Ecol. Prog. Ser. **134:** 187-194.

Paaby, H. (1996): Foranstaltninger til reduceret næringssaltbelastning af vandmiljøet - danske erfaringer [Measures for reducing nutrient loadings to water - Danish experiences]. K. Skogs-o, Landbr.akad. Tidskr. **135:**3 pp. 223-232.

Paaby H., F. Møller, E. Skop, J.J. Jensen, B. Hasler, H. Bruun, and W.A.H. Asman (1996a): Omkostninger ved reduktion af næringsstofbelastningen af havområderne [Costs of reduction nutrient loading to marine waters]. Technical report no. 165 from DMU/NERI (in Danish) .

Paaby H., J.J. Jensen, P. Kristensen, F. Møller, & E. Skop (1996b): Reducing nutrient loadings of marine waters: a cost effectiveness analysis. pp. 285-307 In: B. Madsen, C. Jensen-Butler, J. Birk Mortensen & A.M. Bruun Christensen (eds.): Modeling the Economy and the Environment. Spinger-Verlag Berlin - Heidelberg, 1996.

Pan, J. (1994): Comparative effectiveness of discharge and input control for reducing nitrate pollution. Environmental Management **18:** 33-42.

Parr, W. & M. Wheeler (1996): Nutrient enrichment of sensitive marine areas in England. WRc report No. 4055/1.

Persson, L., G. Anderson, S.F. Hamrin & L. Johansson (1988): Predation regulation and primary production along the productivity gradient of temperate lake ecosystems. In S.R. Carpenter (ed.), Complex interactions in lake communities. Springer Verlag, New York: 45-65.

Phillips, G., D.F. Eminson & B. Moss (1978): A mechanism to account for macrophyte decline in progressively eutrophicated fresh waters. - Aquat. Bot. **4:** 103-126.

Popovský, J. (1981): Losses of total phosphorus from watersheds influenced by various human activity Int. Revue ges. Hydrobiol. **66** (6) pp. 811-820

Quiros, R. (1990): Predictors of relative fish biomass in lakes and reservoirs of Argentina. - Can. J. Fish. aquat. Sci. **47:** 928-939.

Reynolds, C.S. (1984): The Ecology of Freshwater Phytoplankton. - Cambridge University Press, Cambridge, 384 PP.

Reynolds, C.S. (1988): Potamoplankton: paradigms, paradoxes and prognoses. In F.E. Round (ed.) *Algae and the Aquatic Environment,* pp 283-311. Biopress Ltd, Bristol.

RIVM (1992): National Environmental Outlook, 1990-2010. Report from the National Institute of Public Health and Environmental Protection (RIVM). Bilthoven, 533 pp.

Robinson, P.K. and H.A. Hawkes (1986): Studies on the growth of *Cladophora glomerata* in laboratory continuous flow culture. British Phycological Journal, **21:** 437-444.

Rosemond, A.D. (1993): Interactions among irradiance, nutrients, and herbivores constrain a stream algal community. Oecologia, **94:** 585-594.

Rosemond, A.D., P.J. Mulholland & J.W. Elwood (1993): Top-down and bottom-up control of stream periphyton: Effects of nutrients and herbivores. Ecology, **74:** 1264-1280.

Sand-Jensen, K. & J. Borum (1991): Interactions among phytoplankton, periphyton, and macrophytes in temperate freshwaters and estuaries. Aquatic Botany **41:** 137-175.

Sand-Jensen, K., S.L. Nielsen., J. Borum & O. Geertz (1994): Fytoplankton og makrofyt udvikling i danske kystområder. Havforskning fra miljøstyrelsen no. 30.

Scheffer, M., S.H. Hosper, M.-L. Meijer, B. Moss & E. Jeppesen (1993): Alternative equilibria in shallow lakes. - Trends Ecol. Evol. **8:** 275-279.

Smith R.V. (1977): Domestic and agricultural contribution to the inputs of phosphorus and nitrogen to Lough Neagh. Wat. Res. 11, pp. 453-459.

Smith R.V., R.J. Stevens, R.H. Foy, & C.E. Gibson (1982): Upward trend in nitrate concentration in rivers discharging into Lough Neagh for the period 1969-1979. Wat. Res. 16, pp. 183-188.

Smith, S.V. (1984): Phosphorus versus nitrogen limitation in the marine environment. Limnol. Oceanogr. **29:** 1149-60.

Stribe, L. & S. Fleisher (1991): Agricultural production methods - impact on drainage water nitrogen. Verh. Internat. Veriein. Limnol. 24 pp. 1749-1752

Søballe, D.M. & S.T. Threlkeld (1985): Advection, phytoplankton biomass, and nutrient transformations in a rapidly flushed impoundment. - Arch. Hydrobiol. **105:** 187-203.

