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Comparability of assessments of nutrient emissions to inland waters undertaken within eight European Union Member States

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ABSTRACT

The study aimed to compare ten assessment procedures for nutrient emissions to inland waters arising from diffuse agricultural sources. Eight European Union Member States have independently developed these procedures. They essentially relate emissions to the characteristics of the sources and of the medium. The procedures have been systematically compared according to a matrix of criteria dealing with the components integrated within the model, the presentation of the results and the scale of application. It can be concluded that the principles of these procedures are homogeneous. Thus, the implementation of a future harmonised methodology for all Member States of the European Union seems to be feasible.

Key words | agricultural pollution, diffuse sources, emissions, leaching, modelling, nutrients

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INTRODUCTION

The need for an emissions inventory at European level has emerged from the implementation of EU directives, and the work programme of the European Environment Agency (EEA), or of international organisations dedicated to the protection of rivers and seas. Indeed, emission registers and inventories are important tools for the formulation and monitoring of pollution control policies at national and international levels.

The EEA's information needs on pollution sources are linked to its obligations for 'provision of timely, targeted, relevant and reliable information to policy making agents and the public'. Regular reporting on the state of the environment is one of the EEA's actions that requires emissions information.

Box 1 | The European Environment Agency

The European Environment Agency (EEA) was launched by the European Union in 1993. Its mission statement is as follows:

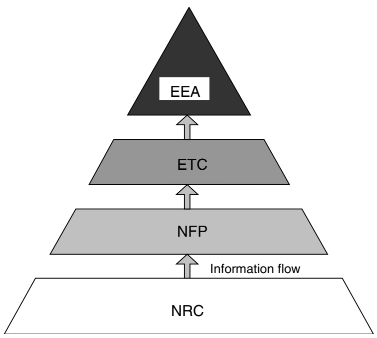
'The EEA aims to support sustainable development and to help achieve significant and measurable improvement in Europe's environment through the provision of timely, targeted, relevant and reliable information to policy making agents and the public.' This information must enable Member States to take the requisite measures to protect their environment, to assess the result of such measures and to ensure that the public is properly informed about the state of the environment.

One of EEA's main objectives is to implement and co-ordinate the European Information and Observation Network (EIONET, detailed below) with EEA Member States. EIONET is made up of:

• Nine European Topic Centres (ETCs), in charge of the collection, analysis, assessment and synthesis of information on precise environmental subjects in Europe (Air Emissions, Air Quality, Catalogue of Data Sources, Inland Waters, Land

Cover, Marine and Coastal Environment, Nature Conservation, Soil, Waste). The nature and number of ETCs are currently under review.
• National Focal Points (NFPs), responsible for national co-ordination of activities related to the EEA work programme.
• National Reference Centres (NRCs), in charge of providing the EEA with national information on different themes.
• Main Component Elements (MCEs), collectors, interpreters and suppliers of environmental data, with expertise in environmental science, monitoring or modelling.

Information originally produced by the numerous NRCs is collected by NFPs and aggregated by ETCs. Finally, after peer review, it is transmitted to the EEA for publication:



Integrated assessments of environmental problems are carried out by a number of organisations interested in assessing the state and evolution of the medium concerned and judging the effectiveness of measures to prevent and reduce pollution. Thus, emission inventories are likely to be carried out. One can mention:

- the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic.
- the HELCOM Commission for the Protection of the Marine Environment of the Baltic Sea Area.
- the International Commission for the Protection of the River Rhine.
- the International Commission for the Protection of the Danube River.

The existence of many requirements for the collection and reporting of information on emissions leads to the need for efficient use of this information in order to avoid duplication (Claverie 1999; Hey and Taschner 1998). To this end, the EEA decided to implement a conceptual model for an Integrated Emissions Inventory. In view of the fundamental differences between emissions to water and to air, it was decided to develop independently a method for emissions to water: a European Emissions Inventory (EEI). The long-term aim of the so-called emission task is to provide Member States with a single template related to emissions data.

Box 2 | Requirements for European directives

The need for an emissions inventory is particularly underlined in the proposed **Water Framework Directive (2000/60/CE)** adopted on 23 October 2000 and published on 22 December 2000. It requires that all measures to achieve the environmental objectives for sustainable protection and use of water have to be co-ordinated and their effects must be overseen and monitored. Estimates have to be made at the river basin district level of point and diffuse source pollution, as well as analysis of other anthropogenic influences on the status of water.

The **Reporting Directive (91/692/EEC)** aims to standardise and rationalise reports on the implementation of directives relating to the environment. Thus, a number of directives in the field of the environment were amended to require Member States to submit information on the implementation of those directives to the Commission every three years.

A number of other directives deal with aspects of water policies and management, focusing either on one specific substance or on one specific process. Requirements for emissions reduction and control are set up, and information on emissions constitutes a tool with which to assess the effectiveness of implemented measures: it will allow the European Commission (DG Env.) to assess compliance with the directives within Member States. Source-oriented directives particularly lead to a need for an emissions inventory. Most important are:

- the Integrated Pollution Prevention and Control Directive (96/61/EEC),
- the Dangerous Substances Directive (76/464/EEC),
- the Urban Waste Water Directive (91/271/EEC),
- the Titanium Dioxide Directive (82/883/EEC),
- the Nitrates Directive (91/676/EEC).

ETC/IW was requested by the EEA to develop a methodology for estimating emissions to water including the requirements from European directives, and to harmonise information collection on this subject. This methodology is intended to address all possible sources of emission. At the end of 1999, a proposed operational methodology had been developed. A data collection test has now to be carried out for a few volunteer Member States. The aim is to test the ability of the Member States to deliver the information required for the EEI proposed methodology.

Independent methodologies currently used by EU Member States have to be analysed and compared, and this is the topic of this paper. Indeed, Member States as a whole will not be able to implement inventory methodology immediately. A first step consists of determining how emissions are presently evaluated within the different States and assessing if the results are comparable with each other. The aim is to determine if results from current national methodologies can be use to draw up a first emissions inventory, without waiting for the broader application of EEA methodology, which will certainly need many years.

This paper is organised in three parts: description of the methodology for the assessment of different models used by Member States; presentation of two case studies (Denmark and the Netherlands); and comparison of the results of these approaches.

METHODOLOGY

Figure 1 illustrates the four step analysis used for the comparison of the different models used by Member States. The methodology is considered under four main headings:

Substances

The commonly adopted approach within the emission task consists of focusing firstly on the most important pollutants in terms of quantity and harmful effect. Here lies the reason to focus on nutrients: they are responsible for the widely occurring problem of eutrophication.

A nutrient is 'a chemical compound (carbon, nitrogen, phosphorus, etc.) which can be used directly by living cells for nutrition or can be assimilated without prior digestion' (*Encyclopaedia Universalis*). This paper focuses on those nutrients that are important in terms of nutritive value and nuisance levels in water, and whose presence in large quantities is clearly related to human activities. They are, in practice, nitrogen and phosphorus compounds.

