OSPAR COMMISSION

Protecting and conserving the North-East Atlantic and its resources

Guideline 6:

Quantification and Reporting of Nitrogen and Phosphorus Losses from Diffuse Anthropogenic Sources, and natural Background Losses

(Reference Number: 2007-8)

Secretariat note:

OSPAR 2000 adopted on a trial basis the OSPAR Guidelines for harmonized Quantification and Reporting Procedures for Nutrients (HARP-NUT) numbers 1-9, except for number 6 on diffuse sources. OSPAR 2000 agreed that the further development of draft Guideline 6 within OSPAR should only start when the results of the EC Fifth Framework Programme EUROHARP project on an intercomparison of quantification models for losses from diffuse anthropogenic sources were available. OSPAR 2004 adopted revised versions of HARP-NUT guidelines 1,3,4,5,7,8 and 9 and noted a report on progress on the EUROHARP project, indicating that the output from this project was expected to become available at the end of 2004 for use in the further development of HARP-NUT Guideline 6. OSPAR 2007 adopted the attached HARP-NUT GL 6 on a trial basis for the 2007/2008 and 2009/2010 implementation reporting rounds under PARCOM Recommendation 88/2.

2010 update (EUC(2) 09/9/1):

EUC reviewed the status of the draft HARP-NUT Guideline 6 on the quantification and reporting of nitrogen and phosphorus losses from diffuse anthropogenic sources and natural background losses (Agreement 2007/8) (EUC(2) 09/3/2). The Guideline had been adopted on a trial basis in 2007 for use in the 2007/2008 and 2009/2010 implementation reporting on PARCOM Recommendation 88/2, with a view to its final adoption.

EUC noted that experience from its use was limited, and that model development was rapid and that in a few years time the Guideline may need to be updated, as would also be the case for the other HARP-NUT Guidelines. EUC adopted the HARP-NUT Guideline 6 and asked the Secretariat to contact relevant Contracting Parties to obtain updated contact names for the various models listed in Annex 1 of the Guideline before its publication by OSPAR 2010.[1]

[1] Updated contact names still required.

Guideline 6:
Quantification and Reporting of Nitrogen and Phosphorus Losses from Diffuse Anthropogenic Sources, and Natural Background Losses

Contents

1. Objectives

1.1 To describe procedures for the quantification and harmonised reporting of total phosphorus (P) and total nitrogen (N) losses from anthropogenic diffuse sources[1] into primary surface water recipients.[2]

1.2 To describe procedures for the quantification and harmonised reporting of natural background losses of total phosphorus (P) and total nitrogen (N) into primary surface water recipients.

2. Introduction

2.1 A full harmonisation of the quantification procedures of total nitrogen and total phosphorus losses from diffuse anthropogenic sources and from natural background losses is difficult to achieve as specific key factors differ considerably among the various regions. Moreover, different developments and experiences exist within Contracting Parties on this issue. Recent investigations have shown that no single model appears capable of adequately representing the wide range of climate, soils, hydrology and land use across European catchments. Furthermore, some of the models only determine nitrate rather than total nitrogen.

2.2 In order to acknowledge the differences on the one hand and to enable transparency and comparability on the other hand, this guideline describes various quantification tools (models) and provides guidance on methodologies for model selection, including when different approaches are appropriate. In addition to quantification approach, the guideline provides harmonised reporting procedures and considerations on normalisation and quality assurance. In this guideline the term quantification tool is used, because a number of these quantification tools consist of some individual models/modules which are separately described, and because the approaches vary e.g. from a very simple difference method to complex mechanistic models.

3. Definitions of diffuse sources and pathways

3.1 Nutrients in the aquatic environment originate from either point sources or non-point sources: Point sources are all pollutant sources amenable to end-of-pipe control. This means that point sources include discharges of nutrients from industrial plants, waste water treatment plants, sewerage, and aquaculture plants. Diffuse sources of nutrients are all sources that are not regarded as point sources (Figures 1a and 1b). An operational definition of the term diffuse sources for the purpose of this guideline is: *pollutant loading of the aquatic environment that derives from source areas and delivery pathways characterised by large spatial and temporal extent and therefore impossible to monitor and manage as end-of-pipe control.*

3.2 Within OSPAR it is decided to include losses from households not connected to public sewerage, including both scattered dwellings and households within urban areas that are not connected and will not be connected in the near future, as a diffuse source (HARP-NUT Guidelines 1 and 5).

3.3 Nitrogen and phosphorus losses to primary surface water recipients from the following sources should be considered diffuse in origin:

- direct atmospheric deposition on inland water bodies (Section 4);
- natural background losses from all land areas (Section 5);
- unmanaged land (Section 5);
- non-agricultural managed land (e.g. forestry) (Section 6); and
- agricultural land (including managed grassland) (Section 7).

It is important to be able to estimate the magnitude of the natural background losses which would occur in the absence of anthropogenic activity, as these cannot be influenced by mitigation measures.

3.4 Whereas point sources are discharging directly into inland surface waters, losses from diffuse sources are delivered via a number of different pathways into inland surface waters. The pathways are characterised

---

[1] Excluding nitrogen and phosphorus losses from households not connected to public sewerage and stormwater flow from paved areas, which are dealt with in HARP-NUT Guidelines 4 and 5.

[2] Nitrogen and phosphorus means nitrogen (tot-N) and phosphorus (tot-P), except where specified differently.
Nitrogen includes both inorganic and organic fractions of nitrogen.
Phosphorus includes both inorganic and organic fractions of phosphorus.
(Source: HARP-NUT Guideline 1)

by different flow patterns in time and space, and include many different processes (see Figure 1). Depending on key factors such as climate, hydrology, geology, soil chemistry and land use, losses of phosphorus and nitrogen can vary substantially from area to area. The HARP-NUT Guideline 6 defines and considers the following pathways:

- Nutrient losses in particulate and dissolved form via erosion and surface runoff from land;
- Stream bank erosion;
- Nutrients transported to surface water via tile drains;
- Nutrients transported to surface water via interflow and from upper and deeper groundwaters;
- Atmospheric deposition on inland surface waters.

3.5 A large number of removal, storage or transformation processes in soils, groundwater and on the fields may influence the final quantities of nitrogen and phosphorus entering inland surface waters. Knowledge about these processes of transformation and retention is necessary to quantify and to predict nutrient losses into river systems in relation to their sources. Therefore, some kind of modelling methodology has to be applied in order to quantify the diffuse nutrient losses.

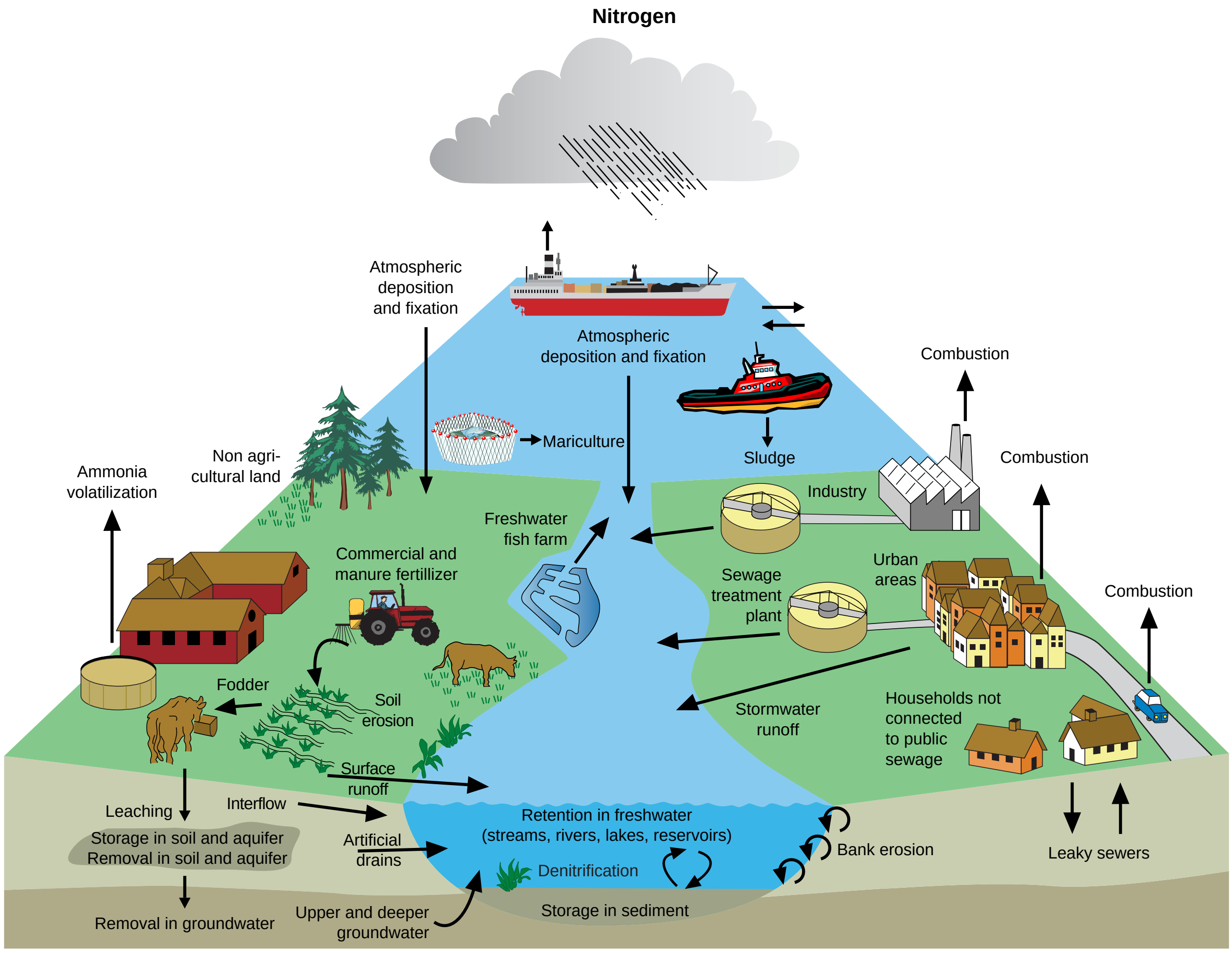


Figure 1 a: Nitrogen sources and pathways. Diffuse sources to the left and point sources to the right.

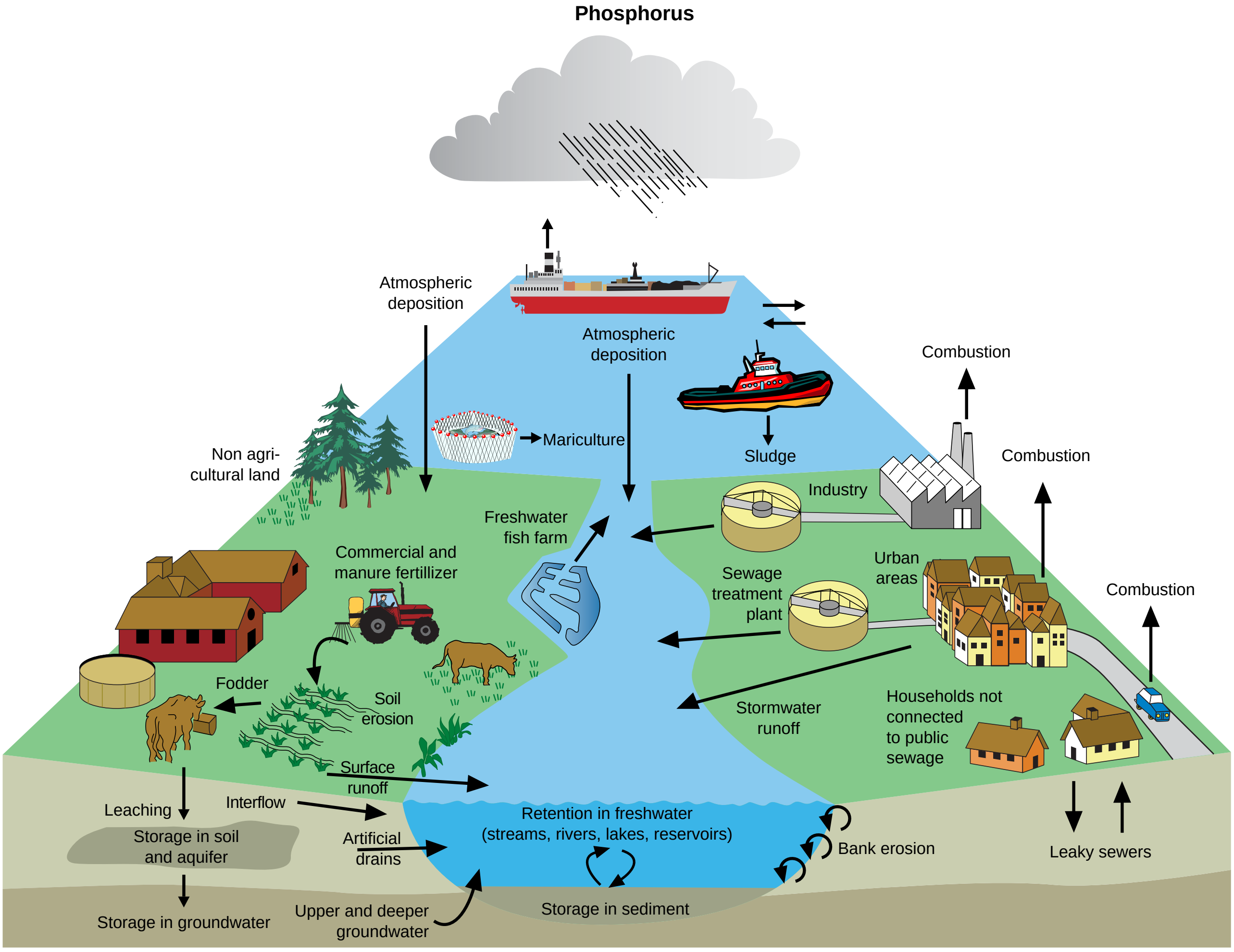


Figure 1 b: Phosphorus sources and pathways. Diffuse sources to the left and point sources to the right.

3.6 Explanation of terms:

Land cover: Main land categories, such as forest, grassland and arable land.

Unmanaged land: Land which is not directly managed, such as via cultivation and harvesting practices, fertilisation, grazing, or manure applications.

Natural background losses: Nitrogen and phosphorus losses that would occur from unpaved areas if they were unaffected by human activities (except anthropogenic atmospheric deposition). This includes losses from unmanaged land and the part of the losses from managed land that would occur irrespective of anthropogenic activities (e.g. agriculture).

Direct atmospheric deposition**:** Direct deposition of anthropogenic and natural originated nitrogen and phosphorus from the atmosphere onto inland surface waters.

Year specific losses: The actual losses of nitrogen and phosphorus for a specific year, influenced by the weather conditions for that year, and the current land use and agricultural practices.

Normalised annual losses: Annual nitrogen and phosphorus losses standardised using either long-term weather data (e.g. 30 years) or weather data for a reference year.

Surface runoff/soil erosion**:** Direct losses of dissolved, organic and particulate associated (erosion) nitrogen and phosphorus from the land surface to primary surface water recipients.

Root zone losses: nitrogen and phosphorus leached from the root zone by pathways other than surface runoff/erosion.

Tile drains: artificial subsurface drainage created using pipes or similar constructions.

Interflow losses: losses of nitrogen and phosphorus in the vadose zone.

Groundwater losses: losses of nitrogen and phosphorus to/from upper and deeper groundwater zones.

***Primary surface waters recipient*:** The open water system to which diffuse inputs of nitrogen and phosphorus from the surrounding catchment and/or the atmosphere arrive through different hydrological pathways.

***Mineral balance*:** The difference, at any scale, between input and output of nitrogen and phosphorus in agriculture, either by applying a 'farm gate level approach' or a 'field level (soil surface) approach'.

4. Approaches to quantify atmospheric deposition to inland surface waters

4.1 Direct atmospheric deposition of nitrogen on inland surface waters may represent an important input and should be quantified. The atmospheric deposition of nitrogen on land is included when quantifying diffuse nitrogen losses reaching the primary surface water recipients via the surrounding catchment-related pathways (Figures 1a and 1b). Atmospheric deposition of phosphorus should be considered if the source is of significant importance, such as in areas where lakes constitute a major part of the catchment.

4.2 National atmospheric deposition rates of nitrogen and phosphorous (partly) are obtained by monitoring, or by monitoring combined with emission and dispersion modelling. Appropriate wet and dry deposition rates should be multiplied by the area of inland surface waters (e.g. rivers, lakes, reservoirs). The approach used should be described by the Contracting Party.

4.3 EMEP can provide regional and national nitrogen deposition rates based on national monitoring results (emission and deposition) combined with a common modelling approach for Europe and the North Atlantic. The quantification of the deposition of phosphorus is not, at present part of the EMEP programme. Further information on the EMEP programme and results may be obtained from the website http://www.emep.int and are also contained in the OSPAR document "Atmospheric nitrogen in the OSPAR convention area and agreed international reduction measures" (OSPAR publication number 2005/232).

5. Approaches to quantify natural background losses

5.1 Procedures for quantification of losses of nitrogen and phosphorous from natural background sources into inland surface waters are described below. Natural background losses cover nitrogen and phosphorus losses that would occur from unpaved areas if they were unaffected by human activities (except anthropogenic atmospheric deposition). This includes losses from unmanaged land and the part of the losses from managed land that would occur irrespective of anthropogenic activities (e.g. agriculture).

5.2 This means that the natural background losses are a part of the diffuse losses. The natural background losses consist of the pristine biogenic nutrient losses and the elevated nutrient losses caused by distant anthropogenic impacts such as the prevailing atmospheric deposition (especially of nitrogen), wind drift of phosphorus-rich material etc.

5.3 In many cases nutrient losses from unmanaged land will be the same as natural background losses. Unmanaged land areas include:

- unmanaged forest and woodlands;
- unmanaged heathland;
- scrub land;
- deserts;
- unmanaged bogs, wet meadows and wetlands;
- abandoned agricultural land.

5.4 The natural background losses can be estimated using two different approaches or a combination of these approaches:

- Monitoring of small unmanaged catchment areas without any point sources;
- Monitoring of groundwater concentrations of phosphorus where these have not been influenced by human activity;
- Use of calibrated nutrient pollution models.

The use of results from defining reference conditions under the Water Framework Directive will assist in this regard.

5.5 Natural background losses of nutrients are monitored in several countries and modelled in others (Table 1). The estimates are obtained from forested catchment areas and/or catchment areas with very low human impact (with the exception of the impact of atmospheric deposition). For Denmark, the results are the average of median monitored values for 15 years (1989-2003) ±2 times standard error (corresponding to the 95% confidence interval) in seven small catchment without or with very low human activities. For Norway the estimates are partly based on monitored data from several years and partly on research projects. The Dutch data on losses from agriculture include natural background losses. It is difficult to distinguish between natural background part and the rest. The only data the Netherlands could provide were data on losses from land with only natural land use, and were obtained by model calculations. These data concern the year 2000 and can only be considered as a rough indication of natural background losses. For other countries, the figures given are related to the period 1990-2000.