Taylor, R., H. Florczyk, & L. Jakubowska (1986): Run-off of nutrients from river watersheds used for agricultural purposes. Environment Protection Enginering 12 (4) pp. 51-65.

Thornton, J.A. & W. Rast (1993): A test of hypotheses relating to the comparative limnology and assessment of eutrophication in semi-arid man-made lakes. - Development in Hydrobiol. **77:** 213-288. Kluwer Academic Publishers, the Netherlands.

Traaen, T.S. & E.A. Lindstrom (1983): Influence of current velocity on periphyton distribution. In R.G. Wetzel (ed.), Periphyton of freshwater ecosystems. Development in Hydrobiology. Junk, The Hague: pp. 121-134.

Umweltbundesamt (1994): Daten zur Umwelt 1992/93. E.Schmidt Verlag, Berlin

Vighi, M., S. Soprani, P. Puzzarini, & G. Menghi (1991): Phosphorus loads from selected watersheds in the drainage area of the Northern Adratic Sea. J. Environ. Qual. 20 pp. 439-444

Woodrow, D., W. Parr, R.L. Norton, and D. Johnson (1994): River eutrophication risk modelling: a GIS approach. WRc Report to SNIFFER, No. NR 3698. WRc, Medmenham.

Wright, G.G., A.C. Edwards, J.G. Morrice & K. Pugh (1991): North east Scotland river catchment nitrate loading in relation to agricultural intensity. Chemistry and Ecology, vol 5, pp. 263-281.

National Environmental Research Institute

The National Environmental Research Institute, NERI, is a research institute affiliated to the Ministry of Environment and Energy. In Danish, NERI is called *Danmarks Miljøundersøgelser (DMU)*.
NERI's tasks are to conduct research, perform monitoring, and give advice on issues related to the environment and nature.

URL: http://www.dmu.dk

Addresses:

National Environmental Research Institute
Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 46 30 12 00
Fax: +45 46 30 11 14

Management
Personnel and Economy Section
Research and Development Secretariat
Department of Policy Analysis
Department of Atmospheric Environment
Department of Environmental Chemistry
Department of Marine Ecology and Microbiology

National Environmental Research Institute
Vejlsøvej 25
PO Box 413
DK-8600 Silkeborg
Denmark
Tel: +45 89 20 14 00
Fax: +45 89 20 14 14

Department of Terrestrial Ecology
Department of Lake and Estuarine Ecology
Department of Streams and Riparian areas

National Environmental Research Institute
Grenåvej 12, Kalø
DK-8410 Rønde
Denmark
Tel: +45 89 20 17 00
Fax: +45 89 20 15 14

Department of Landscape Ecology
Department of Coastal Zone Ecology

National Environmental Research Institute
Tagensvej 135, 4
DK-2200 København N
Denmark
Tel: +45 35 82 14 15
Fax: +45 35 82 14 20

Department of Arctic Environment

Publications:
NERI publishes professional reports, technical guidelines and an annual report on activities. A catalogue of R&D projects is available on the World Wide Web.

A list of publications from the current year is included in the annual report which is available on request.

NERI Technical Reports

1996

Nr. 173: Atmosfærisk deposition af kvælstof. Vandmiljøplanens Overvågningsprogram 1995. Hovedrapport og bilagsrapport. Af Skov, H. et al. 84 s. + 282 s., 100,00 kr. + 300,00 kr.
Nr. 174: Atmosfærisk deposition af kvælstof. Målemetoder og modelberegninger. Af Ellermann, T. et al. 56 s., 70,00 kr.
Nr. 175: Landovervågningsoplande. Vandmiljøplanens Overvågningsprogram 1995. Af Grant, R. et al. 150 s., 125,00 kr.
Nr. 176: Ferske vandområder. Søer. Vandmiljøplanens Overvågningsprogram 1995. Af Jensen, J.P. et al. 96 s., 125,00 kr.
Nr. 177: Ferske vandområder. Vandløb og kilder. Vandmiljøplanens Overvågningsprogram 1995. Af Windolf, J. (red.). 228 s., 125,00 kr.
Nr. 178: Sediment and Phosphorus. Erosion and Delivery, Transport and Fate of Sediments and Sedimentassociated Nutrients in Watersheds. Proceedings from an International Workshop in Silkeborg, Denmark, 9-12 October 1995. Af Kronvang, B. et al. 150 pp., 100,00 DKK.
Nr. 179: Marine områder. Danske fjorde - status over miljøtilstand, årsagssammenhænge og udvikling. Vandmiljøplanens Overvågningsprogram 1995. Af Kaas, H. et al. 205 s., 150,00 kr.
Nr. 180: The Danish Air Quality Monitoring Programme. Annual Report for 1995. By Kemp, K. et al. 55 pp., 80,00 DKK.
Nr. 181: Dansk Fauna Indeks. Test og modifikationer. Af Friberg, N. et al. 56 s., 50,00 kr.