Nitrogen

The most common forms of nitrogen are gaseous nitrogen (N_2), nitrate (NO_3^-), nitrite (NO_2) and ammonia (NH_3). Nitrate will be the main form of nitrogen to consider in emission assessment. It appears that up to 73% of total nitrogen may be transferred as nitrate. A large part of the nitrogen surplus leaches out of the root zone either to groundwater and later to surface waters, or directly to surface waters, for instance through drains.

Phosphorus

Usually, dissolved and undissolved (particulate) phosphorus are distinguished. Phosphorus is often held on soil or organic particles. Erosion and surface runoff are the main pathways involved in phosphorus emissions. High amounts of phosphorus applied for many years result in soils being saturated with phosphorus and hence significantly increased leaching of phosphorus.

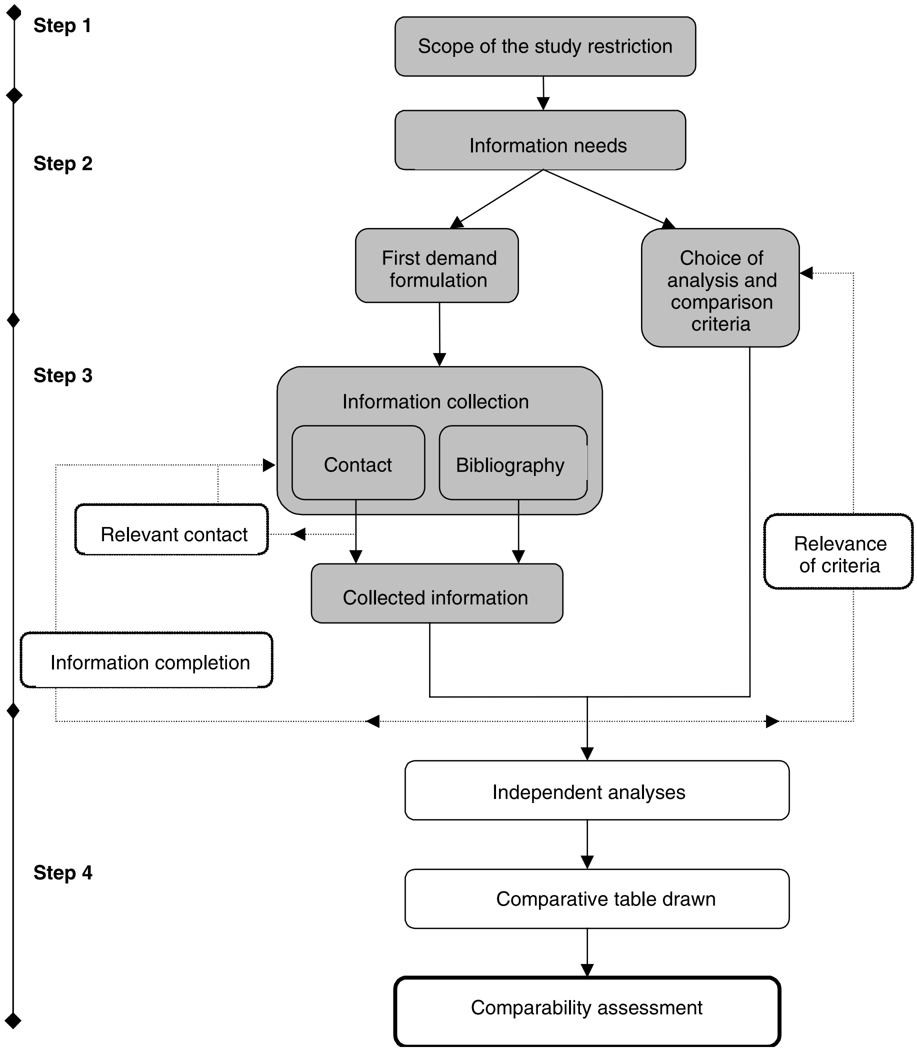


Figure 1 | Methodology.

Effects of nutrient excess

The presence of excessive amounts of nutrients has direct effects and indirect effects both on ecosystems and water uses. Direct effects are observed when the concentrations of nutrients (particularly NO_3) exceed standards or safe values for particular ecosystems. Indirect effects mainly correspond to eutrophication of water bodies. Within the UWW Directive, eutrophication is defined as:

> 'the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned'. (Fairbridge 1972)

Eutrophication is a major environmental issue in both fresh and marine waters. In addition to the impact on the ecosystem, the effects of eutrophication cause problems for the use of surface waters (public water supply, hydroelectric power generation, irrigation or fish hatcheries purposes, recreational activities) (EEA 1999c).

Box 3 | Some definitions

Emission: the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources into the air, water or land (Modified from Integrated Pollution Prevention and Control Directive (96/61/EEC)).

Emissions inventory: whole procedure aimed at collecting information on emissions (collection of data issued either from measurements or modelling): sources of emissions, amount of pollutant generated.

Emissions register: a kind of restoration format of emissions inventory, in which the sources are identifiable economic units (for example enterprises, households) which are *under a legal obligation* to report their emissions.

Source: the origin of an emission, which may be anthropogenic (human activities such as industry, agriculture, or metabolic activities) or natural, which generates emissions of pollutants. Sources are usually classified into categories; for example, urban, industrial, agricultural, exploitation of forests, transport, wastes, natural and semi-natural contributions.

Pollution: direct or indirect introduction as a result of human activity or natural processes, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses in the environment (modified from Integrated Pollution Prevention and Control Directive (96/61/EEC)).

Sources

Emissions sources can be divided into two major categories:

- a point source can be defined as a clearly identified, individual discharge (or a number of discharges in close proximity) to a watercourse or a body of water. These sources can be geographically located with precision.
- Diffuse sources (or non-point sources) cannot be located precisely. As a consequence, their assessment can only be carried out indirectly. Agriculture is largely the most significant diffuse source of nutrient emissions.

This study has been restricted to nutrient emissions from diffuse agricultural sources.

There are both natural and anthropogenic sources of nutrients. If there were no human activities, water composition would be determined only by hydrological and geochemical factors. The non-anthropogenic part of the diffuse sources is the so-called natural background. In general, the loads of nutrients increase with increasing human activity. The main nutrient sources identified are presented in Table 1.

Nitrogen loading comes primarily from agricultural activity, especially the use of nitrogen fertilisers and manure. In those river systems draining catchments in the central and western part of Europe, 46–87% of the nitrogen load to inland waters is related to agriculture. Agriculture partly acts indirectly on nitrogen emissions to inland waters: high livestock densities result in atmospheric emissions of ammonia, which, in turn, lead to atmospheric deposition. Figure 2 presents source apportionment of nitrogen load for some European regions.