Table 1: Examples of annual natural background losses and flow-weighted concentrations of nutrients as reported by Contracting Parties.

Country	Total nitrogen in kg/ha	Total nitrogen in mg/l	Total phosphorus in kg/ha	Total phosphorus in mg/l	Discharge in $l/(s \cdot km^2)$
Belgium					
Denmark	2.23 ± 0.55	1.43 ± 0.11	0.072 ± 0.01	0.049 ± 0.004	5.67 ± 0.43
Finland	0.7 – 2.0		0.03 – 0.7		
France					
Germany	1.23	0.733	0.061	0.036	
Ireland					
Netherlands					
• **clay soil**	19.8		1.01		
• **sand**	8.6		0.40		
• **peat**	15.1		1.05		
Norway					6 – 130
• **mountains**	0.02 – 1.23	0.05 – 0.3	0.005 – 0.252	0.001 – 0.008	
• **forest**	0.01 – 1.64	0.05 – 0.4	0.009 – 0.205	0.001 – 0.006	
Portugal					
Spain					
Sweden	1.0 – 13	0.1 – 2.8	0.03 – 0.25	0.003 – 0.045	4.5 – 30
United Kingdom					

6. Approaches to quantify losses from non-agricultural managed land

6.1 Losses from non-agricultural managed land include:

- managed forest;
- managed heathland;
- other land-use categories not included as agricultural land or unmanaged land.

6.2 In principle a forest or heathland is managed as soon as it is regulated by human activity. For practical reasons at least one of the following activities should be ongoing:

- planting, harvesting, or burning;
- application of fertiliser and/or manure;
- major soil activities (ploughing, new tiles or ditches etc.);
- animal grazing.

6.3 The quantification procedures for phosphorus and nitrogen losses from non-agricultural managed land are in principle the same as for agricultural land and should use appropriate monitoring (see Section 5) and/or modelling (Section 7) approaches.

7. Approaches to quantify nutrient losses from agricultural land

7.1 Introduction

7.1.1 The factors affecting losses of nitrogen and phosphorus from land to inland surface waters are highly complex including a range of processes and pathways, as shown for example in Figures 1a and 1b. It is necessary to use models as it is not possible to measure the contribution of each different diffuse source. As a result, a large number of models have been developed to quantify nutrient losses to inland surface waters, and these models are used for policy support purposes.

7.1.2 The source-oriented approach (SOA) is used to estimate annual diffuse losses of nutrients from land to inland surface waters, which is the task of and will be described in detail in this HARP-NUT Guideline 6. The load-oriented approach (LOA) (riverine load apportionment as described in HARP-NUT Guideline 8) is used to estimate the water-borne annual load of nutrients to the maritime area (see also HARP-NUT Guideline 1) by using the measured riverine flow or load and partition this between different nutrient inputs to the river system. This LOA is also used by some Contracting Parties to calculate nutrient losses from diffuse sources to surface waters. In contrast, many methods are source-oriented, which means they quantify the losses from diffuse sources independently of the measured riverine load using input data such as precipitation, fertiliser and manure inputs to different land areas. By taking into account, where appropriate, the retention processes of nitrogen and phosphorus in river systems and other removal processes (see HARP-NUT Guideline 1), it is possible to compare the aggregated nitrogen and phosphorus discharges/losses entering inland surface waters with the water-borne loads into the maritime area. Nitrogen and phosphorus retention in river systems represents the connecting link between the SOA and the LOA (Figure 2), but comparisons should be done with caution due to the high level of uncertainty in net estimates of in-river retention (see HARP-NUT Guideline 9). Guideline 9 considers only retention in inland surface waters. The source-oriented models used in the application of Guideline 6 include retention processes within the soil system, but not in the water system.

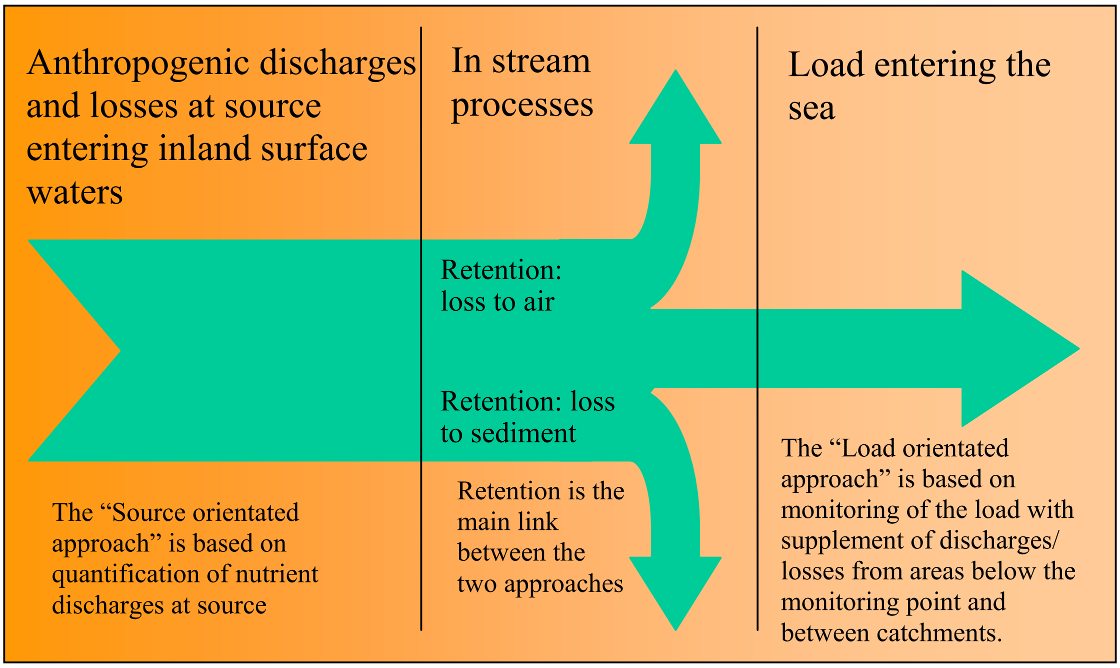


Figure 2. Illustration of in-stream processes (retention) in a river system representing the connecting link between the “Source Orientated Approach” and the “Load Orientated Approach”.

7.1.3 Subsequent sections provide further information on:

- Description and characterisation of existing models (different approaches and data requirements) (section 7.2);
- model selection, including the applicability of models under different circumstances (e.g. different catchment types, data availability) (section 7.3).

7.2 Description and characterisation of existing models

7.2.1 Several different types of quantification tools (models) for nutrient losses to river basins have been developed during the last decade within European countries. These quantification tools were established for different regions and different purposes. They differ in their complexity, their resolution in time and space, and data requirements (Figure 3). Data requirements for these models may include:

- weather or climate (precipitation, temperature, wind speed etc);
- land use;
- nutrient inputs (atmospheric deposition to land, fertiliser and manure applications, soil surface balance[3]);
- soil/plant physical and biochemical characteristics;
- landscape characteristics;
- surface water network (rivers, lakes and reservoirs etc).

[3] In the case of soil surface nutrient balances, guidance is available e.g. PARCOM Guidelines for Calculating Mineral Balances (reference number: 1995-02) or OECD National Soil Surface Nitrogen Balances 2001 (www.oecd.org/agr/env/indicators.htm)

.

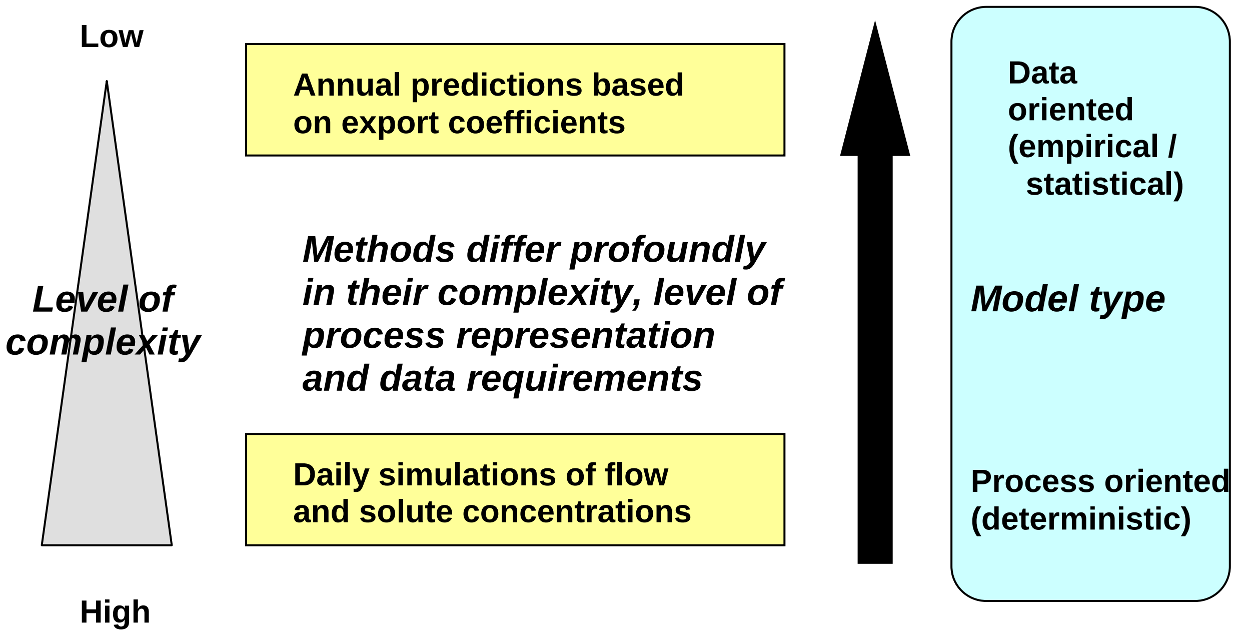


Figure 3. A general relation between the complexity of models (left), model type (right) and the generated output (Schoumans and Silgram, 2003).

7.2.2 A lack of transparency and comparability in the use of models for reporting diffuse nutrient losses to the maritime area, combined with the failure of OSPAR Contracting Parties to agree on previous versions of HARP-NUT Guideline 6 during the period 1996-2000, led to the development of EUROHARP, a project funded under the EC Fifth Framework Research Programme with 22 partners in 17 European countries which ran from 2002-2006. The overall objective of the EUROHARP work was (i) to provide end-users (national and international European environmental policy-makers) with a thorough scientific evaluation of eight contemporary quantification tools and their ability to estimate diffuse nutrient (nitrogen, phosphorus) losses to surface freshwater systems and coastal waters, and thereby facilitate the implementation of international measures with regard to eutrophication, and (ii) to develop an electronic decision support system (toolbox) for the identification of benchmarking methodologies with respect to both costs and benefits. The project included both the assessment of the performance of individual models and the applicability of the same models in catchments with different data availability and environmental condition throughout Europe. The project involved a detailed intercomparison of the abilities of a representative range of contemporary catchment-scale modelling approaches to quantify diffuse nutrient pollution losses from land to surface water systems (Figure 3). The development of HARP-NUT Guideline 6 has been largely based on the experiences, recommendations and conclusions from the EUROHARP project.

7.2.3 Summary descriptions of the nine models tested in EUROHARP are shown in **Annex 1**. The classification of these models is shown in Table 2 and **Annex 2**, and is included in Schoumans and Silgram (2003). Although the model performance results from EUROHARP are catchment and model specific, the principles of model and catchment characterisation, assessments of model suitability, the method of model selection and assessing model performance are universally applicable and are considered in this HARP-NUT guideline. The set of criteria used to characterise the EUROHARP models is presented below and can be applied to other models as well; this will improve transparency and assists in identifying the capabilities and limitations of different model approaches (and thereby assists in selecting the most suitable tools for application given a particular catchment and resource availability). A more detailed explanation of these criteria is included in **Annex 3** (which includes further two criteria).

Criteria for model characterisation

1. Original purpose/status and history of the model application (maturity);
2. Review of pathways and processes described by the quantification tools;
3. Scientific description of the processes involved;
4. Spatial resolution and discretisation (horizontal and vertical);
5. Temporal resolution and discretisation;
6. Forms of nutrient losses described by the quantification tool;
7. Data requirements;
8. Operational experience and skills requirements of users;
9. Participation in previous model evaluation studies; evidence of model performance;
10. Cost indication (based on work load to set up and apply the quantification tool);
11. Capability to evaluate nutrient and watershed management strategies (scenario analysis);
12. Applicability to catchments used for OSPAR reporting.

Table 2. Quantification tools (models) evaluated by EUROHARP

Model no.	Name of the tool	Model approach*
1	NL-CAT (ANIMO/SWAP/SWQN/SWQL)	SOA
2	REALTA	C
3	N-LES CAT	SOA
4	MONERIS	SOA
5	TRK (SOILNDB/HBV-N)	SOA
6	SWAT	SOA
7	EveNFlow	SOA
8	NOPOLU	C

* Source oriented approach (SOA), or combined (C). "C" refers to models which require the measured water flow from different sources as input (in contrast to SOA models which simulate water flow explicitly based on input precipitation)

7.2.4 Models may either be readily available upon request to the model owner (see Annex 1); or available subject to appropriate software licensing; or may currently only be used by the model developers (and may therefore lack a user manual/support documentation to facilitate third party use).

7.3 Model selection

7.3.1 This section provides guidance for the selection of suitable models for use in reporting annual loads of N and P for specific years (1985, 1995, 2000) e.g. as required in the implementation reporting format for PARCOM Recommendation 88/2. The selection of a particular model for OSPAR reporting purposes should be considered on a case by case basis as no single model is likely to be the most appropriate for all purposes and catchment types. Model selection will be driven by the purpose (i.e. reporting requirements of specific OSPAR recommendations) together with a suite of factors including catchment type, models' suitability for use in catchments of that type, whether other related modelling tasks are planned (e.g. scenarios to explore effectiveness of mitigation options), resource availability (data, time, funding), implementation issues and evidence of satisfactory model performance. The flow chart below includes the main elements to be taken into account when faced with the challenge of identifying suitable models for a particular situation.

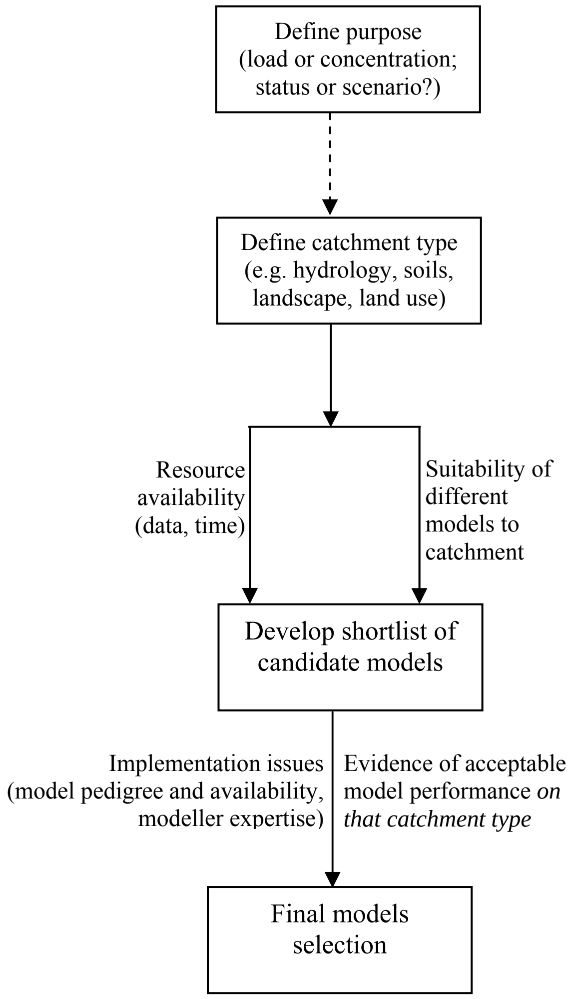


Figure 4. Main elements to be taken into account when faced with the challenge of identifying suitable models for a particular situation.

7.3.2 For selection of the most appropriate model, the following information is needed in general:

- Model characterisation (Section 7.2) and model suitability (See below);
- Characteristics of the catchment types for reporting (See below);
- Resource availability (time & cost, input data availability, modeller experience) (See below);
- Evidence of model pedigree and satisfactory performance (See below).

7.3.3 Specific questions to consider include:

- Is a model consistent with OSPAR reporting requirements?
- Is a model responsive to changes in land and/or water management practices (e.g. OSPAR 50% reduction target)?
- Is the model already applied for land and/or water management practices in the past and was this application successful?
- Is the model's spatial and temporal resolution appropriate for OSPAR reporting? OSPAR reporting requires annual loads, so a subannual or annual timestep model is appropriate for this purpose. The chosen model needs to provide estimates of diffuse nutrient pollution from agricultural land within a catchment area to the river system, and therefore should be capable of operating at (or upscaling to) catchment and/or national scale.

7.3.4 Further information is contained in a EUROHARP software "toolbox" which provides additional evidence to support end-users in evaluating models and provides guidance on model selection (see http://www.euroharp.org/toolbox). A screenshot of this EUROHARP Toolbox is included in **Annex 4**.

7.3.5 Only eight models were studied within this project, but a number of other models exist. One of the conclusions from EUROHARP was that it is not possible to recommend one single model. The principles and processes developed for model selection in the EUROHARP are generally applicable to all catchment models for use for OSPAR reporting purposes. It is not as yet possible to unequivocally recommend a single nutrient model suitable for all catchments. Instead, the benefit of ensemble modelling, applying two models for N and three models for P on the same catchment, should be explored. There is no obvious reason for using the most complex models (more resource and time demanding). There is no specific type of model for all types of conditions.

Characterisation of catchments for OSPAR reporting

7.3.6 It is important to characterise the catchments to ensure that only models capable of adequately representing such environments are used for OSPAR reporting (as some models lack the ability to represent certain environmental conditions) (Table 3).

Table 3: Listing of the overall input data requirements for the eight different quantification tools (models) applied under the EUROHARP project. R: Required information; O: Optional information; N: Not required information.