1997

Nr. 182: Livsbetingelserne for den vilde flora og fauna på braklagte arealer - En litteraturudredning. Af Mogensen, B. et al. 165 pp., 125,00 DKK.
Nr. 183: Identification of Organic Colourants in Cosmetics by HPLC-Photodiode Array Detection. Chemical Substances and Chemical Preparations. By Rastogi, S.C. et al. 233 pp., 80,00 DDK.
Nr. 184: Forekomst af egern *Sciurus vulgaris* i skove under 20 ha. Et eksempel på fragmentering af landskabet i Århus Amt. Af Asferg, T. et al. 35 s., 45,00 kr.
Nr. 185: Transport af suspenderet stof og fosfor i den nedre del af Skjern Å-systemet. Af Svendsen, L.M. et al. 88 s., 100,00 kr.
Nr. 186: Analyse af miljøfremmede stoffer i kommunalt spildevand og slam. Intensivt måleprogram for miljøfremmede stoffer og hygiejnisk kvalitet i kommunalt spildevand. Af Vikelsøe, J., Nielsen, B. & Johansen, E. 61 s., 45,00 kr.
Nr. 187: Vandfugle i relation til menneskelig aktivitet i Vadehavet 1980-1995. Med en vurdering af reservatbestemmelser. Af Laursen, K. & Salvig, J. 71 s., 55,00 kr.
Nr. 188: Generation of Input Parameters for OSPM Calculations. Sensitivity Analysis of a Method Based on a Questionnaire. By Vignati, E. et al. 52 pp., 65,00 DKK.
Nr. 189: Vandføringsevne i danske vandløb 1976-1995. Af Iversen, H.L. & Ovesen, N.B. 55 s., 50,00 kr.
Nr. 190: Fate of Polycyclic Aromatic Hydrocarbons in the Environment. Af Carlsen, L. et al. 82 pp., 45,00 kr.
Nr. 191: Benzin i blodet. Kvalitativ del. ALTRANS. Af Jensen, M. 130 s., 100,00 kr.
Nr. 192: Miljøbelastningen ved godstransport med lastbil og skib. Et projekt om Hovedstadsregionen. Af Nedergaard, K.D. & Maskell, P. 126 s., 100,00 kr.
Nr. 193: Miljøundersøgelser ved Maarmorilik 1996. Af Johansen, P, Riget, F. & Asmund, G. 96 s., 100,00 kr.
Nr. 194: Control of Pesticides 1996. Chemical Substances and Chemical Preparations. By Køppen, B. 26 pp., 40,00 DKK.
Nr. 195: Modelling the Atmospheric Nitrogen Deposition to Løgstør Bredning. Model Results for the Periods April 17 to 30 and August 7 to 19 1995. By Runge, E. et al. 49 pp., 65,00 DKK.
Nr. 196: Kontrol af indholdet af benzen og benzo(a)pyren i kul- og olieafledte stoffer. Analytisk-kemisk kontrol af kemiske stoffer og produkter. Af Rastogi, S.C. & Jensen, G.H. 23 s., 40,00 kr.
Nr. 197: Standardised Traffic Inputs for the Operational Street Pollution Model (OSPM). Af Jensen, S.S. 53 pp., 65,00 DKK.
Nr. 198: Reduktion af CO_2-udslip gennem differentierede bilafgifter. Af Christensen, L. 56 s., 100,00 kr.
Nr. 200: Benzin i blodet. Kvantitativ del. ALTRANS. Af Jensen, M. 139 s., 100,00 kr.
Nr. 201: Vingeindsamling fra jagtsæsonen 1996/97 i Danmark. Af Clausager, I. 43 s, 35,00 kr.
Nr. 202: Miljøundersøgelser ved Mestersvig 1996. Af Asmund, G., Riget, F. & Johansen, P. 30 s., 50,00 kr.
Nr. 203: Rådyr, mus og selvforyngelse af bøg ved naturnær skovdrift. Af Olesen, C.R., Andersen, A.H. & Hansen, T.S. 60 s., 80,00 kr.
Nr. 204: Spring Migration Strategies and Stopover Ecology of Pink-Footed Geese. Results of Field Work in Norway 1996. By Madsen, J. et al. 29 pp., 45,00 DKK.