Most of the dissolved phosphorus loading of inland waters is attributable to discharges from point sources, especially municipal sewage and industrial effluent. In the more densely populated areas, 50–96% of the dissolved phosphorus load to inland waters is derived from point sources, while agricultural activity generally accounts for 20–40%. Figure 3 gives an overview of source apportionment of phosphorus load in some parts of Europe.

Although general trends may be identified, it must be borne in mind that factors influencing nutrient emissions are different between European countries. In particular, there are large regional differences in agricultural characteristics.

Table 1 | Nutrient sources

Point sources	Diffuse sources
Industrial plants	Agriculture, through animal food, mineral fertiliser, animal wastes, sewage sludge and compost application to agricultural land, and manure storage
Urban waste water treatment works	Urban areas without connection to sewage treatment plant
Storm discharges	Scattered dwellings (not connected to sewage system)
Aquaculture plants and fish farms	Atmospheric deposition
	Forestry (by fertilising)
	Natural background

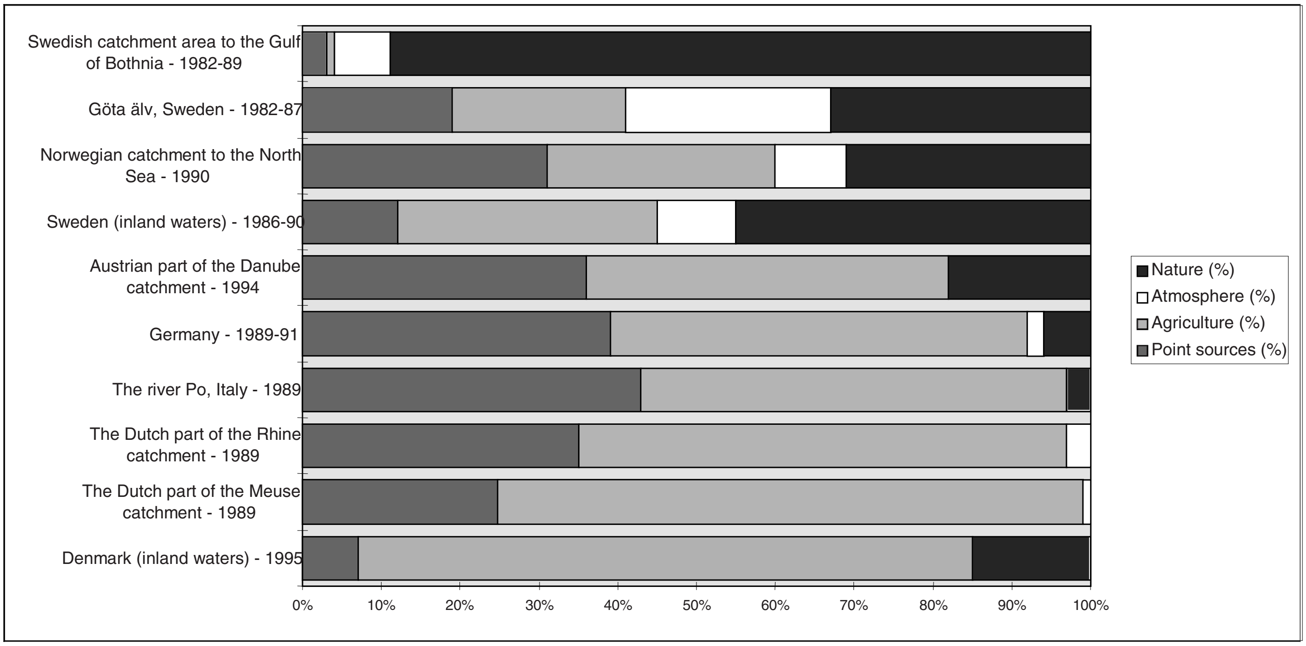


Figure 2 | Source apportionment of nitrogen load.

Approaches

Two categories of approaches can be distinguished: monitoring and modelling. Models are widely used as predictive tools for assessing processes of transport and transformation of pollutants in the environment. It is useful to use both a monitoring and a modelling approach in order to compare the results, and eventually to re-adjust the coefficients used.

Direct sampling monitoring is the most common method used to estimate point source discharges. In contrast, diffuse source pollution can only be assessed by modelling. Within the modelling approach, diffuse pollution is calculated either on the basis of coefficients

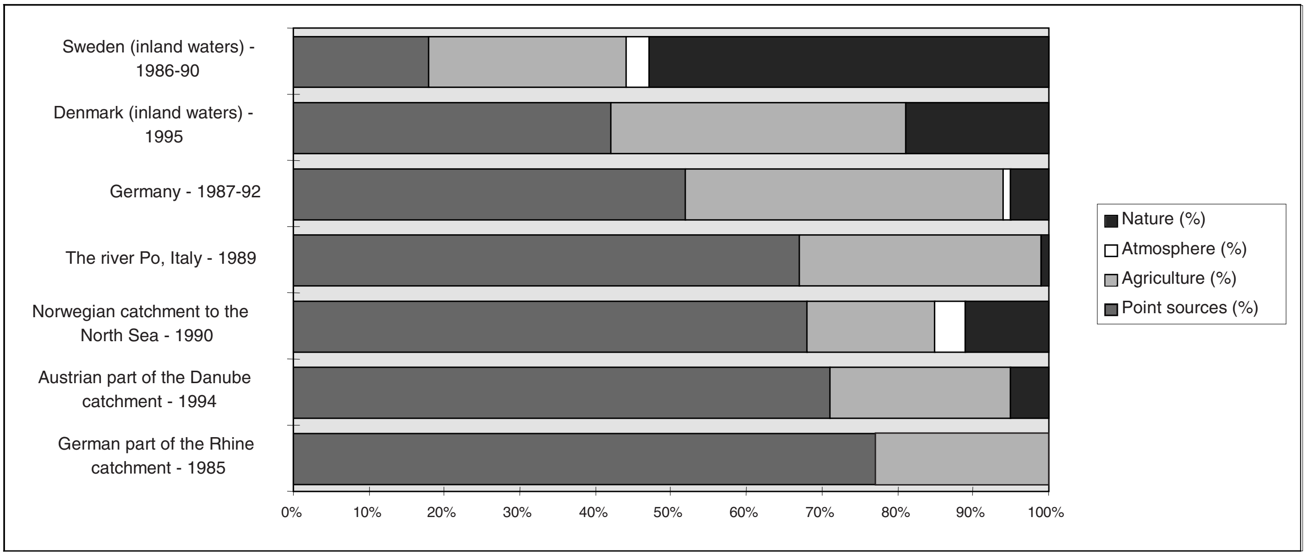


Figure 3 | Source apportionment of phosphorus load.

(area-, population-specific) or indirectly through a source apportionment of the pollution load to a water body. These two point of views are commonly designated as the source-oriented approach and the load-oriented approach (Preti 1996).