	NL-CAT	REALTA	N-LES-CAT	MONERIS	TRK	SWAT	Even Flow	NOPOLU
Topography/DTM	R	R	N	N	R	R	R	R
River network	R	R	N	R	R	R	R	R
Overall catchment information on fertiliser, manure, point sources	O	R	N	N	R	O	R	R
Land cover map	R	R	R	N	R	R	N	R
Land management information	R	N	R	N	R	R	R	R
Soil textural map	R	R	R	R	R	R	R	R
Soil hydrogeological map	N	R	N	R	N	N	N	N
Aquifer information	N	N	N	N	N	N	R	N
Water management information	R	N	N	R	N	R	R	N
Administrative census information on fertiliser, manure, livestock, etc.	N	N	R	R	R	N	R	R
Point source location map	R	R	R	R	R	R	R	R
Weather monitoring stations	R	N	R	R	R	R	R	R
Deposition stations map	R	N		R	R	R	N	N
Surface water monitoring map	N	R	R	R	R	N	R	R
Ground water monitoring map	O	N	N	O	O	O	N	N
Soil loss information	N	N	N	R	R	N	N	N
Longer-term runoff monitoring stations	N	N	N	O	N	N	N	N

7.3.7 Catchments can be classified based on their prevailing environmental conditions. This includes consideration of specific climatic, hydrological, and landscape conditions which may not be represented adequately by some models. For example:

- Does the reported catchment have frozen soils?
- Does the reported catchment have a shallow groundwater table?
- Are the full range of soils, hydrological conditions and land uses in the catchment of interest able to be represented by a particular model?

Model suitability

7.3.8 Table 4 provides an example matrix showing the outcome of an evaluation of model suitability for application to different catchment types (based on EUROHARP results): the same principle can be applied to other models and catchments. The categories for climate, slope, drainage, soil conditions and agricultural intensity are derived from those proposed by Schoumans and Silgram (2003).

Table 4. Example overview of suitability/applicability of quantification tools to different environmental conditions across Europe

Climatic condition: (N)orthern Europe (NO, SE, FI); (W)est Europe (UK, IE, DK, NL, BE, FR); (M)id Europe (DE, AT, CH, CZ); (S)southern Europe (ES, IT, GR); East and (S)outh (E)astern Europe (HU, SK, SI, RO, HR, MK, BG, ME); (N)orth (E)astern Europe (PL, EE, LT, LV)

Landscape: Mountainous slope (M) > 10%; Hilly (H) 2-10%; Plains (P) 0-2%, Deltas (D); Riparian zone (R) (wetlands etc.)
Hydrological flow pathways: Runoff (R); Subsurface Drainage (SS); Artificial drainage (AD); Deep Groundwater flow (DG),
Agricultural activity: Agricultural intensity (mineral fertiliser plus waste from housed and grazed animals):
Intensive (I) (>500 kg N/ha/y and/or >25 kg P/ha/y); Moderate (M) (200-500 kg N/ha/y and/or 5-25 kg P/ha/y);
Extensive (E) (<200 kg N/ha/y and/or <5 kg P/ha/y)
Soil conditions Unstructured Deep soils (UD); Unstructured Shallow soils (e.g. <1 m) (US); Structured soils (e.g. clay and peat) (S)

	Climatic Conditions						Landscape					Hydrological flow pathways				Agricultural activity			Soil conditions		
	N	W	M	S	SE	NE	M	H	P	D	R	R	SS	AD	DG	I	M	E	UD	US	S
NLCAT – N	+/-	++	++	+/-	+	+/-	+/-	+	++	++	+	+/-	++	++	++	++	++	+	++	+	++
NLCAT – P	+/-	++	++	+/-	+	+/-	+/-	+	++	++	+	+/-	++	++	++	++	++	+	++	+	++
SWAT – N	+/-	++	++	+	+	+/-	+/-	++	+	+/-	+	++	++	++	++	++	++	++	++	+	++
SWAT – P	+/-	++	++	+	+	+/-	+/-	++	+	+/-	+	++	++	++	++	++	++	++	++	+	++
TRK – N	++	++	++	+/-	+/-	++	+/-	++	++	+/-	+/-	+/-	++	++	+	++	++	++	++	++	++
TRK – P	+	+/-	+/-	+/-	+/-	+/-	+/-	+	+	+/-	+/-	+	++	++	+	-	+/-	-	++	++	++
MONERIS – N	+/-	++	++	+	+	+	+	++	++	+	+	++	++	++	+/-	++	++	++	+	+	+
MONERIS – P	+/-	++	+	+	+	+	+	+	+	+	+	+	+	+	+/-	+	++	+	+	+	+
EVENFLOW N	+/-	+	+	+/-	+	+	+	+	+	-	-	+	+	+	+/-	++	++	+/-	+	+	+
N-LES CAT- N	+/-	++	+	+/-	+/-	+	+/-	+	+	+/-	+/-	-	-	-	-	++	++	+	+	+	+/-
NOPOLU – N	+/-	+	+	+	+	+	+/-	+	+	+	+	+	+	+	+	+	+	+/-	+	+	+
NOPOLU – P	+/-	+	+	+	+	+	+/-	+	+	+	+	+	+	+	+	+	+	+/-	+	+	+
REALTA – P	-	++	+/-	+/-	+/-	-	+/-	++	–	+/-	-	++	–	–	–	++	++	++	+	+	+

++ = very suitable + = suitable
+/- = uncertain – = not suitable/applicable

Resource availability

7.3.9 The availability of resources should be considered in terms of time, money and demonstrable expertise of the model user with the chosen model. More complex models tend to have more demanding resource requirements (data, time, money), but will include a level of process detail which is likely to enable them to be more responsive to changes in management practices. For example, introduction of mitigation controls on nutrient pollution through targeted agri-environment schemes, Action Programmes, and other catchment management strategies (e.g. nutrient management, water management and land use change). Consideration of these factors, together with the points made previously concerning catchment classification and model characterisation, should enable a suitable catchment scale diffuse nutrient pollution model to be identified. The same principles can also be applied to selecting models for other purposes.

Model performance

7.3.10 The capability of nutrient models to predict annual and subannual flow and nutrient losses (nitrogen and phosphorus) at catchment scale was assessed using different performance statistics shown in **Annex 6**. The evaluation of annual predictions were conducted on model performance in three core catchments: the Vansjø-Hobøl (Norway), the Yorkshire Ouse (England) and the Enza (Italy) where all nine models were applied. The models were evaluated by comparing simulated annual flow and nutrient loads with measured values for a validation period of 5 years. Four statistics have been applied for this purpose: the root mean squared error (RMSE), the mean absolute error (MAE), the mean error (ME), and Nash-Sutcliffe's model efficiency (NS) which are all briefly described in Annex 6.

7.3.11 The annual results show that in most cases all models are able to predict the calculated annual flow and nutrient loads quite well (**Annex 7**). Generally the performance of the models seems to be better in the two catchments situated in the north-western part of Europe (Norway and England) than in the southern European catchment (Italian) (Annex 7). Moreover, the capability of the models to simulate phosphorus seems to be poorer than in the case of nitrogen.

7.3.12 Of the nine methodologies evaluated in the EUROHARP project, four were capable of predicting flows, concentrations and loads at a subannual timestep: EveNFlow, SWAT, TRK-N, and NL-CAT. The ability of models to predict nutrient losses at sub-annual timesteps is significant for the evaluation of policy measures, as it enables the assessment of trends and the frequency of exceedance of water quality parameter thresholds to be predicted. Furthermore, subannual predictions permit assessments of seasonality in predicted concentrations, which is a critical factor when determining a water course's susceptibility to eutrophic conditions and the impact on water quality of management practices such as abstractions for irrigation or drinking water purposes.

7.3.13 Results from this study have indicated that four out of a total of nine models considered are generally capable of adequately simulating flows, concentrations and loads on a daily basis (**Annex 8**). However, individual model performance varied according to the output and catchment concerned, and was strongly influenced by the availability of input datasets and the modeller's familiarity with the hydrogeoclimatic conditions in the area to be studied, as well as by the selected model itself (Annex 8).

7.3.14 Generally, model simulations in the Norwegian catchment were strongly influenced by three key factors. The first was the modeller's assumptions regarding the physical, hydraulic and biochemical characteristics attributed to soils in forested areas, as no spatial data were available for these areas which represent over 80% of the catchment's land surface area. The second factor was the models' capability to represent the build-up and depletion of snow during the winter and spring periods respectively, which have a profound influence on the hydrological regime in this catchment. The final factor was the large effect of the lake immediately above the main catchment outlet, due to its effect both on flow dynamics and on the net retention and release of nutrients.

7.3.15 For the English catchment, simulations of river concentrations in this catchment were hindered by the absence of total nitrogen and total phosphorus data. Particular care is required when dealing with catchments with pronounced spatial gradients in precipitation, combined with the diverse range in soils (including peats) and land uses within the catchment posed amongst the greatest challenges to achieving satisfactory model performance.

7.3.16 In the Enza catchment, the relatively poor quality of the original input meteorological dataset (both in time and in space) introduced additional uncertainty in model applications to this catchment, as modellers used different approaches (e.g. rainfall interpolation algorithms) to produce the spatial grid of input data required by their models. This inevitably introduced a confounding factor which places some limits on our ability to assess model performance in this catchment, and explains why the Modelling Efficiency statistic was typically smallest for applications to this catchment.

7.3.17 The EUROHARP assessment of model performance has highlighted some limitations in the formulation of certain models, such as the challenge of modelling catchments with significant lake areas, as well as the differing solutions developed by modellers when confronted by limited input datasets. Overall, no single model appeared consistently superior in its ability to represent the variations in observed flows, concentrations and loads in all three test catchments, which represented a north-south gradient in European climate.

7.3.18 An overall assessment of the nine models applied in three EUROHARP core catchments is shown in **Annex 9**. The assessment is not intended to be quantitative but shows an evaluation of the overall capability of the different models for a quick guidance of end-users in their choice of model. All the results of the EUROHARP project with guidance for choice of model in different regions of Europe is shown in the EUROHARP Tool Box (http://www.euroharp.org/toolbox) (see Annex 4).

7.3.19 The suitability of the quantification tools for exploring scenario analyses was considered in a review based on a comprehensive description of the models. **Annex 10** shows the results of the qualitative assessment conducted concerning the potential suitability of different models for three different types of scenario analysis. The assessment focused on the potential sensitivity of different models to different management strategies, land use changes and water measures. With respect to scenarios dealing with the nutrient management strategies, it is clear that those models that include agricultural practices such as crop-soil input, manuring, fertilisation, ploughing etc, will have the potential ability to predict the impact of land management strategies on nutrient losses to surface waters due to changes in the amounts and timings of applications of nutrient input related to fertiliser and manure. Most models are able to predict change in nutrient losses due to changes in fertiliser application or livestock numbers. However, the simpler models may not be able to consider some changes in management and therefore may have more limited potential for scenario investigations predicting the impact of land management changes on nutrient loss to surface waters.

7.3.20 The average costs measured as number of man-days of applying the nine different models in the three EUROHARP catchments is shown in **Annex 11**. Assessment of different steps in the model procedures were conducted by each modeller by filling in a log-book for each catchment. It should be emphazised that some of the models simulate both nitrogen and phosphorus, whereas others only simulate nitrogen (see Annex 9. Generally, the models being low in complexity and empirically oriented like SA, REALTA and MONERIS are less costly to apply than fully dynamic and process oriented models as NL_CAT and SWAT.

8. Normalisation in relation to model input and output data

8.1 The quantification tools for diffuse losses of phosphorus and nitrogen often require statistical data on land use, land cover and agricultural census. This information should be based on the most recent available year(s) and should cover the same years for which diffuse losses are estimated.

8.2 There are typically large annual variations in diffuse nitrogen and phosphorus losses due to prevailing weather conditions. Therefore, information both on nitrogen and phosphorus losses during an individual (specific) year, and on nitrogen and phosphorus losses normalised either by using longer-term weather data (e.g. 30 years) or weather data for a reference year is helpful. The normalised nitrogen and phosphorus losses will be most suitable for determining the effect of measures to reduce diffuse losses. Year-specific data are important for the nitrogen and phosphorus load reconciliation method described in Guideline 1 and for evaluating impacts in inland surface waters.

8.3 The applied procedures for normalising data will depend on the approach and the availability of data within individual catchments. Some models include internal normalisation procedures as an integral part of their operation. Contracting Parties should therefore report on:

- Diffuse losses, using long term weather data, or weather data from a reference year; or
- Losses for an individual year.

8.4 Normalised data are more appropriate for OSPAR reporting and should be used wherever possible, together with descriptions of the method used. Examples of normalisation procedures used are given in **Annex 5**. Information on the quantification tools (models) used to provide estimates should also be reported. Guidance on normalisation procedures for riverine data is in HARP-NUT Guideline 7 “Quantification and reporting of the monitored riverine load of nitrogen and phosphorus, including flow normalisation procedures”.

9. Quality control

9.1 Although the specific details of model applications will differ depending on the particular model being applied, there are standard procedures which should be adopted in all model applications. For example, model version number and data inputs should be recorded and retained, and key (i.e. sensitive) parameters used in model applications should be documented and appropriately referenced (e.g. expert judgement, scientific literature, measurements etc). Further details of the requirements of Good Modelling Practice are available for model users at http://www.info.wau.nl/research%20projects/gmp.htm and www.HARMONIQUA.org.

9.2 There are, of course, significant uncertainties inherent in any system of assessing the contribution of diffuse nitrogen and phosphorus losses to surface waters, and these should be communicated to the end-user. The uncertainties in predictions from low and high complexity models may in fact be comparable – the residual process and parametric uncertainty is simply presented differently. For example, in a complex model this uncertainty is evident in the use of “default” parameter values, whereas in a less complex model the uncertainty is less transparent but is reflected in simpler representations of system processes and the lumping of model parameters.

9.3 As a routine quality control measure, model outputs should be checked against published literature and/or measured data and/or results from previous applications of other models relating to the catchment of interest, or other comparable catchment. Estimates of net retention in the river system may be included in the model structure or may need to be estimated independently and deducted from modelled loads in surface waters. Where results differ substantially from available measurements or published data, consideration should be given to investigating the likely cause.

9.4 Assuming weather conditions were not atypical, such an investigation might require, for example, a review of the model parameters – are they all appropriate for the selected catchment and can any be estimated with greater accuracy? Mismatches between measured and modelled data could be associated with poor estimates of retention (see HARP NUT Guideline 9 and EUROHARP NutRet software tool available for download from http://www.euroharp.org). Equally, it should be remembered that measurements carry their own intrinsic errors and uncertainties associated with sample storage, laboratory analysis and the typically infrequent sampling of river concentrations which can lead to inaccurate estimations of measured loads.

10. Reporting procedures

10.1 The diffuse losses of nitrogen and phosphorus should be reported as total nitrogen and phosphorus inputs to primary surface water recipients as a sum of all pathways, but distinguishing as much as possible between the following sources:

- losses from agricultural land (cf section 7)
- losses from non-agricultural managed land (cf section 6)
- natural background losses (cf section 5)
- atmospheric deposition to inland surface waters (cf section 4).

10.2 The reporting format presented in Section 12 should be used for reporting.

10.3 Normalised data should be presented in the table in section 12.1 – year specific data should be presented in the table in section 12.2. More information on normalisation is presented in section 8 and Annex 5, including recommendations on when to apply normalisation.

10.4 For transparency and to enable comparison of data, information should also be provided on the quantification tools used to produce the data. If a quantification tool is new or has not been characterised by EUROHARP, Contracting Parties are invited to provide information in table 12.3 on the characterisation of the tool as described in section 7.4 and Annexes 2 and 3. In addition, you are invited to provide information in Table 12.4 on quality control (cf section 9).

11. References

EUROHARP Tool Box: (http://www.euroharp.org/toolbox).

EUROHARP Report 1-2003: Schoumans, O.F. & Silgram, M. (eds.), 2003. "Review and literature evaluation of quantification tools for the assessment of nutrient losses at catchment scale. EUROHARP report 1-2003, NIVA report SNO 4739-2003, ISBN 82-557-4411-5, Oslo, Norway, 120 pp.

EUROHARP Report 8-2004: Silgram, M., & Schoumans, O.F. (eds.), 2004. Modelling approaches: Model parameterisation, calibration and performance assessment methods in the EUROHARP project. EUROHARP report 8-2004, NIVA report SNO 4740-2003, ISBN: 82-577-4491-3, Oslo, Norway, 18 pp.

S.G. Anthony, M. Silgram, A.L. Collins, J. Strőmqvist, F. Bouraou2, O. Schoumans, A. Lo Porto, P. Groenendijk, B. Arheimer, H. Ejhed, and M. Mimikou, (submitted): Evaluation of diffuse pollution model applications in EUROHARP catchments with limited data, EUROHARP Special Issue.

O.F. Schoumans, M. Silgram, P. Groenendijk, F. Bouraoui, H.E. Andersen, B. Kronvang, H. Behrendt, B. Arheimer, H. Johnsson, Y. Panagopoulos, M. Mimikou, A. Lo Porto, H. Reisser, G. Le Gall and S.G. Anthony (submitted). Description of nine nutrient loss quantification tools: capabilities and suitability based on their characteristics, EUROHARP Special Issue.

O.F. Schoumans, M. Silgram, D.J.J. Walvoort, P. Groenendijk, F. Bouraoui, H.E. Andersen, A. Lo Porto, H. Reisser, G. Le Gall, S. Anthony, B. Arheimer, H. Johnsson, Y. Panagopoulos, M. Mimikou, U. Zweynert, H. Behrendt and S. Borgvang (submitted). Evaluation of the performance of nine quantification tools to assess diffuse annual nutrient losses from agricultural land, EUROHARP Special Issue.

M. Silgram, O. Schoumans, D. Walvoort, S.G. Anthony, B. Arheimer, F. Bouraoui, P. Gronondijk, A. Lo Porto, and Y. Panagopoulos(submitted. Subannual models for catchment management: evaluating model performance on three test catchments. EUROHARP Special Issue.

B. Kronvang, H. Behrendt, H.E. Andersen, B. Arheimer, A. Barr, S.A. Borgvang, F. Bouraoui, K. Granlund, B. Grizzetti, P. Groenendijk, E. Schwaiger, J. Hejzlar, L. Hoffman, H. Johnsson, Y. Panagopoulos, A. Lo 0Porto, H. Reisser, O. Schoumans, S. Anthony, M. Silgram, M. Venohr and S.E. Larsen (submitted). Ensemble modelling of nutrient loads and nutrient load partitioning in 17 European catchments. EUROHARP Special Issue.

F. Bouraoui, B. Grizzetti, G. Adelsköld, H. Behrendt, L. Fawcett, S. Gómez, K Granlund, L. Hoffmann, B. Kronvang, Sigrun Kværnø, A. Lázár, M Mimikou, G. Passarella, P. Panagos, H. Reisser, B. Schwarzl, C. Siderius, A.S.Sileika, R. Sugrue, M. VanLiedekerke, J. Zaloudik (submitted). Basin characteristics and nutrient losses: the Euroharp catchment network perspective. EUROHARP Special Issue.

OSPAR 2005. Atmospheric nitrogen in the OSPAR convention area and agreed international reduction measures. Publication number 232.

OSPAR 1995. PARCOM Guidelines for Calculating Mineral Balances. Reference number: 1995-02.