Source-oriented approach

The source-oriented approach consists of quantifying discharges or losses at source. It is generally based on statistics on land use, agricultural practice (national census) and other descriptors of diffuse pollution pressure. Such information may be expressed by means of loss coefficients: land use data are linked to loss coefficients specific for each loss process/pathway to surface waters. Usually, coefficients are multiplied by a characteristic unit (production, livestock, etc.) to provide discharge/loss amounts. A more detailed methodology can be implemented by the use of specific precise models for each pathway (e.g. leaching model, runoff model, atmospheric deposition model). Results from each specific model are summed to give diffuse emissions assessment. One advantage of the source-oriented approach is the possibility of testing the effects on emissions of any change in input data. It is the most commonly used approach.

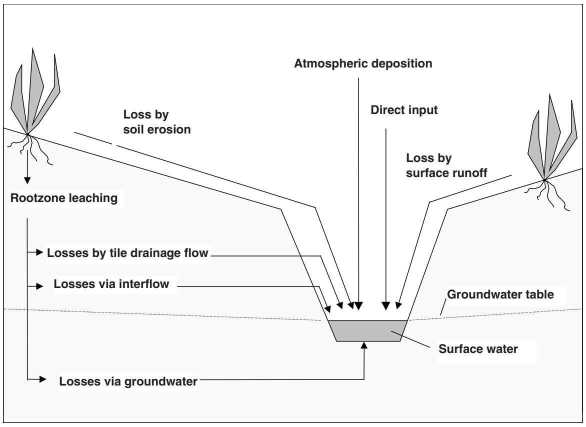
Box 4 | Pathways

Pollution from diffuse sources can reach the receiving medium via several pathways:

- Runoff (surface and subsurface (interflow) runoff)
- Leaching
- Soil erosion (wind erosion, surface water erosion, etc.)
- Drainage
- Groundwater: pollutant transfer to surface water occurs via groundwater

The total input to inland waters is seen as the sum of inputs from diffuse sources via the different pathways and from point sources. The schemas overleaf present existing pathways.

The balance between different pathways depends on a large number of factors. Regarding losses from agricultural land into surface waters, these controls can be subdivided into natural controls and farm management. Natural controls are dynamic and highly variable in both space and time.



The most important 'hydrological' processes/pathways as regards nitrogen and phosphorus losses from diffuse sources to aquatic systems

Adapted from: HARP-NUT group – **Draft OPSAR Guidelines for Harmonised Quantification and Reporting Procedure for Nutrient (HARP-NUT)** – *London, OSPAR Commission, October 1999 – 168 p.*

The most important are climate, topography and hydrology, and soil characteristics. Impacts of these controls on nitrogen losses are better understood than on phosphorus losses. Farm management can strongly modify the impact of the natural controls on nitrogen and phosphorus losses. Most important are land use and crop rotation, animal waste and fertiliser application (both amount and method of application), grazing system and management, soil phosphorus management and erosion control, groundwater level control (drainage) and irrigation management.

In view of the number of factors mentioned above, pathway distribution will be highly heterogeneous, and general trends are hardly identifiable.

Load-oriented approach

The load-oriented approach consists of quantifying the nitrogen and phosphorus loads at downstream monitoring points. The load transported by the river is then apportioned between sources. Source apportionment can be carried out at different detail levels. Observed load can be apportioned to its origin of either diffuse or point sources, without any further subdivision. It is assumed in these models that point source contributions do not depend on rainfall, and diffuse sources depend on flow. The load-oriented approach is often seen as a more qualitative methodology than the source-oriented one. Current research in Member States or within the EEA or HARP-Group deals most of the time with source-oriented approaches.

The load-oriented approach can, however, be really helpful if combined with the source-oriented approach in a verification procedure.

In addition to the source-oriented and load-oriented approaches, three other types of approach may be identified:

- A 'black box' approach, in which emissions are not apportioned according to pathways. This generally corresponds to the load-oriented approach, although some source-oriented approaches do not identify pathways.
- A specific approach, which deals with one pathway, most of the time runoff or leaching. The load-oriented approach does not allow this specific approach.
- A more global approach, which deals independently with many pathways and gathers, as a final step, emissions arising from the different pathways.

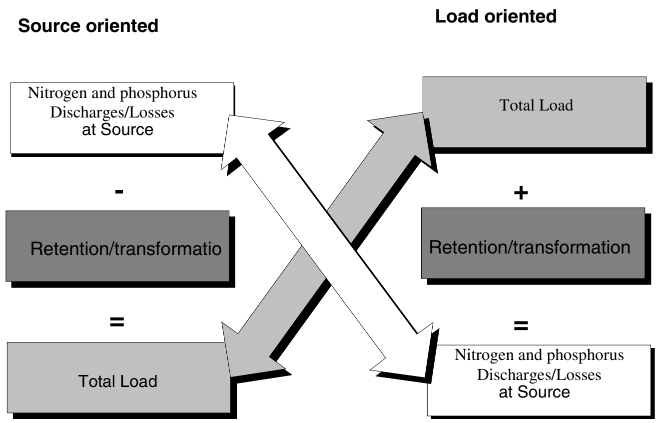


Figure 4 | Link between source oriented approach and load oriented approach.

Table 2 | Analysis and comparison criteria

Considered elements related criteria	Results restoration related criteria	Complementary criterion
Type of methodology applied (source-oriented or load-oriented approach)	Spatial scale (for calculation and results restoration)	Current application scale
Substance targeted	Time scale	
Sources taken into account, and detail level		
Pathways studied		
Reduction processes included		
Input data to the methodology (type and source)		

Information

One characteristic of this study is its entire dependence on Member States' responses. Information needs had therefore to be precisely set up at the beginning.

Analysis and comparison had to be rationally organised, that is to say common criteria had to be identified between every methodology. Analysis and comparison would then be carried out successively for each criterion. The criteria finally chosen are presented in Table 2.

Ideally, the study should have dealt with every European Union Member State. However, reaching an exhaustive presentation of methodologies developed within Member States to assess nutrient emissions from diffuse agricultural sources was not possible in the time available. The study therefore only involves nine methodologies developed within eight European countries. Table 3 lists the methodologies that have been analysed as well as the sources of information.

CASE STUDY

Two methodologies (from Denmark and The Netherlands) are presented in detail within this section to give the reader an example of the analysis procedure.

Denmark: empirical regression model

The National Environmental Research Institute of Denmark (NERI) is currently developing the first steps of a method for assessing nutrient emissions. A source-oriented approach has been chosen. An empirical multiple regression model for water discharge and nitrogen transport has henceforth been implemented for the whole of Denmark. It sets up empirical relationships between catchment characteristics, nitrogen losses with runoff from agriculturally dominated areas and nitrogen loads to surface waters. The objective is to calculate annual river runoff and nitrogen loads for ungauged areas at the regional scale.

Scope of the methodology

The substance targeted is total nitrogen. The model focuses on nitrogen emissions in runoff from agricultural sources. However, as it is based on water monitoring, without apportionment of the results between agricultural sources and natural background, it can be postulated that this source is indirectly taken into account. Point source emissions are added to the results of model runs at a later stage.

Calculation principles

As a preliminary step, groundwater catchments have to be calculated from a groundwater potential map (Dorioz and Ferhi 1994; Leblanc and Crouzet 1999).

Table 3 | Studied methodologies and related sources of information

Country	Methodology	Source of information
Denmark	Empirical regression model	National Environment Research Institute (NERI)
France	PEGASE model	Agence de l'Eau Rhin-Meuse; literature
France	Loire-Bretagne model	Agence de l'Eau Loire-Bretagne
Germany	MONERIS model	Umweltbundesamt
Ireland	Loss-coefficient procedure	Literature
The Netherlands	Combination of 3 models: WLM-AGRI + DEMGEN + ANIMO	Institute for Inland Water Management and Waste Water Treatment (RIZA); literature
The Netherlands	Source apportionment in the River Rhine	National Institute of Public Health and the Environment (RIVM)
Sweden	HBV-N model	Swedish Environmental Protection Agency
UK	MAGPIE model	Literature
Walloon Region	EPIC model	Faculté universitaire des sciences agronomiques de Gembloux

Two distinct regression models have been developed, for hydrology and for nitrogen loads. The first model leads to assessment of annual runoff. This result is then used in the second model to evaluate annual diffuse loss of total nitrogen.

Input data to the hydrological model are annual precipitation, land use (from CORINE Land Cover), hydrogeology (from the unofficial groundwater potentials map), mean local slope and topographic catchment area. As to the nitrogen load model, it requires data on soil characteristics and land use in addition to hydrological results.

Application

Model application consisted of the calculation of riverine runoff and nitrogen transport to coastal areas at the national scale; that is, for an area of 43,000 km^2.

Regression equations are used to calculate annual water runoff and nitrogen transport for ungauged areas. N-pollution from point sources is then added. For the gauged areas, measurements on both hydrological runoff and nitrogen loads are carried out. Finally, runoff and nitrogen loads from both monitored and unmonitored areas are aggregated. Calculation is carried out annually.

Comments

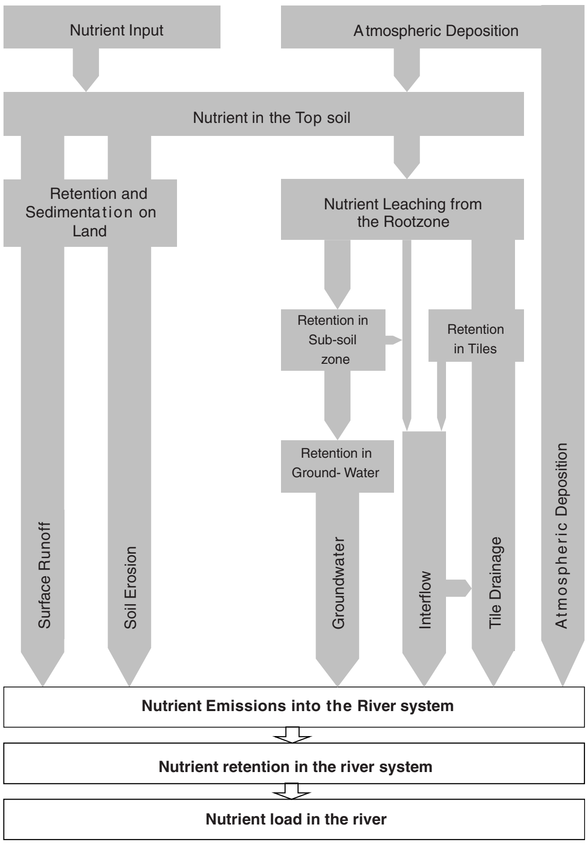
Generation of groundwater catchments causes some uncertainty as no official and homogeneous map on groundwater potential exists for the whole of Denmark (Kronvang *et al.* 1996).

Retention and transformation processes within rivers and soils are not taken into account. Indeed, the nitrogen load model has been developed from measurements on catchments with an area smaller than 30 km^2, so that reduction process effects are negligible.

Box 5 | Retention and transformation

Retention and transformation processes occurring in soils influence the final amount of nutrient transported to surface water along the different hydrological pathways. Retention also occurs in the river system. This phenomenon will be the link between emissions and load observed in the river. Retention processes not only act in decreasing the amount of pollutant observed in the river; retention may be a temporary phenomenon, and some of the nutrients are finally released back into the river, mainly because of saturation. Introduction of a lag-time function is one solution to take into account the progressive release of nutrients. Retention processes occur at different stages of pollutant transfer from source to receiving body. The figure opposite presents the main retention phenomenon.

Many of the parameters influencing retention and transformation are difficult to measure and therefore difficult to implement in calculation procedures. Retention and transformation in river systems is, in most cases, quantified on the basis of the mass balance of investigated lakes and rivers: difference between nutrient input (e.g. fertiliser application) and output (e.g. load at the river mouth) represents nutrient reduction. Retention models can also be used, or measurements provide retention coefficients, which can be applied to streams and rivers. However, this approach entails errors due to insufficient knowledge about the hydrological processes in the catchment. Transformation and retention processes are of major importance (up to 45% of the gross load).



Retention and transformation processes

Adapted from: HARP-NUT group – **Draft OPSAR Guidelines for Harmonised Quantification and Reporting Procedure for Nutrient (HARP-NUT) –** *London, OSPAR Commission, October 1999 – 168 p.*

The Netherlands: combination of three models

Model computations of the present and future emissions of nitrogen and phosphorus from agricultural areas in The Netherlands were performed by the Institute for Inland Water Management and Waste Water Treatment (RIZA) (Boers *et al.* 1996). This source-oriented approach was used within the framework of the Fourth National Policy Document on Water Management in The Netherlands in order to analyse effects of different scenarios of fertiliser management on N- and P-leaching from rural areas into Dutch surface waters (Kroes *et al.* 1996; Oenema and Roest 1998).

Scope of the methodology

Total nitrogen and total phosphorus arising from diffuse agricultural sources are targeted. Pathways taken into account are leaching and surface and subsurface runoff.