OECD 2001. National Soil Surface Nitrogen Balances. www.oecd.org/agr/env/indicators.htm

12. Reporting formats

12.1 Nitrogen and phosphorus inputs to primary surface water on the basis of normalised data

	Total phosphorus losses (tonnes/year) per catchment					Total nitrogen losses (tonnes/year) per catchment					Description of quantification tools used [4]
	Catchment 1 Coastal areas	Catchment 1 Inland waters		Catchment n		Catchment 1 Coastal areas	Catchment 1 Inland waters		Catchment n		
	Direct	Moni tored	Unmonit ored			Direct	Moni tored	Unmonit ored			
Agricultural land (section 7)											
Non-agricultural managed land (section 6)											
Direct atmospheric deposition on inland water surfaces (section 4)											
Total anthropogenic sources per catchment											
Natural background losses of nitrogen and phosphorus constitute (section 5)[5]											
Total national figures											

To the Summary Reporting Format in Guideline 1	***To the Implementation Format in Guideline 1***

[4] if not characterised by EUROHARP, please complete table 12.3

[5] The figures on natural losses could be given either by catchment or as total national figures within the OSPAR Convention area.

12.2 Nitrogen and phosphorus inputs to primary surface water on the basis of year specific data

	Total phosphorus losses (tonnes/year) per catchment					Total nitrogen losses (tonnes/year) per catchment					Description of quantification tools used [6]
	Catchment 1 Coastal areas	Catchment 1 Inland waters		Catchment n		Catchment 1 Coastal areas	Catchment 1 Inland waters		Catchment n		
	Direct	Moni tored	Unmonit ored			Direct	Moni tored	Unmonit ored			
Agricultural land (section 7)											
Non-agricultural managed land (section 6)											
Direct atmospheric deposition on inland water surfaces (section 4)											
Total anthropogenic sources per catchment											
Natural background losses of nitrogen and phosphorus constitute (section 5)*											
Total national figures											

To the Summary Reporting Format in Guideline 1

To the Implementation Format in Guideline 1

[6] if not characterised by EUROHARP, please complete table 12.3

Table 12.3 Information on new quantification tools, according to section 7.4 and Annexes 2 and 3

Table 12.4 Information on quality control, according to section 9

Annexes to the HARP-NUT Guideline 6

Annex 1. Summary of description of models and assessment tools

The summaries of the following models and assessment tools are based on the summaries published on the EUROHARP website.

ANIMO (Alterra, the Netherlands)

Model name	Agricultural Nutrient Model
Acronym	ANIMO
Ref. Model description	Groenendijk, P. and J.G. Kroes, 1999. *Modelling the nitrogen and phosphorus leaching to groundwater and surface water with ANIMO 3.5.* Report 144. Winand Staring Centre, Wageningen Rijtema, P.E., P. Groenendijk and J.G. Kroes, 1999. *Environmental impact of land use in rural regions. The development, validation and application of model tools for management and policy analysis.* Series on environmental science and management, vol. 1. Imperial College Press, London. Schoumans, O.F. and P. Groenendijk, 2000. *Modelling Soil Phosphorus Levels and Phosphorus Leaching fron Agricultural Land in the Netherlands.* J. Environ. Qual. 29:111-116. Rijtema, P.E. & J.G. Kroes, 1991: *Some results of nitrogen simulations with the model ANIMO*. Fertilizer Research 27: 189-198 Vereecken, H., E.J. Jansen, M.J.D. Hack-ten Broecke, M. Swerts, R. Engelke, S. Fabrewitz & S. Hansen, 1991: *Comparison of simulation results of five nitrogen models using different datasets.* In: Soil and Groundwater Research Report II, Nitrate in Soils, Final report of contracts EV4V-0098- NL and EV4V-00107-C, Commission of the European Communities.
Ref. Users guide	Kroes, J.G. and J. Roelsma, 1997. ANIMO 3.5 *User's guide for the ANIMO version 3.5 nutrient leaching. model Technical Document* 46 Winand Staring Centre, Wageningen.
Main contact	Ir. P. Groenendijk P.O.Box 47 NL-6700 AA Wageningen + 31 317 486 434 piet.groenendijk@wur.nl
Alternative contact	Ing. L.V. Renaud P.O.Box 47 NL-6700 AA Wageningen + 31 317 486 454 Leo.Renaud@wur.nl
Objectives	Simulation of nutrient losses to the environment, with an emphasis on nitrogen and phosphorus leaching to groundwater and surface water systems, as influenced by: - soil type and climate - fertilisation - agricultural practise

	- water management Currently, the model is primarily used for the ex-ante evaluation of fertilisation policy and legislation at regional and national scale. The ANIMO model aims to quantify the relation between fertilization level, soil management and the leaching of nutrients to groundwater and surface water systems for a wide range of soil types and different hydrological conditions.
Short description of the model in words	The model is a functional model incorporating simplified formulations of processes. Five leaching substances have been distinguished: three soluble nitrogen substances (nitrate-N, ammonium-N, dissolved organic-N) and two soluble phosphorus substances (mineral-P and dissolved organic-P). The mass conservation and transport equation (CTE) is solved for these species individually. Leaching of dissolved organic matter results from additions and dissolution processes in the carbon cycle (fig. 3). Four organic substances are distinguished: 1) fresh organic matter originating from crop residues and the organic manure; 2) root exudates, excreted by living roots and dead root cells discarded by plants; 3) dissolved organic matter; 4) humus, a lumped pool consisting of dead soil organic matter or living biomass. The input of fresh organic matter to the soil system occurs by additions of manure, root materials, grazing and harvest losses and any other organic materials defined by the model user. Decomposition of fresh organic materials results in dissimilation of organic carbon, solubilization and transformation to the humus/biomass pool. Decomposition of dissolved organic compounds results in dissimilation and transformation to the humus/biomass pool. The humus/biomass pool decomposes to a residual fraction, accompanied by partial dissimilation of these residues. This residual material has been lumped with the humus/biomass pool, so only nett dissimilation of this pool has been taken into consideration. Since the nitrogen and the organic phosphorus behaviour in soil is closely related to the organic matter transformations, organic-N and organic-P processes are described analogous to the carbon cycle.
Conceptual boundary conditions (e.g. root zone, ditch, river)	Top boundary: interface between crop/vegetation and atmosphere. The simulation core includes a simple description of the crop. Bottom boundary: a user defined depth in the soil (e.g. 10 or 20 m below soil surface). The bottom boundary is defined according to hydrological circumstances. (deep aquifers, shallow bedrock formations, ..). Lateral boundary: the interface between the soil system and the surface water system. If leaching of a single field plot is simulated, then only the field ditches and field drains act as a lateral boundary. But when the load on the surface waters in a subcatchment is simulated by the model, the whole suite of existing surface waters act as the lateral boundary.
Main processes implemented	**Organic transformations** Fresh organic materials and dissolved organic matter are applied as instantaneous pulse-type doses. The organic part of the applied substance is divided over fresh organic matter and dissolved organic matter. Dry matter production of arable crops is defined as input to the ANIMO model, but for dry matter production and nutrient uptake of grassland the model comprises a dynamic sub-model. In this sub-model grassroots die continuously throughout the year.

	Decomposition of fresh organic materials results in dissimilation of organic carbon, solubilization and transformation to the humus/biomass pool. Decomposition of dissolved organic compounds results in dissimilation and transformation to the humus/biomass pool. The humus/biomass pool decomposes to a residual fraction, accompanied by partial dissimilation of these residues. This residual material has been lumped with the humus/biomass pool, so only net dissimilation of this pool has been taken into consideration.

Realta (KMM, Ireland)

Model Name	Réalta The Irish Phosphorus Model
References	Kirk McClure Morton (2001). The Lough Derg and Lough Ree Catchment Monitoring and Management System. Final Report. Magette WL (1998). Factors affecting losses of nutrients from agricultural systems and delivery to water resources. Draft Guidelines for Nutrient Use in Intensive Agricultural Enterprises, Teagasc.
Contacts	**Main Contact** Dr Alan Barr Kirk McClure Morton 74 Boucher Road Belfast BT12 6RZ N Ireland Phone +44 2890 667914 e mail: alan.barr@kmm.co.uk **Alternative Contact** Ms Alison Murdock Kirk McClure Morton 74 Boucher Road Belfast BT12 6RZ N Ireland Phone +44 2890 667914 e mail: alison.murdock@kmm.co.uk
Objectives	- To identify potential agricultural risk areas at a River Basin District level. - To quantify phosphorus export rates from the River Basin District and its main subcatchments.
Model Description and Main Processes Implemented	A Geographical Information System (GIS) is used to investigate the relationship between a set of agricultural indicators and water pollution potential. Variation in both physical (land) characteristics and usage (management) practices are considered to influence the risk of phosphorus loss to surface waters. The factors considered in evaluating the potential for loss and transport of phosphorus from agricultural systems are as follows: (a) Runoff Risk to Surface Waters. The physical characteristics which influence the transport of phosphorus to surface waters: geology, soil type, slope and rainfall are combined in a runoff risk map. (b) Land use. (c) Soil Phosphorus Levels. (d) Mineral Fertiliser Loading. (e) Organic Fertiliser Loading (cattle, sheep). (f) Organic Fertiliser Loading (Intensive Agricultural Enterprises – pigs, poultry).

	Other factors that have a significant bearing on phosphorus loss from agriculture include farmyard condition and the management of land spreading activities. An equal bias for these factors is assumed across the River Basin District in the absence of quantitative information. However it is considered that the organic loading data in part reflects this variation in that greater volumes of manure are generated, stored and disposed of in areas of higher stocking density. **Development of the Potential Agricultural Risk Map** A ranking scheme is developed whereby each of the phosphorus loss indicators is subdivided into zones of relative risk, each of which has a numerical value for scoring purposes. The relative importance between factors is also represented by a further scoring system or 'weighting'. A 'score' or 'rank' for a given combination of factors affecting loss and transport of phosphorus is developed in two steps: 1. Multiply the weight of each factor by the relative risk associated with the magnitude of each factor; and 2. Sum all of the products derived in Step 1. The resulting composite map establishes the range of potential agricultural risk areas across the River Basin District. The ranking scheme developed for predominantly grassland catchments in Ireland is presented in Table 1. The total scores used to derive the potential risk classes are presented in Table 2. At present landuse data is only used to distinguish between agricultural and non-agricultural areas. Non-agricultural areas are excluded from the analysis. The potential agricultural risk map is updated once in every five years when agricultural statistics are made available from census data and/or national farm survey data. **Calibration of the Potential Agricultural Risk Map** The potential agricultural risk map is calibrated on an annual basis by the physical measurement of in-stream phosphorus loadings in selected agricultural areas. These physical measurement results are then extrapolated across each of the main subcatchments to enable the quantification of the annual phosphorus export rate from the River Basin Districts. The application of the model therefore requires a limited programme of physical in-stream measurements in small agricultural areas each year to take account of annual variations in hydrological conditions, farm management practices, and the associated impact on agricultural losses to water.
Boundary Conditions	The conceptual boundary of the model is the point at which the loss and transport of phosphorus is measured in-stream from predominantly agricultural areas. (Normally 10-30 km^2 in size).
Main Model Input Parameters	The main model input parameters, ranked in order of their importance (highest to lowest) are as follows: (i) Organic Fertiliser Loading; Land Use; Runoff Risk to Surface Waters. (ii) Soil Phosphorus Levels (iii) Mineral Fertiliser Loading

Validation Requirements	▪ Annual phosphorus export loading from the River Basin District and the main subcatchments, for a 2-3 year period; and ▪ Annual quantification of all point source discharges within the River Basin District.
Retention	In-stream and lake retention is not included in the model and must therefore be calculated independently.
Strengths	▪ The model has proven to work in Irish grassland catchments. ▪ Data requirements are available for most River Basin Districts. ▪ The model is relatively easy to use and is therefore cost effective.
Weaknesses	▪ In-stream and lake retention is not included. ▪ The model has not been tested outside Ireland. ▪ Additional calibration data will be required for land uses and agricultural practices not found in Ireland. ▪ A limited programme of physical in-stream measurements is required each year.
Temporal Resolution	The quantification of phosphorus export rates from the River Basin District can be updated annually.
Spatial Resolution	Agricultural data of the highest resolution available for the River Basin District should be used to maximize the performance of the model. In Ireland, agricultural statistics available at a District Electoral Division level (approximately 10-15 km^2) have been successfully used in conjunction with CORINE land use data.

Table 1 Phosphorus Ranking Scheme for Irish grassland catchments

Factor	Factor Weighting	Risk Class	Score
Chemical Fertiliser Loading	12	1. (0-9 kg/ha) 2. (10-11 kg/ha) 3. (12-14 kg/ha) 4. (15-19 kg/ha) 5. (20+ kg/ha)	0.8 1.6 2.4 3.2 4.0
Organic Fertiliser Loading (cattle, sheep, poultry)	24	1. (0.0-1.0 LU/ha)* 2. (1.0-1.5 LU/ha) 3. (1.5-2.0 LU/ha) 4. (2.0 + LU/ha)	1.0 1.5 2.0 4.0
Organic Fertiliser Loading (piggeries)	24	1. (low potential) 2. (moderately low potential) 3. (moderately high potential) 4. (high potential)	0.8 1.6 3.6 4.0
Soil Phosphorus Levels	16	1. (0-5 mg/l) 2. (6-9 mg/l) 3. (10-14 mg/l) 4. (15+ mg/l)	1.0 2.0 3.0 4.0
Runoff Risk to Surface Waters	24	1. (very low risk) 2. (low risk) 3. (medium risk) 4. (high risk)	1.0 1.5 2.5 4.0

*Unit LU/ha is livestock units/hectare

Table 2 Total Scores used to derive Potential Risk Classes, applicable to Irish grassland catchments

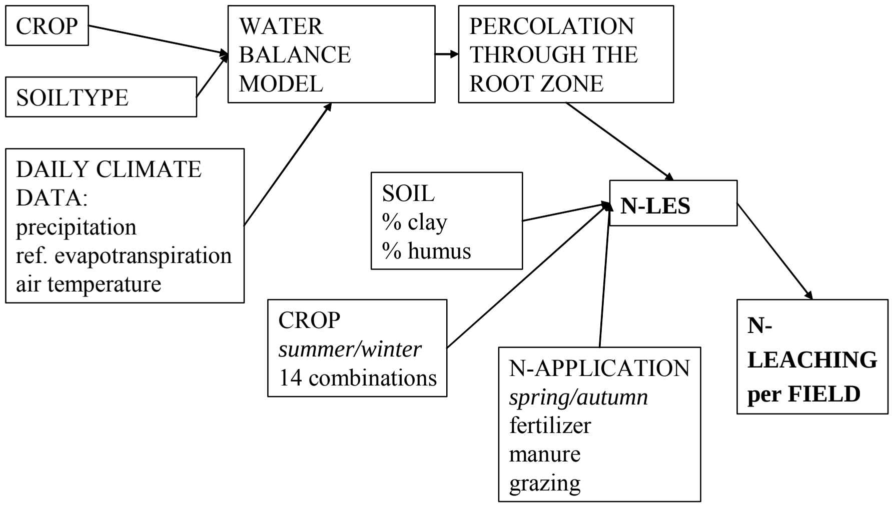
Total Score	Potential Risk Class
0	Non-agricultural areas
0 – 120	Index 1 Low Risk
120 - 200	Index 2 Medium Risk
200 – 280	Index 3 High Risk
>280	Index 4 Very High Risk

N-LES (NERI, Denmark)

Model name	Nitrate Leaching Estimator
Acronym	N-LES
Ref. Model description	Simmelsgaard, S. E., Kristensen, K., Andersen, H. E., Grant, R., Jørgensen, J. O. and Østergaard, H. S. (2000): An empirical model for calculation of root zone nitrate leaching. DJF rapport Markbrug no. 32, Danmarks JordbrugsForskning, 67 pages (in Danish)
Ref. Users guide	-
Main contact	Hans Estrup Andersen Nat. Env. Research Inst. Vejlsøvej 25, p.o.box 314 DK-8600 Silkeborg, Denmark phone +45 89 20 14 00 email hea@dmu.dk
Alternative contact	Brian Kronvang Nat. Env. Research Inst. Vejlsøvej 25, p.o.box 314 DK-8600 Silkeborg, Denmark phone +45 89 20 14 00 email bkr@dmu.dk
Objectives	The aim was to develop a model, which reliably on an annual basis could calculate the level of root zone nitrogen leaching and changes in root zone nitrogen leaching following changes in land use and agricultural practices. The model should be well supported concerning leaching of nitrogen originating from application of both fertilizer and manure, including long term effects of manure. The model should be robust and describe the effects of the main factors determining nitrogen leaching.
Short description of the model in words	N-LES is an empirical model for calculation of annual values of root zone nitrogen leaching. The model comprises a combination of additive and multiplicative effects. N-LES was developed on 600 observations of annual leaching of nitrogen from the root zone from both experimental fields and fields in normal agricultural production in Denmark. The model explained 68% of the observed variation. The systematic effects included in the model are: level of total-nitrogen added in the crop rotation; fertilization in spring; autumn fertilization; nitrogen left by grazing animals; effect of ploughing-in of grass; soil type (clay- and humus-content); water percolation through the root zone, and crop type. In Denmark, percolation has been calculated by EVACROP, which comprises rather simple conceptual models for describing vegetation and for calculating the water balance. N-LES has since 1992 been used in Denmark as a tool for evaluating the effect of policy measures for combating diffuse nitrogen pollution from the agricultural production.
Conceptual boundary conditions (e.g. root zone, ditch, river)	N-LES is a one-dimensional model, which calculates nitrogen leaching out of the root zone on an annual basis operating on the field as the smallest unit.
Main processes implemented	EVACROP describes development of LAI and roots, and calculates evaporation from soil and transpiration from plants, and water percolating through the root zone. N-LES being a statistical model implements as such no processes.

Main model input (sensitive) parameters	- level of total-nitrogen added in the crop rotation; fertilization in spring; - autumn fertilization; - nitrogen left by grazing animals; - nitrogen fixation by leguminous plants; - timing of ploughing-in of grass; - soil type; - water percolation through the root zone; - crop type (main crop and winter or catch crop).
Main validation data required	Field root zone nitrogen leaching data or measured nitrogen concentration just below the root zone of individual fields. Alternatively flow and nitrogen concentration data from tile drained subcatchments. For catchments with zero subsurface nitrogen retention/removal the model can be validated on river data (flow, nitrogen concentration, nitrogen load). NERI is working on an add-on module for estimating subsurface retention/removal. Combined with this module N-LES could be validated on river data for all catchments.
Retention module for surface waters	Not included. Not an option.
Perceived strengths (inc. applicability)	Easy to set up and use. Transparent – easy to understand. Modest data requirement making it suitable for areas with limited data. Being empirical the model will - when used within its range of validity - yield estimates in the correct order of magnitude. Has been used in Denmark with considerable success as a tool for evaluating the effect of policy measures for combating diffuse nitrogen pollution from the agricultural production, including scenario analysis.
Perceived weaknesses (Inc. Limitations)	Only valid within the range of the calibration data set. Less dynamic. For use in other agro-climatic regions than Denmark the model needs a calibration data set from experimental fields which for some countries/regions might be lacking. Some factors influencing nitrogen leaching – e.g. the effect of an unsuccessful harvest – are not included in the model.
Temporal resolution	Annual estimates.
Spatial resolution	The field is the smallest unit.
Main flow chart	See chart diagram below.