Principle

The model instrument describes transport and transformations of nutrient in the soil system from soil surface to small surface waters. It consists of the following elements:

- A procedure for spatial and vertical schematisation. Basic data (meteorology, drainage, hydrogeology, soil physics, soil chemistry and land use from national sources of data) are used in a GIS environment to arrive at a set of calculation units (plots). Each plot is required to be uniform in term of soil type, land use and hydrological conditions. The defined soil units were schematised into soil horizons, characterised by soil physical and chemical properties, for the upper part of the soil, to a depth of 7 m below the soil surface.
- A fertiliser distribution model: WLM-AGRI (statistic model). Initialisation of the nutrient simulations required a fertiliser distribution for the historical period 1940–1993. The WLM-AGRI model produces type and level of fertiliser applications by combining data on the use of inorganic fertiliser and the use of animal manure (issued from national statistics) with land use data from the spatial schematisation. The calculations resulted in fertiliser additions for a period of nearly 100 years.
- A hydrological model: DEMGEN (mechanistic dynamic model). DEMGEN performs the hydrological simulations of the top system for each plot. Two different surface water systems are distinguished: a primary system, consisting of canals, small rivers and brooks, and a secondary system, which includes ditches as well as artificial drains. Within this model, it is assumed that all horizontal flow in the hydrological top layer is directed towards the surface water systems. This implies that there is no horizontal interaction between different plots.
- The plots are vertically divided into 15 soil compartments, and the moisture contents, vertical fluxes and interactions with surface water systems are computed for each compartment. Results from the hydrological model, especially fluxes and moisture contents, are used as input for the nutrient simulations.
- A nutrient model: ANIMO (mechanistic dynamic model). The ANIMO model computes the behaviour and transport of phosphorus and nitrogen in the soil based on animal manure and fertiliser applications and computed water balances. Previous results from the hydrological and fertiliser model runs constitute input data. ANIMO simulations generated N- and P-mass balances of each plot from soil to groundwater and surface water. The N- and P-loads towards surface water systems were derived on the basis of these results.

Interactions between models used within the ANIMO procedure are presented in Figure 5.

Application

The methodology was applied to the rural areas of The Netherlands. Nutrient behaviour is simulated for each plot, and results can be aggregated to regional or national scale. ANIMO results were analysed using general statistics within a GIS environment.

Comments

The spatial schematisation is a first and crucial step in the analysis, because spatial variability of input data should be considered in the model simulations. The model instrument is based on a large number of basic data files. Evaluation of this instrument revealed that some data files, especially historical manure use, manure distribution, land use and characterisation of drainage systems are of poor quality. The influence on the model results is substantial.

Adequate modelling of the hydrology appeared essential for an adequate modelling of nutrient runoff. The description of preferential transport in the soil needs to be incorporated into the simulation, as well as farm management models. The nutrient model does not include processes taking place in surface water systems. A more direct link between nutrient leaching models and surface water quality models is therefore recommended.

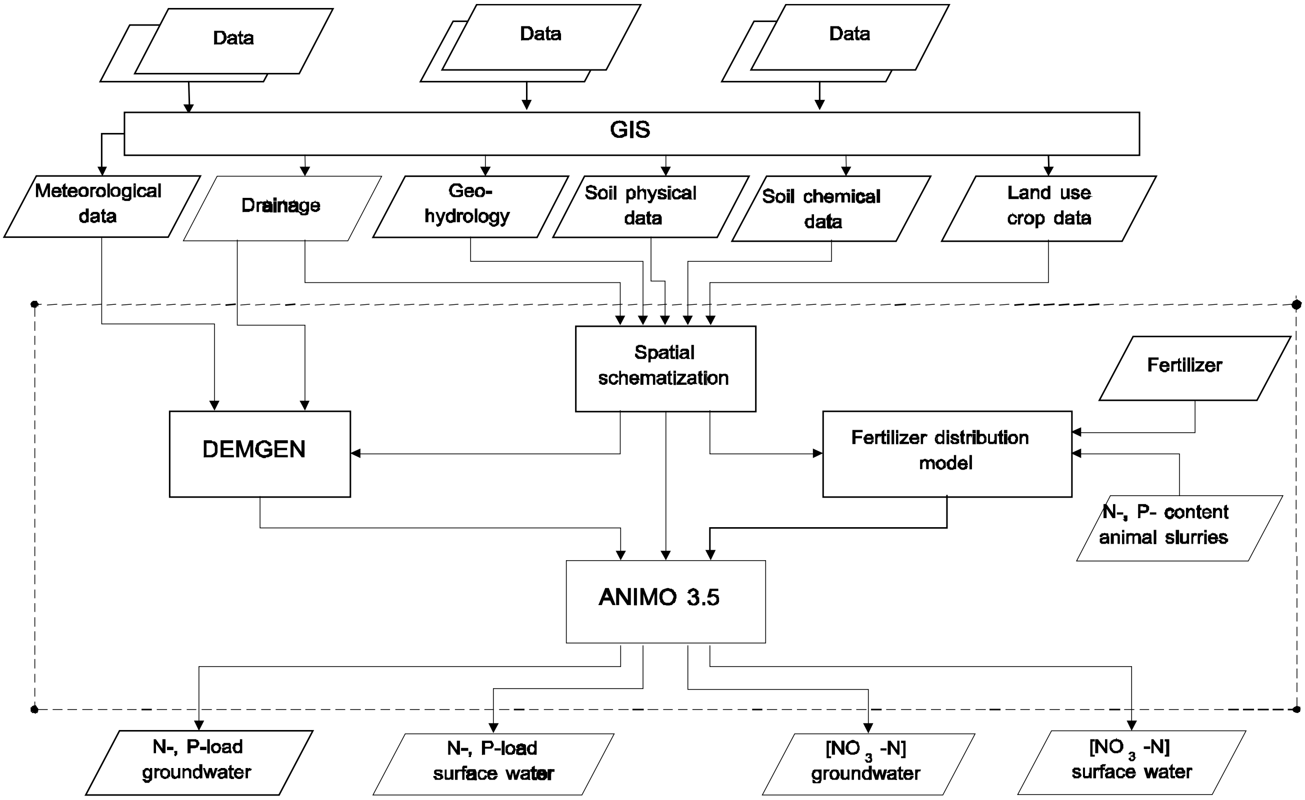


Figure 5 | Set of models used for the simulation of regional nitrogen and phosphorus leaching (between the dotted lines) and main data flow.

ASSESSMENT OF THE COMPARABILITY

Approaches

The approach chosen by most of the studied countries is the source-oriented one. The River Rhine study is the only one based on a load-oriented approach. The adaptability of this type of methodology to any modification of input data explains the preference for it. The principles of source-oriented or load-oriented approaches do not directly create difficulty in the comparison of results. However, discrepancies are likely to appear following the application of the procedures.

Substances

Every methodology inventoried deals at least with nitrogen compounds. Total nitrogen is generally targeted, except in the case of the UK and Walloon Region where nitrate is considered. The main part of total nitrogen is transferred as nitrate. Thus, British and Walloon results can be under-estimated since only part of total nitrogen is studied, but comparison with other results remains acceptable.

Phosphorus components are studied in few methodologies. Phosphorus behaviour affects both model structure and data requirements. Only France, Germany, Ireland and The Netherlands have yet integrated phosphorus into their assessment methodology. Other countries are intending to take it into account, and research is ongoing in order to adapt the existing model to phosphorus components.

Sources

Every methodology takes diffuse agricultural sources into account, either independently or as part of diffuse sources without any further distinction. Most of the methodologies do not consider only diffuse agricultural sources, and the ability to apportion the results according to the sources taken into account has to be examined.

Natural background is often implicitly included within the model results. Actually, the Dutch and Walloon methodologies seem to be the only ones not considering natural background: emissions assessment is based on fertiliser distribution and agricultural data. Thus, nutrient emissions assessed are only derived from agriculture. However, natural background contribution in nutrient emissions is much lower than the contribution of diffuse agricultural sources. This will therefore not be a decisive criterion for comparability although Walloon or Dutch results are likely to be under-estimated.

French and Swedish methodologies do not allow apportionment of results according to sources. Indeed, 'disaggregating' global results would be required as emissions from different sources are aggregated at various levels. With the approach of the River Rhine study it is not possible to identify the role of agricultural sources.

Pathways

Few countries have already implemented a global approach (Germany, The Netherlands and Sweden) (Behrendt *et al.* 1999; Arheimer and Brandt 1998). Most of the specific or global methodologies take into account runoff and/or leaching (Dutch, Danish, German and Walloon approaches). Within the black box approach, implemented by France, Ireland, the UK and for the River Rhine, all pathways are theoretically taken into account.

Analysis of each methodology independently has led to the production of a comparative table (Table 4), which sums up the characteristics of each approach.

In Table 5 the shaded boxes indicate where particular care must be taken when making a comparison of the different methodologies. Taking French, Irish or British results as a reference, Danish and Walloon methodologies provide the most under-estimated results (only one pathway is considered) (Dautrebande *et al.* 1999). Dutch results are also under-estimated (runoff and leaching involved), whereas the German assessment is likely to be the closest estimate (many pathways taken into account). However, it must be underlined that 'black box' results may not be completely reliable since specificity of nutrient transport to receiving water is not taken into account.

Input data

Most of the methodologies are based on data available at national level, sometimes even at municipal level. Only Danish, French and German approaches make use of data from CORINE Land-Cover, stored according to a precise format. The format of national or municipal data is specific for each country, so that comparability may need data treatment as a preliminary step.

Land use, soil characteristics and meteorological data are largely employed (except for the River Rhine). Likewise, agricultural practices are present in most of the methodologies, sometimes indirectly (Germany and Denmark). Catchment physical characteristics are important for Danish and Walloon methodologies (integration of mean local slope).

Integration of hydrogeological data appears to be a parameter that heavily influences runoff. It is more or less directly integrated in all methodologies. However, the PEGASE model (France) is noteworthy as it is not clear if hydrogeological data have been taken into account while developing 'input functions' used to assess soils inputs (Smitz *et al.* 1997).

Administrative statistics, point source discharges, industrial discharge measurements and WWTP characteristics are the main input data necessary to assess point discharges.

Input data for source apportionment in the River Rhine (load-oriented approach) are widely different from those for all source-oriented approaches (Van Dijk *et al.* 1997).

Transformation/retention processes

The impact of transformation and/or retention processes is important, and it is not correct to compare results that integrate these processes with results that neglect them.

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Table 4 | Comparison criteria of the methodologies

	Country									
Criteria	**Denmark**	**France (Loire-Bret.)**	**France (PEGASE)**	**Germany**	**Ireland**	**Netherlands**	**River Rhine**	**Sweden**	**U.K.**	**Walloon Region**
Approach										
Source oriented	✔	✔	✔	✔	✔	✔		✔	✔	✔
Load oriented							✔			
Substances										
Nitrogen	✔	✔	✔	✔	✔	✔	✔	✔	✔(1)	✔(1)
Phosphorus		✔(2)	✔	✔	✔	✔				
Sources										
Diffuse agricultural	✔	✔			✔	✔			✔	✔
Nautral background	✔(3)				✔(3)				✔(3)	
Rural household								✔		
Diffuse urban sources		✔		✔						
Atmospheric deposition				✔				✔		
Diffuse source without further			✔(4)	✔(5)			✔	✔(6)		
Industrial point		✔	✔	✔				✔		
WWTP discharges			✔	✔				✔		
Direct discharges from livestock			✔							
Point sources without further	✔(7)						✔		✔(7)	
Pathways										
Emissions not apportioned into		✔	✔		✔		✔	✔(8)	✔	
Runoff	✔			✔		✔		✔		
Leaching						✔		✔		✔(9)
Erosion				✔						
Drainage				✔						
Groundwater				✔						

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Table 4 | *Continued*

	Country									
Criteria	**Denmark**	**France (Loire-Bret.)**	**France (PEGASE)**	**Germany**	**Ireland**	**Netherlands**	**River Rhine**	**Sweden**	**U.K.**	**Walloon Region**
Input data nature										
Land-use	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Meteorological data	✔			✔	✔	✔		✔	✔	✔
Soil characteristics	✔		✔	✔	✔	✔		✔	✔	✔
Catchment physical	✔				✔				✔	✔
Hydrogeology	✔			✔	✔	✔				
Agricultural practices			✔		✔	✔		✔	✔	✔
Nutrient surpluses		✔		✔	✔					
Atmospheric deposition				✔				✔		
Water sampling (N-load)					✔		✔			
Administrative statistics		✔	✔	✔			✔	✔		
All point sources discharges					✔		✔	✔		
Industrial discharges		✔	✔	✔				✔		
WWTP characteristics		✔		✔			✔	✔		
Input data source										
National data/statistics	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Communal		✔	✔		✔					
CORINE Land-Cover	✔	✔	✔	✔						
Previous study		✔	✔		✔					✔
Processes within the river/soils										
Retention			✔	✔	✔(3)		✔(10)	✔	✔	✔(11)
Transformation			✔	✔	✔(3)			✔	✔	✔(11)
Calculation spatial scale	?									
Plot						✔(12)			✔(13)	✔
Administrative unit		✔	✔							
Subcatchment					✔		✔	✔		
Catchment			✔	✔(14)						

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Table 4 | *Continued*

	Country									
Criteria	**Denmark**	**France (Loire-Bret.)**	**France (PEGASE)**	**Germany**	**Ireland**	**Netherlands**	**River Rhine**	**Sweden**	**U.K.**	**Walloon Region**
Results spatial scale	?									
Plots						✔(12)				
Administrative unit		✔(15)								
Subcatchment					✔		✔	✔(16)		
Catchment		✔(17)	✔	✔(14)					✔(18)	✔
Results time scale										
Daily			✔					✔		✔
Annual	✔	✔	✔(19)	✔	✔	✔	✔	✔(19)	✔	✔(19)
Longer period				✔		✔	✔			
Results support	?									
GIS		✔	✔	✔	✔	✔		✔	✔	✔
Classical software (e.g. Excel)		✔	✔			✔	✔		✔	
Current application										
Catchments					✔					
Regional		✔	✔				✔	✔		✔
National	✔			✔		✔		✔		