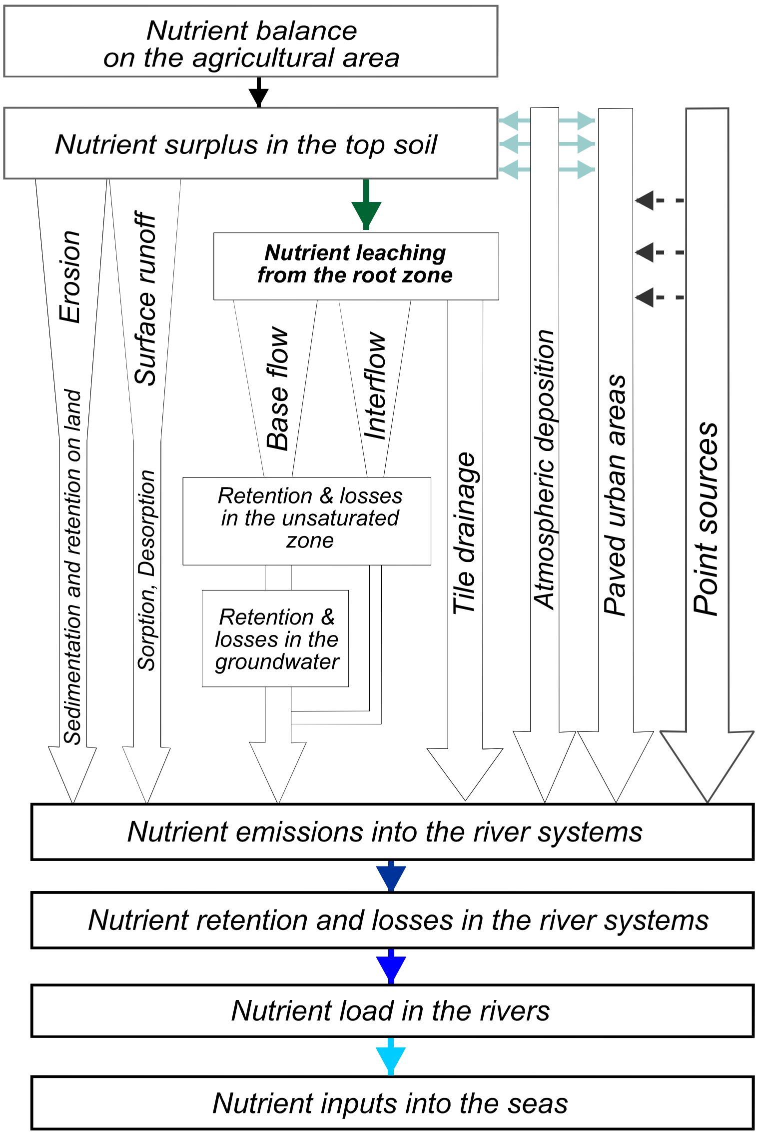
Model calculations with N-LES



MONERIS (FV-IGB, Germany)

Model name	**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems
Acronym	**MONERIS**
Ref. Model description	Behrendt, H., Huber, P., Ley,M., Opitz, D., Schmoll, O., Scholz, G. & Uebe, R. (1999): Nährstoff-bilanzierung der Flußgebiete Deutschlands. UBA-texte, 75/99, 288 S. Behrendt, H., Huber, P., Kornmilch,M., Opitz, D., Schmoll, O., Scholz, G. & Uebe, R. (2002): Estimation of the nutrient inputs into river basins - experiences from German rivers. Regional Environemental Changes, Spec. Issue, (in print; online published). Behrendt, H., Dannowski, R., Deumlich, D., Dolezal, F., Kajewski, Kornmilch, M., Korol, R., Mioduszewski, W., Opitz, D., Steidl, J. & Stronska, M. (2002): Nutrient and heavy metal emissions into the river system of Odra - results and comparison of models. Schriftenreihe des Institutes für Abfallwirtschaft und Altlasten, Technische Universität Dres-den, Bd. 28, Vol.2, 213-221.
Ref. Users guide	Not available
Main contact	Horst Behrendt Forchungsverbund Berlin e.V., Müggelseedamm 310 12561 Berlin Germany +493064181683 behrendt@igb-berlin.de
Objectives	MONERIS was developed for investigating nutrient inputs via various point and diffuse pathways in German river basins. The basis for the model is data on runoff and water quality for the studied river catchments and a Geographical Information System (GIS), in which digital maps as well as extensive statistical information are integrated.
Short description	MONERIS apportions riverine load based on conceptual pathways including: - Direct nutrient input to water surfaces by atmospheric deposition, - Nutrient input into the river systems by surface runoff, - Nutrient input via natural interflow which represents a fast subsurface flow component - Nutrient input via tile drains and - Nutrient inputs via base flow (groundwater) realised by the slow subsurface flow component.
Conceptual boundary conditions	Spatial resolution is c. 10 km^2 or more, depending on the resolution of input GIS data layers.
Main processes implemented	Estimates for the following specific inputs to riverine load are possible for a given catchment area: - Point sources - Atmospheric deposition - Surface runoff - Urban areas - Tile drainage areas

	- Groundwaters Nitrogen and phosphorus transformations are model modelled explicitly: the net effect is represented via lumped parameters. The model allows the estimation of N loads and concentrations in groundwaters (using regional groundwater data and measurements in rivers during low flow), in tile drained areas, in urban systems such as sewer systems and overflow (combined/separate sewer), and retention in surface waters.



TRK (SLU, SMHI, Sweden)

Model name	**TRK (Soil-N/HBV)** **TRK-The Swedish system**
Acronym	**TRK**
Ref. Model description	The TRK system: Swedish EPA, 1997. Nitrogen from land to sea. Main report. Swedish Environmental Protection Agency, Report 4801, Nordstedts tryckeri AB, Stockholm. HBV (catchment water-balance): Bergström, S., 1995. The HBV model. In Singh, V. P. (ed.) *Computer Models of Watershed Hydrology*, Water Resources Publications, Littleton, Colorado, pp. 443-476. Lindström, G., Johansson, B., Persson, M., Gardelin, M., and Bergström, S., 1997. Development and test of the distributed HBV-96 hydrological model, *J. Hydrol., Vol. 201*, pp. 272-288. SOILNDB & SOILN (arable N leaching): Johnsson, H., Larsson, M., Mårtensson, K., Hoffmann, M. 2002. SOILNDB: A decision support tool for assessing nitrogen leaching losses from arable land. *Environmental Modelling & Software* (in press). Johnsson, H., Bergström, L., Jansson, P.-E. & Paustian, K. 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. *Agric. Ecosystems Environ. 18*, 333-356. Method N leaching estimates: Hoffmann, M. & Johnsson, H. 1999. A method for assessing generalised nitrogen leaching estimates for agricultural land. *Environmental Modeling and Assessment*, 4:35-44. Johnsson, H. & Hoffmann, M. 1998. Nitrogen leaching from agricultural land in Sweden – Standard rates and Gross loads in 1985 and 1994. *Ambio 27*:481-488 Revised Method for N leaching estimates*:* Johnsson, H. & Mårtensson, K. 2002. Kväveläckage från svensk åkermark – beräkningar av normalutlakning för 1995 och 1999. Manuscript. (in swedish) Phosphorus model for arable land: Ulén, B, Johansson G. and Kyllmar, K., 2001, Model predictions and long-term trends in phosphorus transport from arable lands in Sweden. *Agricultural Water Management* 49, 197-210. HBV-N (catchment N-transport and retention): Pettersson, A., Arheimer, B. and Johansson, B., 2001. Nitrogen concentrations simulated with HBV-N: new response function and calibration strategy. *Nordic Hydrology 32(3):227-248.* Arheimer, B and Brandt, M., 2000. Watershed modelling of non-point nitrogen pollution from arable land to the Swedish coast in 1985 and 1994. *Ecological Engineering 14:389-404.* Arheimer, B. and Brandt, M., 1998. Modelling nitrogen transport and

	retention in the catchments of Southern Sweden. *Ambio 27*(6):471-480.
Ref. Users guide	
Main contact	Helene Ejhed, IVL Svenska Miljöinstitutet AB/ IVL Swedish Environmental Research Institute, Sweden helene.ejhed@ivl.se
Alternative contact	Berit Arheimer, SMHI, 601 76 Norrköping, Sweden berit.arheimer@smhi.se Holger Johnsson, Dep. of Soil Sciences, SLU, Box 7072, 750 07 Uppsala, Sweden jonas.olsson@smhi.se
Objectives	In Sweden a system for nitrogen (N) and phosphorus (P) gross and net load calculations, retention and source apportionment have been developed and applied for the southern half of Sweden (145 000 km^2 with 3 725 sub-basins modelled for year 1985-1994) and for the whole of Sweden (for year 2000) reporting to HELCOM, PLC-4.
Short description of the model in words	**The TRK system combines;** 1. Preparation of areal distribution of different land-use categories and positioning of point sources using GIS; 2. Calculations of concentration and areal losses of diffuse sources (for N from arable land by using the dynamic soil profile model SOILNDB); 3. Calculations of the water balance (by using the distributed dynamic HBV model) and N transport and retention processes in water (by using the model HBV-N). The results are presented in the GIS, and source apportionment is made for each sub-basin as well as for the whole river basins. The results from the system have been used for international reports on the transport to the sea, for assessment of the reduction of the anthropogenic load on the sea and for guidance on effective measures for reducing the load on the sea on a national scale. **<u>N- leaching from arable land</u>:** Generalized N root-zone leaching estimates for arable land are calculated using the SOILNDB modelling tool. The method is based on calculating a number of standard N leaching rates (i.e., nitrogen leaching from the root zone for a specified year if the weather and harvest would have been normal) for a number of combinations of soils, crops and fertilization forms and regions (catchment, area etc.). For this calculation the following is used: SOILNDB, a crop rotation generator, longer time-series of meteorological data, agricultural statistics of crops and areal distribution, standard yields, normal fertilization rates and crop management information. Leaching is simulated for a large number of years using the meteorological time-series repeatedly to get acceptable mean values of the standard leaching rates for the different crop-soil combinations. Thus, leaching estimates are normalised with respect to year to year variation in weather conditions and crop production. The system has been used for

calculating leaching estimates for combinations of different climates, soil textural classes, crops, organic matter classes and fertilisations regimes in the Nordic countries and Sweden.

SOILNDB is a management oriented modelling tool based on the one-dimensional SOIL-SOILN models describing N dynamics and losses in arable soils, a parameter database and parameter estimation algorithms. The soil N model, SOILN is coupled in series with the soil water and heat model, SOIL. SOIL provides driving variables for the SOILN model, i.e., infiltration, water flow between layers and to drainage tiles, unfrozen soil water content and soil temperature. The SOIL model includes snow dynamics, frost, evapotranspiration, infiltration, surface runoff and drainage flows as well as water uptake by vegetation. The SOILN model includes the major processes determining inputs, transformations and outputs of N in arable soils: Inputs of fertilization and deposition, mineralisation dependent on soil temperature and moisture, decomposition to CO_2, humus and recycling within the pool, soil temperature function, Q10, for regulation of all biological processes, plant uptake from empirical functions, denitrification dependent on soil temperature, soil oxygen status and soil nitrate content. Nitrate transport is calculated as the product of water flow and nitrate concentration in the soil layer. Ammonium is considered to be immobile in the soil profile.

Gross load from arable land is calculated using areal distribution of crops and soil types.

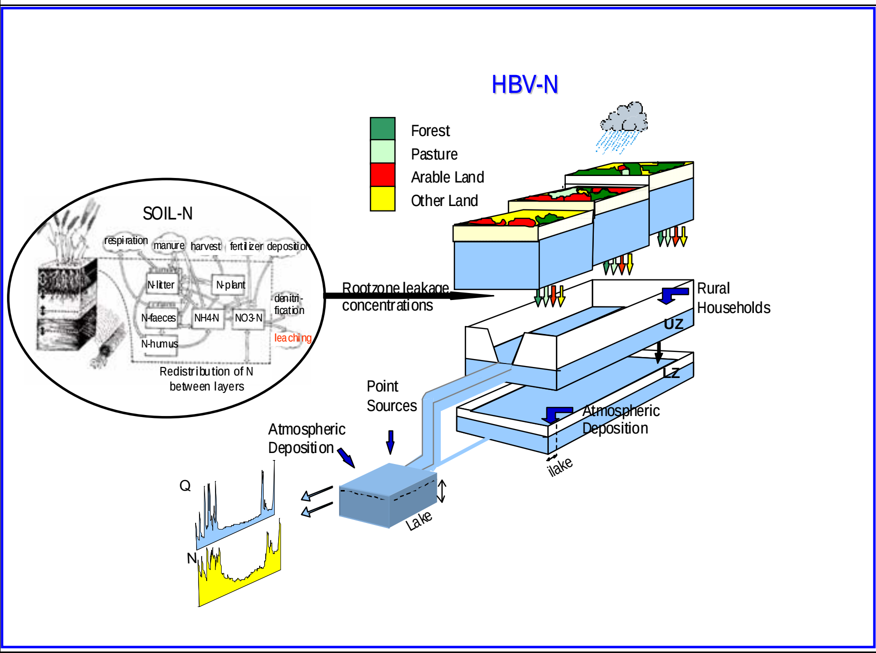
Catchment modelling of water discharge:

The HBV model is a conceptual, continuous, dynamic and distributed rainfall-runoff model. When applying the model the catchment is divided into several coupled sub-basins. The daily water balance is calculated for each sub-basin using daily precipitation and temperature data from climate stations. It provides daily values of areal precipitation, snow accumulation and melt, soil moisture, groundwater level, and finally, runoff from every sub-basin, and routing through lakes and larger basins. The model is calibrated and validated against observed time-series. The HBV model has been applied in more than 40 countries over the world and is used operationally in the Nordic countries. Normalised water flow is based on an average from 10-20 years of daily modelling.

N transport and retention:

The HBV-N model simulates N transport and retention in groundwater, river and lake systems at the catchment scale. The N model is based on the HBV-model and has separate routines for daily simulations of inorganic and organic N. The soil leakage from different land-use is mixed with discharge from rural household in the ground water. Concentration variations in the local runoff, due to biological and chemical processes in e.g. open ditches and riparian zones, are described with simple functions mainly based on temperature, concentration and hydrology. The local N runoff is then mixed with contribution from upper sub-basins and lake water. In the river and lake routines, N atmospheric deposition on the water surface and load from industry and treatment plants are included. N retention is calculated in rivers and, more important, in lakes. The inorganic N may be reduced due to denitrification, sedimentation and biological uptake, while organic N may increase due to biological production or decrease by sedimentation and mineralisation. These processes are also simulated with simple conceptual functions. The N routine is calibrated and validated against observed time-series. N transport and retention, that are normalised from temporal weather and

	flow variations, are achieved by calculating averages from 10-20 years of daily modelling. **<u>P-leaching from arable land</u>:** P transport is based on water discharge simulated by HBV linked to multiple regression models. Four parameters influence the P concentration from arable land; livestock density, P concentration in topsoil, duration of high water flow and soil specific area.
Conceptual boundary conditions (e.g. root zone, ditch, river)	• SOILNDB produces N leakage concentrations and loss from arable land to the root zone. • Concentrations in runoff from other land-uses are estimated from measurements in small streams. • HBV produces distributed runoff coefficients. • HBV-N produces distributed retention coefficients (based on calculations from root-zone to river, in rivers and in lakes). • <u>Whole system</u>: input to catchment soil and water, and riverine output from the catchment
Main processes implemented	**<u>SOILNDB:</u>** Water flow from root-zone in arable land Nitrogen root zone leaching from arable land(soil water and heat flow) (soil nitrogen turnover) **<u>HBV:</u>** Optimal interpolation of precipitation and temperature, snow melt and storage, evapotranspiration, interception, soil moisture dynamics, groundwater response, routing in rivers and lakes. **<u>HBV-N:</u>** distributed mixing of N load from various sources, N retention in groundwater, N retention in rivers, N retention in lakes.
Main model input (sensitive) parameters	**<u>SOILNDB:</u>** Crops Harvest & crop management Fertilization and manuring Soil type (texture) and organic content Deposition rates & concentration Meteorological data (air temperature, precipitation, air humidity, insolation, wind speed) **<u>HBV:</u>** Digitalized subbasin boundaries and elevation maps Land cover Daily precipitation and temperature from climate stations Average potential evapotranspiration Lake rating curve and regulation regime for power dams Observed time-series of water flow in the river **<u>HBV-N</u>** (additional to the HBV-input data): Soil type and crop distribution of the arable land Soil leakage concentrations Lake depths Atmospheric N-deposition Point-source N emissions Rural households and person equivalents of N contribution Observed time-series of N in the river

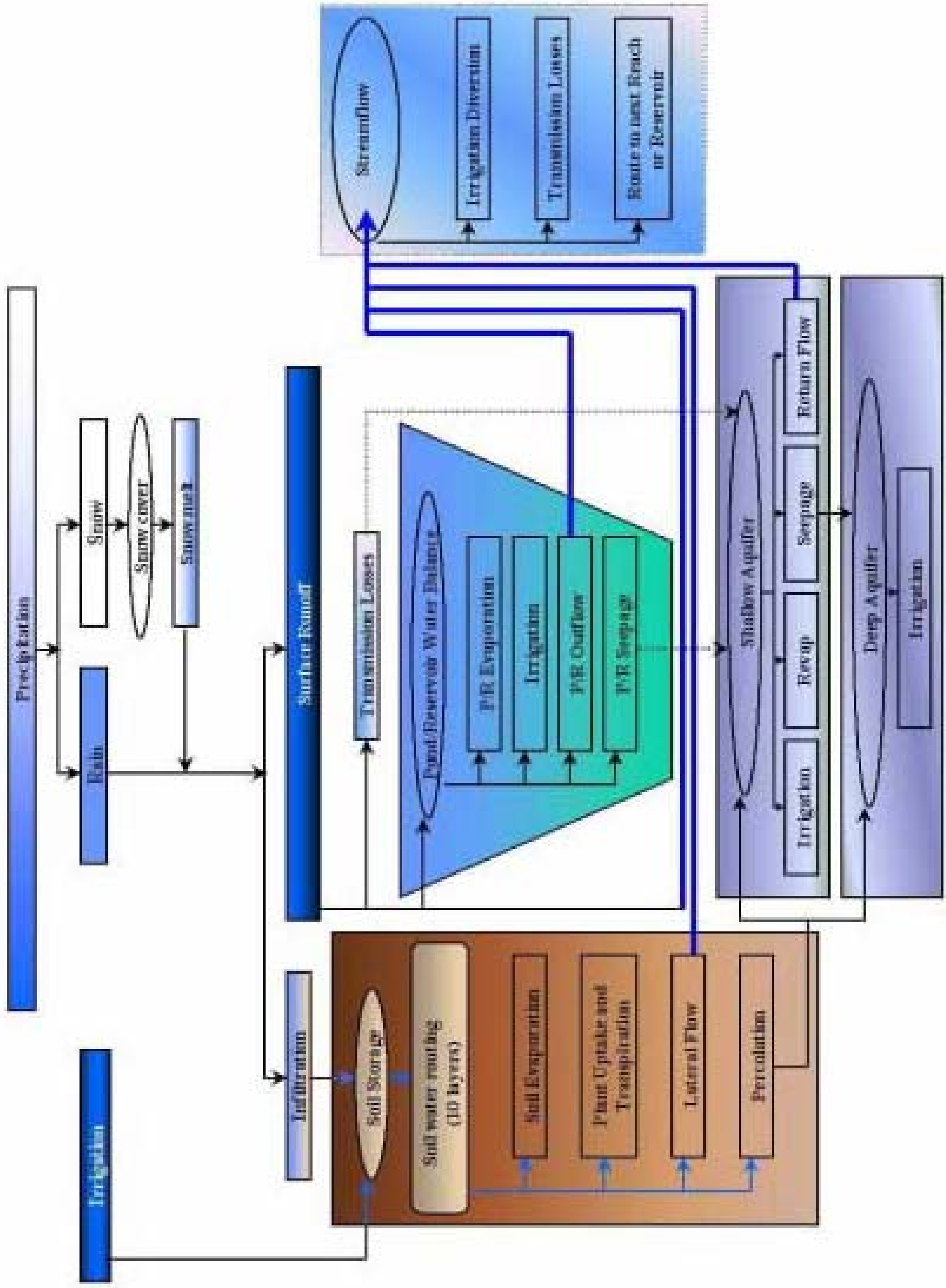
	<u>TRK-P:</u> Livestock density P concentration in topsoil Runoff Soil specific area
Main validation data required	**<u>HBV</u>:** Time-series of several years of daily or monthly water flow - nested catchments if possible! (moreover: groundwater levels, ^{18}O observations in rainfall and discharge, snow-cover, snow depths, frozen-ground depth) **<u>HBV-N:</u>** Time-series of several years of grab-samples; $NO_{2\text{-}3}$, NH_4, Org.N, Tot.N. in up-stream subbasins without lakes, at several sites along the river section, at lake outlets.
Retention module for surface waters	Is included using HBV-N. HBV-N runs separately and is therefore optional.
Perceived strengths (inc. applicability)	• Integrated catchment modelling • Enables large-scale applications • Process-based with scenario possibilities • HBV and HBV-N includes an automatic calibration routine • Validated against independent measurements
Perceived weaknesses (Inc. Limitations)	• Application skills necessary (can also be a strength!) • Model set-up may be time-consuming • Simplified process descriptions involves uncertainties • Internal variables that are unvalidated (involves uncertainties)
Temporal resolution	The method calculates normalized nutrient load for a specific year. SOILNDB: The model runs with a daily time-step and results produced are annual standard arable root-zone N-leaching estimates. HBV: The model runs with a daily time-step and results produced are annual normalized runoff coefficients. HBV-N: The model runs with a daily time-step and results produced are annual normalized retention coefficients.
Spatial resolution	The catchment is distributed down to a sub-basin scale. The number of subbasins (and thereby spatial distribution) is chosen by the modeller for each application.
Main flow chart	

SWAT (IRSA, Italy)

Model name	Soil and Water Assessment Tool
Acronym	SWAT
Ref. Model description	Neitsch S.L., Arnold J.G., Kiniry J.R., Williams J.R., (2001), Soil and Water Assessment Tool – Theoretical Documentation - Version 2000, Blackland Research Center – Agricultural Research Service, Texas - USA
Ref. Users guide	Neitsch S.L., Arnold J.G., Kiniry J.R., Williams J.R., (2001), Soil and Water Assessment Tool – User Manual Version 2000, Blackland Research Center – Agricultural Research Service, Texas - USA
Main contact	Antonio Lo Porto IRSA-CNR, Via De Blasio 5, 70123 Bari, Italy loporto@area.ba.cnr.it
Alternative contact	Faycal Bouraoui JRC-UE, TP460 Via Fermi, 21020 ISPRA (VA), Italy Faycal.bouraoui@jrc.it
Objectives	SWAT is a continuous time model that operates on a daily time step at basin scale. The objective of such a model is to predict the long-term impacts in large basins of management and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing). It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture It can also help in assessing the environmental efficiency of BMP's and alternative management policies.
Short description of the model in words	SWAT uses a two-level dissagregation scheme; a preliminary subbasin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. The physical properties inside each subbasin are then aggregated with no spatial significance. The time step for the simulation can be daily, monthly or yearly, which qualify the model for long-term simulations.
Conceptual boundary conditions (e.g. root zone, ditch, river)	
Main processes implemented	The hydrology model is based in the water balance equation comprising surface runoff, precipitation, evapotranspiration, infiltration and subsurface runoff. Evapotranspiration: depending on data availability, both the Priestley-Taylor and Penman-Monteith methods can be used to calculate the potential ET. Precipitation can be estimated using a weather generator included in SWAT; however, measured time series can also be used, thus reducing uncertainties. Infiltration: the soil profile involves up to 10 soil layers, a shallow aquifer and also a deep aquifer. When the field capacity in one layer is exceeded, the water is routed to the lower soil layer. If this layer is already saturated, a lateral flow occurs. Bottom layer percolation goes into the shallow and deep aquifers. Water reaching the deep aquifer is lost, but a return flow from the shallow aquifer due to the deep aquifer saturation is added directly to the subbasin channel.

	Surface runoff: runoff volumes are computed by the SCS Curve Number Method. Surface runoff is then estimated as a non-linear function of precipitation and a retention coefficient. Also the Green & Ampt approach is available. SWAT also incorporates models to predict channel losses, runoff in frozen soils, snow melt, or capillary rise. Once all hydrological processes are calculated for an homogeneous part of the subbasin, the resulting flows are considered to contribute directly to the main channel. SWAT includes a routing module based on the ROTO model. This routing procedure moves downstream the water budget taking into account how subbasins and reservoirs are connected. Sediment yield is determined for each subbasin with the Modified Universal Soil Loss Equation, including runoff, soil erodibility, slope and crop factors. A simplified EPIC model is used to simulate crop growth (e.g., wheat, barley, alfalfa, corn) using unique sets of parameters for each crop. Natural vegetation (i.e., forest, grass, pasture) are also included in the crop database. The chemicals considered include nutrients (N-based, P-based, O-based and algae) and pesticides. Nutrient loadings to the channel are calculated from the concentrations in the upper soil layer and the runoff volumes. Use of P and N by crops is estimated using a supply and demand approach. The nitrogen module also includes processes like mineralization, denitrification, and volatilization. Phosphorus association with the sediment phase is also considered in the phosphorus module. Both modules are based on the CREAMS model. After considering the N and P dynamics, the chemicals are also routed into the subbasin channels. With respect to pesticides, the GLEAMS approach is incorporated into SWAT, considering also degradation.
Main model input (sensitive) parameters	A) Soil Map. For each soil layer: Textural properties: Physico-chemical-properties: B) Landuse Map Landuse information: crop, water bodies (lake,pond, etc.) Cropping information: planting and harvest date, yield, etc. Management practices: fertilizer and pesticide application timing and amount C) Climate Information Daily rainfall, minimum and maximum air temperature, net solar radiation Monthly average wind speed Average monthly humidity D) Water Quality Information F) Point sources Location average daily flow average daily sediment and nutrient loading G) Hydrogeological Map Groundwater abstraction timing and amount H) Digital Elevation Model

	I) Monitoring Data for model calibration: Observed flows at subbasin /basin outlet(s) Nutrient loadings at subbasin/basin outlet (s) Sediment loadings at subbasin/basin outlet(s)
Main validation data required	Observed flows at subbasin /basin outlet(s) Nutrient loadings at subbasin/basin outlet (s) Sediment loadings at subbasin/basin outlet(s)
Retention module for surface waters	It is included. It is optional.
Perceived strengths (inc. applicability)	• The model is mostly physically based, • is quite widely used all across the world and in Europe • uses almost readily available inputs, • is computationally efficient to operate on large basins in a reasonable time, • allows point sources impact to be modelled, • is continuous time and capable of simulating long periods for computing the effects of management or climate changes. • GUI available for ESRI ArcView® (Windows NT/ 2K) and GRASS (Unix) GIS, • semi-distributed Parameter • allows a flexible watershed config uration (unlimited Number of Sub-watersheds) • a very co-operative user network is available.
Perceived weaknesses (Inc. Limitations)	Forest growth simulation is poor P simulation: somewhat too simple Hydrological Response Units are not georeferenced within a subbasin
Temporal resolution	Daily, monthly, annual estimates
Spatial resolution	The model has no theoretic limitation regarding the smallest unit, the GUI, however, allows one hectare as the smallest subbasin


Precipitation
Snow
Snow cover
Snowmelt
Rain
Irrigation
Surface Runoff
Infiltration
Soil Storage
Soil water routing
(10 layers)
Soil Evaporation
Plant Uptake and
Transpiration
Lateral Flow
Percolation
Transmission Losses
Pond/Reservoir Water Balance
P/R Evaporation
Irrigation
P/R Outflow
P/R Seepage
Shallow Aquifer
Irrigation
Revap
Seepage
Return Flow
Deep Aquifer
Irrigation
Streamflow
Irrigation Diversion
Transmission Losses
Route to next Reach
or Reservoir

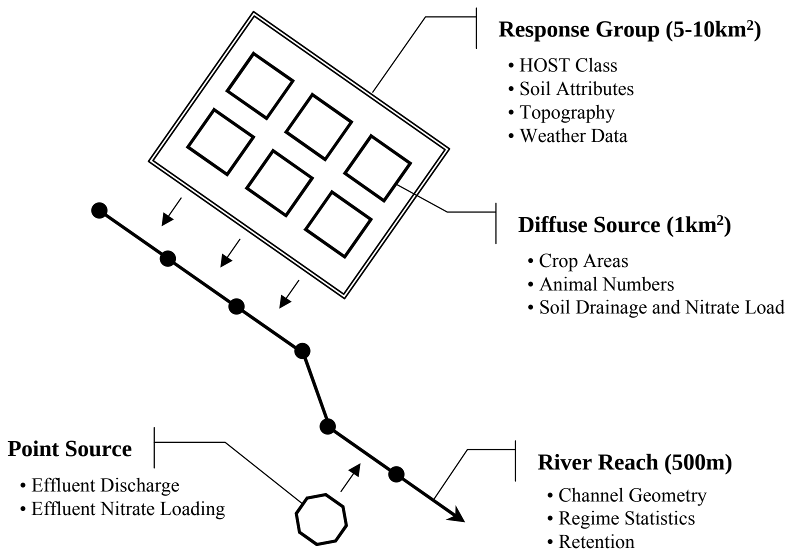
EveNFlow (ADAS, the United Kingdom)

Model name	*EveNFlow*
Acronym	**EveNFlow**
References	Anthony, S. G., Quinn, P., and Lord, E. I. 1996. Catchment scale modeling of nitrate modeling. *Aspects of Applied Biology* 46, 23-32. Lord, E. I. 1992. Modelling of nitrate leaching: Nitrate Sensitive Areas. *Aspects of Applied Biology* 30, 19-28. Lord, E. I. and Anthony, S. G., 2000. MAGPIE: A modelling framework for evaluating nitrate losses at national and catchment scales. *Soil Use and Management*, 16: 167-174. Scholefield, D., Lockyer, D.R., Tyson, K.C. & Whitehead, D.C. 1991. A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. *Plant & Soil* **132**, 165-177. Addiscott, T.M. & Whitmore, A.P. 1991.Simulation of solute leaching in soils of differing permeabilities. *Soil Use & Management* **7(2)**, 94-102. Chambers, B. J., Lord, E. I., Nicholson, F. A. and Smith, K. A. 1999. Predicting nitrogen availability and loses following applications of manures to arable land: MANNER. *Soil Use and Management*, **15**, 137-143. Beven K, Lamb R, Quinn P, Romanowicz R, Freer J. 1994. TOPMODEL. In *Computer Models of Watershed Hydrology*. Singh V, (ed). Water Resource Publications; 1-43. Boorman, D., Hollis, J. and Lilly, A. 1995 Hydrology of soil types: a hydrologically based classification of the soils of the United Kingdom. Institute of Hydrology Report No. 126, Wallingford, Oxfordshire. A. D. Friend. 1998. Parameterisation of a global daily weather generator for terrestrial ecosystem modelling. *Ecological modelling*, 109, 121-140. de Witt, M. J. M. (2001) Nutrient fluxes at the river basin scale. I: the PolFlow model. *Hydrological Processes*, 15, 743-759.
Contacts	First contact: Dr Steven. G. Anthony +44 (0)1902 693192 Steve.Anthony@adas.co.uk Second contact: Dr Martyn Silgram +44 (0)1902 693354 Martyn.Silgram@adas.co.uk ADAS Woodhorne, Wergs Road, Wolverhampton, WV6 8TQ
Objectives	**EveNFlow** The objective of this work was to develop a robust model system for estimating inorganic nitrogen fluxes and concentrations in river waters, primarily originating from agricultural land, for any catchment within England and Wales. The system is intended to work in two modes: the national mapping of annual total nitrate losses at a spatial resolution of 1 km^2; and the simulation of daily river flow and nitrate concentrations at the mouth of river catchments that are between 100 and 2,000 km^2 in area.
Model description and main processes implemented	EveNFlow is a semi-distributed model with five modular components. The system developed uses as input statistical data on land use, farming practices, climate and soil characteristics, collated at a spatial resolution of one square kilometre as a National Environment Database. The components of EvenFlow incorporate a number of simple *meta-models*

	that are adapted to the scale and information content of the environment database. The model concerns only diffuse inputs, effluent contributions to the river nitrate load are estimated either on the basis of catchment population figures and per capita estimates of effluent volumes and nitrogen load, or information on licensed dry weather flow discharges. Component 1 is a soil nitrate model that simulates the soil crop interaction that controls the mass of nitrate present in the soil at the onset of winter drainage that is vulnerable to leaching. The model comprises elements of the NITCAT (Lord, 1992), N-CYCLE (Scholefield *et al*., 1991) and MANNER (Chambers *et al*., 1999) field scale models of nitrogen cycling under arable grassland. Component 2 is a soil drainage model. The model comprises elements of the MORECS and IRRI GUIDE evapotranspiration models and can be driven by data generated by the Friend (1998) stochastic weather generator which has been parameterized for Europe. Alternatively observed, interpolated data may be used. Component 3 is a leaching function that predicts the cumulative proportion of available nitrogen that is leached as a function of rainfall and soil water content. The model was derived from the SLIM and SACFARM models (Addiscott and Whitmore, 1991). Component 4 is a drainage routing model based upon a one-dimensional form of TOPMODEL (Beven *et al,* 1995). The model simulates the river hydrograph and mixes rapid and slow soil drainage derived from different depths in the soil profile. The model is parameterized from soil HOST class (Boorman *et al*, 1995). Component 5 concerns nitrate retention. Retention in aquifers or the vadose zone is currently not simulated, but can be by application of denitrification rate parameters from de Witt (2001) to the deepest soil water store in the routing model. The retention in the river is calculated on a daily basis using empirical relationships between discharge and channel geometry to estimate the proportion of nitrate removed by bed processes. *An overview paper integrating all these elements is available:* *Anthony, S.G., Fawcett, L.E., Silgram, M. and Collins, A.L. 2007. EveNFlow: catchment river water quality modelling for policy support. In press.*
Boundary conditions	▪ Concentrations of nitrate in runoff from non-agricultural land are estimated from observation; ▪ Whilst nitrate losses to the river system are modeled in a semi-distributed manner, retention in the river system is treated in a lumped manner.
Main model input parameters	Soil Nitrate: component 1 Crop types and yields, fertilizer and manure management, soil type and characteristics, grazed stocking density, mean climate data. Soil Drainage: component 2 Soil type and characteristics, daily weather data, crop type. Soil Leaching: component 3 HOST class, soil type and characteristics. Drainage routing: component 4 Host Class. Nitrate Retention: component 5 River network, river bed characteristics, point source inputs.

Validation requirements	▪ Observed river flow data time series; ▪ Observed nitrate concentrations in river.
Retention	Optional. Main river channel only (not lakes).
Strengths	▪ Data required are typically widely available; ▪ In principle the model does not require calibration for application to new catchments; ▪ EveNFlow is a conceptual approach and is of relatively low to moderate complexity; ▪ The model components are modular and can be validated independently; ▪ The model includes snowmelt and in-river retention modules; The model outputs daily resolution flow, concentrations and loads, and so is able to capture system dynamics.
Weaknesses	▪ EveNFlow does not explicitly model the interaction between the root zone and groundwater. In EveNFlow, crop growth is not subject to nutrient limitation. The model does not model weather related variation in crop yields and does not explicitly model net nitrogen mineralisation.
Temporal resolution	The model operates on a daily time-step.
Spatial resolution	For EveNFlow the smallest unit is 1 km^2 In practice the catchment is subdivided into group response units (1-10 km^2) based upon topography, rainfall and HOST (Hydrology of Soil Types) classes.