Meterorological data, precipitation, temperature.
Soil characteristics, physical and chemical characteristics of soils, soil erosion map, soil P-level, drainage, potential evapotranspiration.
Catchment physical characteristics, slope, topographic catchment area, altitude.
Agricultural practices, agricultural census, fertiliser use, production and storage capacity of slurry/manure, yields, date of field activities.
Administrative statistics, population, levy and taxes to which industry is subject, mean connection rate to sewerage network, rural household.
WWTP characteristics, size, inputs, load reduction rate, outflow concentrations.
(1) Nitrate.
(2) Not for agricultural emissions.
(3) Indirectly taken into account within the model (most of the time because the model is based on measurements).
(4) Soil inputs.
(5) Via runoff, erosion, drainage, groundwater.
(6) Via leakage, runoff.
(7) Added after model runs.
(8) Point sources, rural household.
(9) Leaching to groundwater only.
(10) Only in river system.
(11) Denitrification in the unsaturated zones adjacent to the root zone not included.
(12) Average size of 750 ha.
(13) 1 km grid cells.
(14) Regional differentiation for river basins of a size of more than 500 km^2.
(15) Results aggregation at 'departement' scale.
(16) Average area of 35 km^2.
(17) RNDE catchments, average size 10,000 km^2.
(18) Possibly split into subcatchments.
(19) Annual results available after aggregation.

Table 5 | Nutrient models assessment

	Denmark	France	Germany	Ireland	Netherlands	River Rhine	Sweden	U.K.	Walloon Region
Approach	Source oriented	Source oriented	Source oriented	Source oriented	Source oriented	Load oriented	Source oriented	Source oriented	Source oriented
Substances	Total N	Total N + Total P	Total N + Total P	Total N + Total P	Total N + Total P	Total N	Total N	Nitrate	Nitrate
Sources	Natural background included. Point sources added after model runs	Natural background included. Within soil inputs', emissions from agricultural sources not identifiable. Desegregating' procedure required	Natural background included. Independent sub-models specific of source or pathway. Studied pathways correspond to diffuse	Natural background included. Only assessed sources are natural background and agriculture	Natural background excluded. Only assessed source is agriculture	Natural background included. Riverine approach: no distinction within diffuse sources. Input–output approach source distinction	Natural background included. Desegregating' procedure required. Land-use categories not limited to agricultural ones	Natural background included. Point sources added after model runs	Natural background excluded. Only assessed source is agriculture
Pathways	Specific approach. Runoff assessed	Black box approach	Global approach. Many pathways independently assessed, including runoff, erosion, drainage	Black box approach	Global approach. Runoff and leaching assessed together	Black box approach	Global approach. Runoff and leaching assessed together	Black box approach	Specific approach. Leaching groundwork assessed
Input data nature	Importance of mean local slope	Importance of hydrogeology not clear	No particularity	No particularity	No particularity	Soil characteristics not used. Importance of water sampling	No particularity	No particularity	Importance of mean local slope
Input data source	Use of CORINE Land-cover	Use of CORINE Land-cover	Use of CORINE Land-cover	Use of national data only	Use of national data only	Use of national data only	Use of national data only	Use of national data only	Use of national data only

Table 5 | *Continued*

	Denmark	France	Germany	Ireland	Netherlands	River Rhine	Sweden	U.K.	Walloon Region
Reduction processes	Not taken into account	Included as final step	Included as final step	Indirectly included, not distinguishable	Not taken into account	Assessed for each sub-basin	Included as final step	Included as final step	Distinguishable. Do not include denitrification process unsaturated zone adjacent the root zone
Calculation spatial scale	?	Catchment. Administrative unit for point sources	Catchment	Sub-catchment	Plot	Sub-catchment	Sub-catchment	Plot	Plot
Results spatial scale	?	Watershed	Watershed	Sub-catchment. Possible aggregation at watershed	Plot. Possible aggregation at watershed	Sub-catchment. Possible aggregation at watershed	Watershed	Watershed	
Results time scale	Annual	Daily. Annual aggregation possible	Annual	Annual	Annual	Annual	Daily. Annual aggregation possible	Annual	Daily. Annual aggregation possible
Results support	?	Complex GIS	Complex GIS	Emissions assessment not included in the GIS	Complex GIS	No GIS	Emissions assessment not included in the GIS	Complex GIS	Complex GIS
Current application sacle	National	Basin of the Agence de l'Eau Rhine–Meuse	National	Catchment	National	River Rhine basin	Southern Sweden	National	Regional

Only two methodologies do not take such phenomena into account. Comparison with results of other methods will thus be relevant only if gross results are available before integration of transformation/retention processes. This will not be possible for the Irish model: reduction processes are taken into account indirectly as it is based on water sampling necessarily integrating transformation/retention processes.

Presentation of the results

Spatial scale

The largest observed spatial scale for the presentation of the results is the watershed scale (France, Germany, UK, Walloon Region). In the case of smaller scales, comparison requires the possibility of aggregating results to the watershed scale. This condition is met by every methodology. As regards the spatial scale of calculation, most countries have chosen to work at sub-catchment or catchment levels. The Irish approach is likely to be problematic since it is to be implemented only at a local scale. Thus, currently available results are limited. Application at a larger scale is likely to take time and difficulties may appear.

Countries should communicate information on studied watersheds when transferring emissions figures. Indeed, if watershed is put as a reference, large area discrepancies may appear between different regions according to topographic characteristics.

Time scale

The time scale of results is uniform for all methodologies: an annual scale is used for the presentation of the results. This scale allows for trend identification while being large enough to avoid heavy calculation procedures. It has also been chosen by the EEA for its reporting requirements.

Information support

All countries have developed a geographical information system (except in the case of the River Rhine study). But this has not reached the same implementation level for all methodologies. In some cases (France, Germany, The Netherlands, UK and Walloon Region), GIS combines many types of information: physical data, hydrological data, economic data, as well as results from emissions assessment. In contrast, the Swedish system includes input data, point sources and measurements from monitoring programmes, but assessment results are not represented. As for the Irish system, it only produces an 'Agricultural Risk Map'.

CONCLUSIONS

- Most of the models are based on existing databases and their implementation does not require any additional data collection.
- They are also more or less homogeneous in their principles. The majority are source-oriented. The main difference lies in the pathways taken into account, e.g. in integration of runoff only, or integration of leaching, erosion and runoff. Even in this case, the model uses the same type of input data.
- Models have been developed for various objectives; hence their structure is different. For example, some models have been developed to assess emissions to the sea and hence take into account retention and transformation processes occurring within the water system. In contrast, some models aim at evaluating emissions from a catchment into the river and can then neglect retention and transformation.
- Two models seem to be problematic.
  The source apportionment in the River Rhine is based on a load-oriented approach. Thus its principle is totally different from the others. In particular, measurements are required to make emission assessment, and the model is not predictive. Germany and The Netherlands have developed other tools (source-oriented models) which provide more reliable results.
  The Irish model has only been implemented at a local scale, and generalisation is not possible.
- Owing to the homogeneity of models already developed by Member States, application of the future harmonised methodology tested by the EEA

should not be a source of difficulties for Member States and should be a useful tool for the implementation of environmental policies at European level.

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