EvenFlow data structures



PRINCIPAL MODEL DATA STRUCTURES

NOPOLU (IFEN, France)

Model name	**NOPOLU system 2®**
Acronym	NOPOLU
References	European Environment Agency/IFEN (2000). Technical report N°51. Calculation of nutriment surplus from agricultural sources. Statistics spatialisation by means of CORINE Land Cover. Application to the case of Nitrogen. Spatial Application Division K.U. LEUVEN Research & Development. Version 20/12/2001. Dr. P. CAMPLING, Lic. S. VANDE WALLE, Dr. Ir. J. VAN ORSHOVEN, Prof. Dr. Ir. J.FEYEN. Final Report. Calculation of Agricultural Nitrogen Quantity for EU River Basins.
Contacts	**Main Contact** Guillaume LE GALL BETURE CEREC 2 rue Stephenson F-78181 Saint Quentin en Yvelines France Tél. : +33 (0)130 129 105 Fax.: +33 (0)139 449 187 e-mail : guillaume.legall@beture-cerec.com ***Alternative Contact*** Hervé REISSER BETURE CEREC 2 rue Stephenson F-78181 Saint Quentin en Yvelines France Tél. : +33 (0)130 129 106 Fax.: +33 (0)139 449 187 e-mail : herve.reisser@beture-cerec.com
Objectives	The integrated assessment of emissions to continental catchments requires a comparable method for agricultural inputs computation, considered as a part of this integrated assessment.
Model description	The methodology developed especially for that purpose makes a throughout usage of CORINE L.C. layer to standardize the transfer of information between the administrative and the catchment layers. These layers represent the source of data on the one hand and the target for results on the other hand. This computation system is a part of *NOPOLU system 2®* ("NOPOLU2" in further citations), which is a comprehensive system designed for integrated emissions and impact assessment at any catchment / administrative scale. It benefits the following features: NOPOLU2 is a software platform, developed by the BETURE-CEREC consulting firm. It comprises an original data base architecture, is linked to a GIS and manages different modelling software. A very important feature of NOPOLU2 is that it works on the " exception" principle. This principle permits to deal simply with the numerous, and little weight items, whilst the less numerous or very important items can be dealt with at the utmost detail level. The burden for the user is reduced to the minimum. This software already treats industrial and municipal point sources, and with all river-related computations as well. Industrial and municipal data

	are dealt with according to the general principles summarized in the introduction (merging coefficient and measures based assessment methods). For the most complicated cases, a model, derived from the SIMPLETREAT model ([1]) agreed by OECD, is available. Sewerage management can be considered as well. The newly implemented agricultural model is presently based on the French official fertilization model agreed by EUROSTAT. The CORINE L.C. layer is used to dispatch the statistical data available in agricultural census files (administrative level, data not geo-referenced) on the most likely real area that belongs to the catchment belonging to the same administrative area. Phosphorus computations are currently under checking, some technical coefficients being presently not available. The model has been designed so that the load assessment on the one hand, and dispatching the results on the other hand are procedures rather independent. This independence is achieved using customizable links between, for example, the CORINE Land Cover codes (which are unique at the European scale) and agricultural census codes (country dependant). To improve the versatility of the agricultural modeling system, NOPOLU2 handles regional tables. These tables permit to consider that in a given region, the crop to land cover relationship, as well as the fertilizer and yield values are not the same. This may be the case for example for maize crops in production area compared to the same type of culture in hunting area, where this cultivation is made to feed game birds.
Boundary conditions	None applicable

[1] Implementation of SIMPLETREAT 2 is underway.

SA (NERI, Denmark)

Model name	**Source Apportionment Soil and Water Assessment Tool**
Acronym	**SA**
Ref. Model description	HARP Guideline 8 and Kronvang, B., Jeppesen, E., Conley, D.J., Søndergaard, M., Larsen, S.E., Ovesen, N.B. & Carstensen, J. 2005: Nutrient pressures and ecological responses to nutrient loading reductions in Danish streams, lakes and coastal waters. - Journal of Hydrology 304: 274-288.
Ref. Users guide	HARP Guideline 8.
Main contact	Brian Kronvang, NERI, Dept. Fresh water Ecology, Vejlsøvej 25, DK-8600 Silkeborg Denmark. Phone: +45 8920 1400; email: BKR@DMU.DK.
Alternative contact	
Objectives	The source apportionment method enable catchment owners to use existing monitoring data to analyse the importance of point sources and diffuse sources for the export of nutrients from a catchment.
Short description of the model in words	The source apportionment tool is a standard way of calculating the quantitative and qualitative importance of point sources and diffuse sources for the observed total annual nutrient export from the river basin in question. The source apportionment approach is based on the assumption that the annual nitrogen and phosphorus load at a selected river monitoring site (L_{river}) represents the sum of the various components of the nitrogen and phosphorus discharges to surface waters from point sources (D_P), the nitrogen and phosphorus losses from diffuse sources (LO_D) to surface waters and the natural background losses of nitrogen and phosphorus (LO_B) to surface waters. Furthermore, it is necessary to take into account the retention of nitrogen and phosphorus in surface waters and wetlands within the catchment after the nutrients have been emitted to surface water (R) and the atmospheric deposition of nitrogen and phosphorus on surface waters (A). This may be expressed as follows: $$L_{river} = D_P + LO_D + LO_B - R + A$$ The aim of the source apportionment is to evaluate the contributions of point and diffuse sources of nitrogen and phosphorus to the total riverine nitrogen and phosphorus load, i.e. to quantify the nitrogen and phosphorus losses from diffuse sources (LO_D) as follows: $$LO_D = L_{river} - D_P - LO_B - A + R$$ The Source Apportionment tool has been used in numerous cases in the Danish National and Regional Monitoring Programmes since the early 1970'ies. Moreover, the Source Apportionment tool has been applied in many other European National Monitoring Programmes and within Marine Conventional Areas (eg. HELCOM and OSPAR).
Conceptual boundary conditions (e.g. root zone, ditch, river)	None as the method relies on empirical information from the catchment.
Main processes implemented	None. However, nutrient retention in surface waters and inundated wetlands has to be predicted applying some other quantification tool.

Main model input (sensitive) parameters	The tool needs input data from the river measurement site on annual total nitrogen and total phosphorus transport. Catchment related data needed is catchment area, land use categories including as a minimum area of arable land, permanent grassland, forested areas, other natural areas, total population, population connected to sewage systems, number of households not connected to public sewerage, N and P values for 1 PE (person equivalent) and atmospheric deposition of N and P (kg/ha). Point source inventory needed on an annual basis is discharge of total nitrogen and total phosphorus from industrial plants, discharge of total nitrogen and total phosphorus from municipal waste water treatment plants, discharge of total nitrogen and total phosphorus from aqua-culture plants and discharge of total nitrogen, total phosphorus from households not connected to public sewerage, other point sources, such as stormwater outfalls from paved areas. Information on the N and P loss from natural areas (unmanaged forest, heathland, etc.) is also needed as an annual export coefficients (kg/ha) of total N and total P from natural areas and/or discharge weighted annual mean concentrations (mg/l) of total N and total P from natural areas.
Main validation data required	None.
Retention module for surface waters	Not included. Therefore, measured data or model calculated information in nutrient retention in streams, rivers, lakes, reservoirs and riparian wetlands have to be achieved (eg. use of EUROHARP-NUTRET).
Perceived strengths (inc. applicability)	Very easy and rapid to apply on a given river basin as a first screening tool to analyse the sources of nutrients. Is suitable in all types of catchments across Europe.
Perceived weaknesses (Inc. limitations)	Only valid catchment by catchment as it depends on monitored information. Cannot be used for scenario analysis.

Annex 2. Pathways and processes described by the quantification tools.

From EUROHARP

Model pathway, process or characteristic	**NL-CAT**	**REALTA**	**N-LES**	**MONERIS**	**TRK**	**SWAT**	**EVEN-FLOW**	**NOPOLU**	**SOURCE AP**
QT number	1	2	3	4	5	6	7	8	9
Spatial and temporal resolution of application									
- Horizontal boundaries (m); (Field: FD)	1	10-15	FD	1	1	1	1	10-15	1
- Vertical boundaries (m); (Root Zones:RZ)	*	N	RZ	~1	1.5	*	3	N	-
- Internal timestep for calculation (Hour, Day, Year)	D	Y	Y	Y	D/H	H	D	Y	Y
- Temporal resolution of output (Day, Year)	D	Y	Y	Y	Y	D	D	Y	Y
Nutrient Inputs and Management									
- Atmospheric deposition	Y	N	Y	Y	Y	Y	I	Y	Y
- Fertiliser additions	Y	Y	Y	Y	Y	Y	Y	Y	N
- Livestock density / manure additions	Y	Y	Y	Y	Y	Y	Y	Y	N
Method of manure application	Y	Y	Y	N	Y	Y	Y	N	N
- Plant nutrient cycle/uptake	Y	N	Y	Y	Y	Y	Y	Y	N
- Land management practices	Y	N	Y	Y	Y	Y	Y	N	N
- N fixation (legumes)	Y	N	Y	Y	N	Y	I	Y	N
- Non-agricultural land	Y	N	Y	Y	Y	Y	Y	Y	Y
- Anthropogenic effects (point sources and water transfer)	Y	Y	Y	Y	Y	Y	Y	Y	Y

Keys:
(Y)es, (N)o,
(E)xplicit, (I)mplicit,
*: The vertical discretisation is represented by the top of the deep aquifer and subdivided into ca. 10 layers.

Pathways and processes described by the quantification tools (Continued)

Model pathway, process or characteristic	**NL-CAT**	**REALTA**	**NLES**	**MONERIS**	**TRK**	**SWAT**	**EVEN-FLOW**	**NOPOLU**	**SOURCE AP**
QT number	1	2	3	4	5	6	7	8	9
Water balance									
Rainfall interpolation corrections for alt. (e.g. to grid)	N	N	N	Y	Y	Y	Y	N	N
Frost and snow	Y	N	Y	Y*	Y		N	N	N
Anthropogenic effects (point sources and water transfer)	Y	Y	Y	Y	Y	Y	Y	Y	N
Canopy interception	Y	N	Y	N	Y	Y	Y	N	N
Evapotranspiration	Y	N	Y	E	Y	Y	Y	Y	N
Hydrological pathways									
Overland flow									
Hortonian overland flow	Y	N	N	Y	Y	Y	Y	N	N
Saturation excess	Y	N	N	Y	Y	N	Y	N	N
Subsurface drainage volume									
- Routing: Preferential flow	Y	N	T	N	N	Y	T	N	N
- Routing: Matrix flow (Interflow)	Y	N	T	T	Y	Y	T	N	N
- Routing: Tile drainage	Y	N	N	Y	T	Y	Y	N	N
- Groundwater input/loss	Y	N	N	T	T	Y	N	N	N
- Shallow (S) and/or deep (d) groundwater	Sd	N	N	Y	Y	Sd	S	N	N
- Measured flow used to calculate water balance	N	Y	Y	Y	N	N	N	Y	
- Model prediction of river hydrograph	Y	N	N	N	Y	Y	Y	N	N
- Travel time	Y	N	N	Y	Y	Y	Y	N	N
Soil physical/chemical/biochemical processes									
- N and P mineralization/immobilisation	Y	N	N	I	Y	Y	N	N	N
- Linked to C cycle	Y	N	N	N	Y	N	N	N	N
- P sorption/desorption	Y	N	N	I	N	Y	N	N	N
- P precipitation	Y	N	N	N	N	Y	N	N	N
- Nitrification	Y	N	N	N	Y	Y	I	N	N
- Denitrification	Y	N	N	Y	Y	Y	I	N	N
- Ammonia volatilisation	Y	N	N	I	Y	Y	I	N	N
- Erosion (gross/net)	Y	N	N	I	Y	Y	N	N	N
- Sediment delivery function	N	N	N	Y	N	Y	N	N	N
- Enrichment ratio	N	N	N	Y	N	Y	N	N	N
- 1, 2 or 3D solute transport processes	1,3	N	N	N	1	3	1	N	N
- Implicit lumping of processes	N	Y	Y	Y	Y for P	N	Y	Y	Y

Keys:
(Y)es, (N)o, (E)xplicit, (I)mplicit, (T) Combined

Pathways and processes described by the quantification tools (Continued)

Model pathway, process or characteristic	**NL-CAT**	**REALTA**	**NLES**	**MONERIS**	**TRK**	**SWAT**	**EVEN-FLOW**	**NOPOLU**	**SOURCE AP**
QT number	1	2	3	4	5	6	7	8	9
River flow and prediction of stream concentrations									
- Model prediction of river hydrograph	Y	N	N	N	Y	Y	Y	Y	N
- Hydrograph separation approach	N	N	Y	Y	N	N	N	N	N
- Instream retention (streams and rivers)	Y	N	N	Y	Y	Y	Y	Y	Y
- Retention in lakes	N	N	N	Y	Y	N	N	N	Y
- Retention below the root zone	Y	N	Y	Y	Y	Y	N	N	N
- Load and/or concentration emission from land to water bodies (excluding retention in the surface waters)	L C	L	L C	L C	L C	L C	L C	L C	L C
Soluble inorganic P	Y	Y	N	N	N	Y	N	N	N
Dissolved organic N/P	Y	N	N	N	Y	N	N	N	N
Particulate organic N/P	Y	N	N	N	N	Y	N	N	N
Particulate inorganic P	N	N	N	N	N	N	N	N	N
Total P	Y	Y	N	Y	Y	Y	N	Y	Y
Suspended solids	N	N	N	N	N	Y	N	N	N
Nitrate-N	Y	N	Y	N	N	Y	Y	N	N
Ammonium-N	Y	N	N	N	N	Y	N	N	N
Nitrite-N	N	N	N	N	N	Y	N	N	N
DIN (dissolved inorganic nitrogen)	Y	N	N	Y	Y	Y	N	N	N
Total nitrogen	Y	N	N	Y	Y	Y	N	Y	Y
Intermediate Output									
Runoff	Y	N	N	Y	Y	Y	N	N	N
Root zone	Y	N	Y	Y	Y	Y	N	N	N
Subsurface	Y	N	N	Y	Y	Y	N	N	N
Groundwater/base flow	Y	N	Y	Y	Y	Y	N	N	N

Keys:
(Y)es, (N)o,
(E)xplicit, (I)mplicit,
(T) Combined
(L)oad and/or (C)oncentration

Annex 3. Description of criteria developed for different model types

The methodologies that are currently u sed for quantifying *diffuse* nutrient losses have been developed at a national level within Europe, and differ profoundly in (i) their level of complexity, (ii) their representation of system processes and path ways, and (iii) resource (d ata and time) requirements. They range from co mplex, process-based models - which typically have demanding data requirements - to se mi-empirical (conceptual) meta-models with some export coefficients, and approaches based on mineral balances and source apportionment. With m any nations using varying approaches, there is no w an urgent need for an intercomparison of these contrasting methodologies in order to form an objective judgem ent of their performance under different agricultural, geophysical and hydrological conditions throughout Europe.
Based on a discussion at a workshop in Berlin (17-18 April 2002), with all modellers of the EUROHARP project, the following scientific details were selected for the intercomparison of the quantification tools.

1) Original purpose/status and history of the model application (maturity)
2) Dependencies on previous models (scientific evolution)
3) Review of pathways and processes described by the quantification tools
4) Scientific description of the processes involved
5) Spatial resolution and discretisation (horizontal and vertical)
6) Temporal resolution and discretisation
7) Forms of nutrient losses described by the quantification tool
8) Data requirement
9) Operational experience and skills requirement of users
10) Participation in previous model comparison studies
11) Sub-modules that can be independently checked
12) Existing sensitivity analysis
13) Cost indication (based on work load to set up and apply the quantification tool)
14) Capability to evaluate nutrient and watershed management strategies (scenario analysis)
15) Applicability

These factors are discussed below.

1) Original purpose/ status and history of the model application (maturity)

Since the ori ginal purpose underlying the development of each model may differ, it is important to know these differences in order to understand the assumptions that have been made in each modelling approach. Furthermore, this will provide inform ation on the sc ope, applicability and capability to eva luate water and nutrient management strategies for each model considered.

2) Dependencies on previous models

Pat of the q uantification tools may have been deri ved from modules in other models. In this way the quantification tools have often evolved based on already peer-reviewed models.

3) Review of pathways and processes described by nutrient quantification tools

Nutrient loads of surface waters from non-point sources, mainly agriculture and nature, are caused by transport of different forms of nutrie nts over and through the soil to surface wat ers. Since a lot of quantification tools were developed for specific situations/circumstances (e.g. just for applications within a nation) simplifications were made from that persp ective. However, from an European point of view it is important to understand which pathways and forms of nutrient losses are described by each of the nutrient quantification tools. This information will be used to identify some of the restri ctions of the nutrient quantification tools (applicability; see also point 9)
Review and Literature Evaluation of Quantification Tools of Nutrient Losses EUROHARP 1-2003 11

4) Scientific description of processes

Since the biological, chemical and physical interaction of nutrients in soil is rather complex and difficult to (understand and) describe, many model developers have made appropriate simplifications or assumptions. In order to assess the capability of nutrient quantification tools to evaluate nutrient and watershed managemen t strategies (scenario analysis; see also point 14) information should include the extent to which t he quantification tools are able to describe the impact of different strategies on nutrient losses to surface waters.

5) Spatial resolution and discretisation (horizontal and vertical)
This factor covers the way in which the horizontal as well as the vertical (profile) discretisation is handled. Some quantification tools have limits on the smallest "unit" that can be modelled, and/or the range of catchment sizes for which the approach is valid.

6) Temporal resolution and discretisation
Some models only describe the mean annual or seasonal nutrient loss while others describe the dynamics in smaller timesteps (e.g. daily).

7) Forms of Nutrient losses
Nutrient losses from agricultural land to surface waters contain different forms/species of phosphorus and nitrogen e.g. the bioavailability of phosphorus in surface waters depends on the distribution of P-forms of the total load of P. Within this study, phosphorus is considered as soluble inorganic P, soluble organic P, particulate P, and total P; while nitrogen is considered as NO3, NH4, organic N and total N components.

8) Data requirement
Since the original aim of the quantification tools differ, the type as well as the amount of data differs remarkably. With regard to data requirements, the following type of data will be distinguished: management (fertilisation/crops), soil physical and biochemical characterisation, water balance.

9) Operational experience and skills requirement of users
This information is needed in order to determine if watershed managers will be able to use the quantification tool themselves, or whether applications and the processing of results should be conducted by independent experts.

10) Participation in previous model comparison studies
If available, results of earlier model comparison studies will be mentioned.

11) Sub-models that can be independently checked
Most models contain different modules and each module has their own functionality. Some of these modules/functions can be considered separately (e.g. water balance), which assists in the identification of sources of model error. This point is also related to point 2.

12) Existing sensitivity analysis
If available, detailed reported sensitivity analysis will give additional information about the most important input parameters of the model. Such work shows that the model has been tested for many different combinations of parameter settings and a large number of different values. An awareness of the most sensitive parameters assists in model applications as modellers are able to focus efforts on the accurate identification of the most sensitive model parameters.

13) Cost indication
The quantification tools can be classified in terms of complexity. Often it is the application of data-based models, such as dynamic process orientated tools, which require the greatest workload (through from data collection, processing, parameterisation, and calibration)
Review and Literature Evaluation of Quantification Tools of Nutrient Losses EUROHARP 1-2003
12 compared to simpler statistical approaches. As time is money, there is therefore a cost implication associated with selecting a particular model which may be a factor in model selection. We provide an indication of the total months of workload needed to apply the quantification tool for a particular "new" catchment.

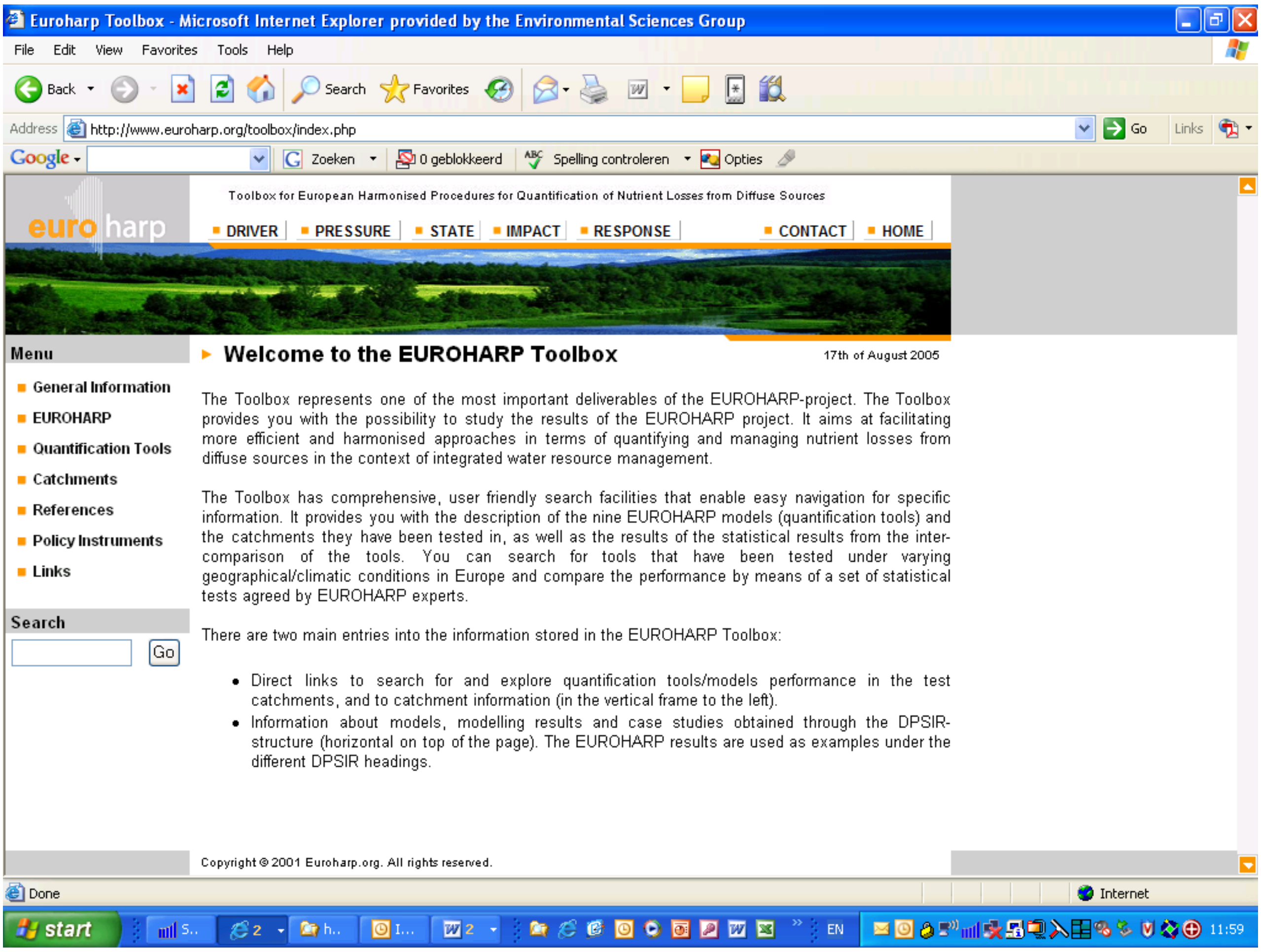
14) Capability to evaluate nutrient and watershed management strategies (scenario analysis)

The capability of quantification tools to determine the effects of different types of measures will be considered based on the mathematical description of the processes described in the tools. The measures that will be looked at include: nutrient management, land use changes and changes in watershed management.

15) Applicability

The potential applicability of the quantification tool to different environments will be considered by the model owner. This will be a qualitative indication because the "applicability" issue will be examined in greater detail later in Work Package 5 in the EUROHARP project.

Annex 4. Screenshot of EUROHARP Toolbox



Annex 5. Examples of normalization procedures

1. Danish methods for normalisation of model output

Lowess normalisation

Lowess normalisation for use in connection with trend detection in time series of concentration data together with eg. the Seasonal Mann-Kendall test.

Both total nitrogen and total phosphorus concentrations are highl y depending on discharge. This substance-specific relationship can be m odelled by the non-param etric and robust curve fitting method LOWESS (Locally W eigthed Scatterplot Sm oothing, Cleveland, 1979). The nutrient concentrations must be adjusted for runoff in or der to m inimise the impact from climate and to prevent a deterioration of the trend detection thereby increasing th e power of the test. To remove the effects of runoff calculate residuals, i.e.

$$r = x - \hat{x}_{(LOWESS)},$$

where $\hat{x}_{(LOWESS)}$ is the estimated concentration from LOWESS and x is the observed concentration. A time series plot of the residuals will reveal if the trend is still present in the adjusted values (residuals).

Modelled data

In order to establish a reference year for comparison of changes in nitrogen leaching we have used the following method:

A reference climate period is defined being minimum a 10 year period. A hydrological model is run with climate data as input for the 10 year period. The output data (year, month, day) is used to calculate an average (standard) climate year which is used as a reference. The new synthetic climate year can then be used as input to eg. leaching models and the output compared to the leaching in the present year.

Cleveland, W.S. (1979): Robust locally weighted regression and smoothing scatterplots. *Journal of American Statistical Association*, 74, 829-836.

2. Dutch method for normalisation of nutrient emissions from agriculture

Nutrient emissions from agriculture are calculated in the Netherlands with the model "STONE". This model looks much like the NL-CAT model. Model results are frequently used in policy analysis and policy evaluations.

Normally the STONE model is fed with real data for meteorology. For forecasts and model initialisation the time series 1971-1985 is used. This series is commonly used in the Netherlands for all kinds of hydrological analysis, mainly because this series is more or less representative for the climate in the Netherlands, especially for precipitation and precipitation excess. The average precipitation equals the long time average precipitation and the series contains both a 10% wet and a 10% dry year. Although recent years seem to deviate from the long time average, a recent eveluation of the data dids not result in a better "average" period. Long time series are constructed by repeating this time series.

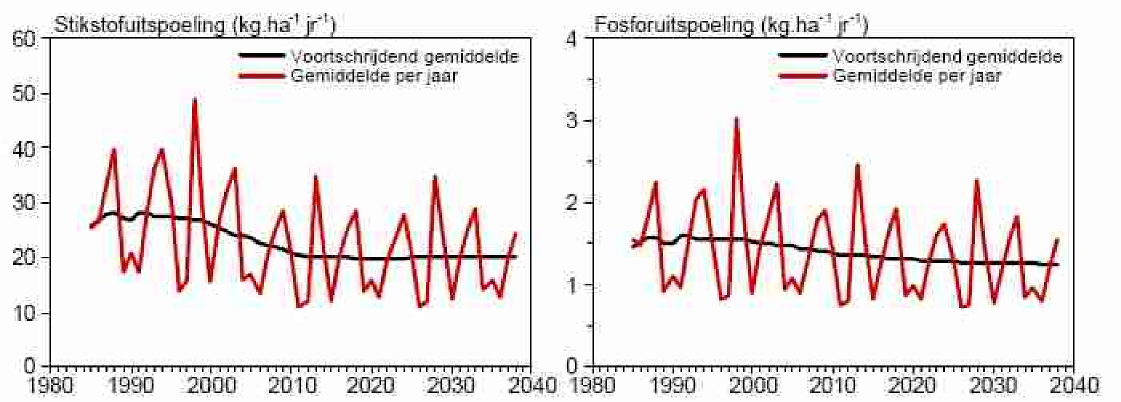


Figure 1. shows the results of nutrient emission calculations for such a long period. They show clearly that the influence of weather is much larger than that of policy measures. For this reason, it is useless to compare data of two arbitrary years. To overcome this problem, two methods are used:

1) for graphical presentation purposes the 15year running average is presented (see figure). This results in easy-to-read graphs, but the effects of policy are diluted;

2) for comparison of data from two or more specific years, model results from calculations with the meteorology of 1985 are used. The system of using the 1971-1985 series automatically results in the possibility to compare data from 1970, 1985, 2000 etc. If standardised data for another year is needed, then the year 1985 is inserted on the right place in the meteorological series. This this input a new hydrology and subsequently new nutrient emission data are calculated.

The main reason to use the year 1985 as a "standard" year is that it is the reference year for reductions in nutrient emission as agreed by the North Sea Ministers conference. Further analysis lateron showed that although the total precipitation of that year is a bit below average, the calculated nutrient emission for that year is very close to the average.

Annex 6. Overview of the statistics that have been applied to evaluate model performance in the EUROHARP project as shown in Annexes 7 and 8.

Root mean squared error

The Root Mean Squared Error ($RMSE$) is a measure of accuracy and is given by:.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}$$

where n is the number of data points, O_i is the average observation for year i and P_i is the average model prediction for year i. The lower limit for $RMSE$ is zero. Lower values indicate greater accuracy.

Mean Error

The mean error (ME) is a measure of systematic error or bias:

$$ME = \frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)$$

ME<0 denotes overestimation and ME>0 underestimation. Its optimum value is zero.

Mean Absolute Error

The mean absolute error (MAE) is given by:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|P_i - O_i\right|$$

Like the RMSE, its optimum value is zero. However, the MAE is less susceptible to large errors since the errors are not squared.

Nash-Suttcliffe's Model Efficiency

Nash-Suttcliffe's model efficiency (NS) is given by (Nash and Suttcliffe, 1970):

$$NS = \frac{\sum_{i=1}^{n}(O_i - \overline{O})^2 - \sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2}$$

where $\overline{O}$ is given by:

$$\overline{O} = \frac{1}{n}\sum_{i=1}^{n} O_i$$

Its optimal value is 1. Values smaller than 0 indicate that the model is less efficient than simply using the average observation $\overline{O}$ as prediction.

Annex 7. Annual statistical results of the model performance at outlet gauging stations in the three core catchments modelled in the EUROHARP project.

The statistics is for flow given in m3/s and dissolved inorganic nitrogen (DIN), total nitrogen (TN) and total phosphorus (TP) given in kg/ha.

Statistical test	model	No, Mosselva			UK, Ouse			It, Coenzo		
		flow	TN	TP	flow	DIN	TP	flow	DIN	TP
MAE	EveNFlow	0.8			3.4	6.2		2.0	3.0	
	MONERIS		1.8	0.02		3.5	0.77		2.0	0.66
	NL-CAT	0.9	0.5	0.04	6.2	2.8	0.95	1.9	19.9	0.76
	NLES-CAT		1.4			3.4			2.7	
	NOPOLU		0.7	0.03						
	REALTA			0.03			0.97			
	SWAT	2.6	2.2	0.08	2.2	2.7		0.5	1.1	0.78
	TRK	0.5	0.8		3.1	5.2	0.74	2.7	1.7	
ME	EveNFlow	0.6			3.4	5.9		-1.3	-2.0	
	MONERIS		1.4	0.01		0.6	0.77		-1.3	0.64
	NL-CAT	-0.8	0.2	0.04	6.2	2.4	0.95	1.0	-19.9	0.76
	NLES-CAT		0.8			2.0			-2.1	
	NOPOLU		0.7	0.03						
	REALTA			-0.01			0.97			
	SWAT	2.6	2.2	0.08	1.1	2.4		0.1	0.2	0.18
	TRK	0.0	0.8		-0.3	5.2	0.74	2.7	-0.2	
NS	EveNFlow	1.0			0.9					
	MONERIS		0.4	0.91		0.6			0.2	
	NL-CAT	0.9	1.0	0.67	0.8	0.7				
	NLES-CAT		0.4			0.6				
	NOPOLU		0.9	0.85						
	REALTA			0.91						
	SWAT	0.6	0.1	0.03	1.0	0.7		0.8	0.8	
	TRK	1.0	0.9		1.0				0.5	
RMSE	EveNFlow	1.0			4.4	7.4		2.7	3.6	
	MONERIS		2.2	0.04		4.0	0.80		2.2	1.21
	NL-CAT	1.1	0.7	0.07	8.2	3.6	1.02	2.1	26.6	1.27
	NLES-CAT		1.8			4.1			3.4	
	NOPOLU		0.9	0.05						
	REALTA			0.04			1.08			
	SWAT	2.9	2.7	0.12	2.3	3.7		0.5	1.2	1.10
	TRK	0.5	1.0		3.4	6.6	0.80	3.3	1.8	

Annex 8. Sub-annual statistical results of the model performance at outlet gauging stations in the three core catchments modelled in the EUROHARP project.

The statistics is for flow given in m3/s and dissolved inorganic nitrogen (DIN), total nitrogen (TN) and total phosphorus (TP) given in kg/ha.

SUBANNUAL	flow_m3s	NO3N_mgl	DIN_mgl	TN_mgl	TP_mgl	NO3N_kgha	DIN_kgha	TN_kgha	TP_kgha
Mean Error									
ENO_EveNFlow	3.41	0.056	0.197			0.007	0.008		
ENO_NL-CAT	6.25		0.615		0.169		0.004		0.002
ENO_SWAT	1.00	-0.488	-0.624			0.000	0.000		
ENO_TRK	-0.28		0.753				0.007		
ITE_EveNFlow	-1.27	-0.262				-0.011			
ITE_NL-CAT	1.05	-1.648	-1.446		-0.341	-0.056	-0.057		0.006
ITE_SWAT	0.07	0.955	1.236		-0.011	0.011	0.013		0.004
ITE_TRK	2.68		-1.142				-0.003		
NOV_EveNFlow	0.56								
NOV_NL-CAT	-0.76			0.091	0.002			0.001	0.000
NOV_SWAT	2.60			-0.384	0.010			0.001	0.000
NOV_TRK	0.00			0.115				0.002	
RMSE									
ENO_EveNFlow	49.53	1.697	1.732			0.040	0.041		
ENO_NL-CAT	30.90		1.653		0.315		0.046		0.004
ENO_SWAT	36.40	1.988	2.162			0.034	0.036		
ENO_TRK	24.50		1.733				0.033		
ITE_EveNFlow	17.52	1.101				0.040			
ITE_NL-CAT	16.54	4.599	4.526		1.041	0.196	0.191		0.046
ITE_SWAT	17.81	1.318	1.606		0.412	0.031	0.043		0.047
ITE_TRK	16.16		1.722				0.032		
NOV_EveNFlow	12.10								
NOV_NL-CAT	5.51			0.283	0.012			0.010	0.001
NOV_SWAT	7.42			8.993	0.058			0.070	0.002
NOV_TRK	5.34			0.247				0.009	
MAE									
ENO_EveNFlow	20.59	1.270	1.300			0.018	0.019		
ENO_NL-CAT	15.60		1.310		0.183		0.022		0.002
ENO_SWAT	18.29	1.502	1.675			0.017	0.018		
ENO_TRK	14.08		1.187				0.015		
ITE_EveNFlow	7.02	0.787				0.017			
ITE_NL-CAT	6.28	2.506	2.647		0.445	0.064	0.067		0.007
ITE_SWAT	8.03	1.020	1.274		0.192	0.014	0.018		0.009
ITE_TRK	6.19		1.407				0.015		
NOV_EveNFlow	7.13								
NOV_NL-CAT	4.04			0.222	0.008			0.007	0.000
NOV_SWAT	5.28			1.940	0.036			0.027	0.001
NOV_TRK	4.25			0.177				0.007	

Annex 9. Overall assessment of the performance of the models applied in the three core catchments in the EUROHARP project.

Model	Average costs for setting up and running the model[1]	Nutrient species modelled	Annual N load[2]	Annual P load[2]	Annual diffuse N loss from agricultural land[2]	Annual diffuse P loss from agricultural land[2]	Sub-annual losses	Spatial distributed results[3]
SWAT	******	TN.NO3.NH4. TP.PO4-P	****	**	***	*	Yes	***
NL_CAT	******	TN.NO3.NH4. TP.PO4-P	***	***	***	***	Yes	***
EvenFlow	***	NO3	***	-	****	-	Yes	**
MONERIS	**	TN.NO3.TP.PO4-P	****	****	****	***	No	**
TRK	*****	TN	****	-	****	-	Yes	***
REALTA	*	TP	-	-	-	***	No	**
NLES_CAT	**	NO3-N	****	-	****	-	No	**
NOPOLU	*****	TN.TP	***	-	-	-	No	**
SA	*	TN.TP	-	-	**	****	No	*

1: Average number of man-days spent on model calibration and running the model in the three core catchments: < 10 man-days = *; 10-20 man-days = **; 20-30 man-days = ***; 30-40 man-days = ****; 40-50 man-days = *****; > 50 man-days = ******.

2: Number of times the model was outside the average modelled results plus/minus the Standard Deviation on an annual level in the core catchments: 0/3 = ****; 1/3 = ***; 2/3 = **; 3/3 = *.

3: The possibility of applying the model to give spatial information: field level: ***; sub-catchment level: **; catchment level: *.

Annex 10. An overview of the potential suitability of the quantification tools to assess the impact of nutrient losses from agricultural land to surface waters for different type of scenarios

QT	Nutrient Management	Land use Changes	Water Measures
NLCAT - N	++	++	++
NLCAT - P	++	+	++
SWAT - N	++	++	++
SWAT - P	+	+	++
TRK - N	++	++	++
TRK - P	–	–	–
MONERIS - N	+	+	–
MONERIS - P	+	o	–
EveNFLOW - N	o	+	+
N-LES CAT - N	+	o	–
NOPOLU - N	o	o	–
NOPOLU - P	–	–	–
REALTA - P	–	–	–
SA - N	–	–	–
SA - P	–	–	–

++ = very suitable
\+ = suitable
o = more or less suitable
– = not suitable

Annex 11. Average costs shown as number of man-days for setting up, calibrating and running the nine EUROHARP models on the core catchments.

Note that the number of man-days spend on modelling to a great extent depends on the quality of the input data for each specific catchment.

	NL_CAT	SWAT	EvenFlow	MONERIS	NOPOLU	TRK[1]	SA	REALTA	NLES_CAT
	Average number of man-days spend for modelling								
1. Extraction and inspection of catchment data and contact to catchment owner	5.0	15.7	5.3	4.3	10.0	18.7	2.0	1.3	2.3
2. Transferring catchment data into the right format and inclusion of transfer functions. etc.	17.0	17.3	5.0	3.0	5.0	12.3	0.5	3.3	10.0
3. Delineation and discretisation of the catchment	13.6	18.2	3.0	1.3	15.0	6.0	NA	NA	1.0
4. Calibration of the model based on monitored data	25.3	29.2	5.0	2.7	5.0	2.0	NA	NA	2.0
5. Running of the model and creation of demanded output data (validation)	7.3	12.7	6.3	1.0	5.0	2.0	1.0	NA	1.0
Sum	68.3	93.1	24.7	12.3	40.5	41.0	3.5	4.6	16.3

NA: Not applicable for the model.