Integration and Coupling of Hydrological Models with Water Quality Models:

Applications in Europe

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Summary

The new EU Water Framework Directive (WFD), which shall be implemented by all EU nations by 2004, calls for more profound water-quality assessment and planning in Europe. Water-quality models are powerful tools for efficient water management and planning. The environmental problems that has been approached so far includes e.g., eutrophication, acidification, and emission dispersion. Different approaches to model water-quality have been identified, and there is a large variety of model concepts available. However, many of these are still applied on a research basis or are site specific. More frequent water-quality modelling in Europe would be beneficial for decision-makers and for the introduction of the WFD, but yet no review or compilation of present European model applications is available. Hence, it is not easy for water managers to know what models to apply.

Extensive integration and coupling of hydrological models with water quality models have been performed during the last 20 years. Independently of which part in the hydrological cycle that is considered most of these models origin from the U.S.A., but some have also been modified and applied for European conditions and others are developed within Europe. This report includes a compilation of the most frequently applied models in Europe at present, categorised according to scale and hydrological compartment or domain modelled (i.e., catchment scale, soil water and field scale, groundwater, river channels, lakes, urban storm water, and coastal zone). In total 37 models (Table 1) are described briefly and accomplished with web-page addresses, information of European distribution and references in refereed journals. The report also presents some decision support systems and on-going model comparisons in Europe. Moreover, the results are given from a questionnaire on model applications distributed among authorities in Europe (including 22 models), and finally, water quality modellers are recommended to contribute to a meta-database, which is available on WWW.

Table 1. Summary of the compilation and categorisation of the models described in the report.

Compartment / Scale		**Process description**		**Environmental problem addressed**		
		Mechanistic	Conceptual	Eutrophication	Acidification	Dispersion
catchment	9	3-5	4-6	6	3	0
soil / field	9	6-7	2-3	5	0	5
groundwater	2	2	0	0	0	2
river channels	6	3-6	0-2	1-3	0	3-5
lakes	5	5	?	5	0	0-2 (?)
urban stormw.	2	2	0	0	0	2
coastal zone	4	4	0	3	0	3
TOTAL	**37**	25-31	6-11	20-22	3	15-19

Acknowledgement

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Glossary

Model characterisation:

Conceptual	only the most prominent processes are described and/or several processes may be lumped into a single expression
Continuous	simulate seasons, years, or decades
Distributed	consider a hydrological compartment as a spatially variable system
Dynamic	time dimension with specific rates for different processes, creating time-series for temporal variability
Emission	summarise leakage coefficients and/or empirical emission data for different contribution classes to reveal the outlet conditions
Equifinality	the model is too complex in relation to the information in the data used for calibration
Eulerian	consider changes as they occur at a fixed point in the fluid
Event-based	simulate transport development only during a single storm
Finite-difference	finite approximations to the conventional derivative of a continuous function
Holistic	views in which the individual elements of a system are determined by their relations to all other elements of that system
Imission	estimated transport or concentration at the catchment outlet is related to upstream characteristics
Lagrangean	consider changes which occur as you follow a fluid particle
Lumped	the hydrological compartment is described in terms of average quantities
Mechanistic	all processes are described based on physical, chemical, and biological laws
Semi-distributed	conceptual functional relationships for hydrological processes that are applied to a relatively small number of what are assumed to be homogeneous parts of the catchment treated as "lumped units"
Source apportionment	estimation of contribution from various sources to the total load of pollution
Steady state	have no time component but describe average temporal conditions for the period studied

1. Introduction

The EU Water Framework Directive states that all waters within the Union shall be brought to a ”good status” and shall be managed in a sustainable way. According to the definition this includes both water quantity and quality aspects, and at present most rivers, lakes and coastal waters, do not fulfil this goal. The common use of water as a transport medium or as a recipient for unwanted substances prevents a multiple use of the resource and is not a sustainable management strategy. The new policy instruments that have been introduced to protect and improve European waters, include an ecological and holistic water status assessment approach; river basin water planning; a strategy for elimination of pollution by dangerous substances; public information and consultation and finally, new financial instruments. The EU Water Framework Directive aims at reaching “good water status” in year 2014, at the latest, and management plans for river basins must be presented in the year 2009. The directive calls for analysis to be made for groundwater, surface water and coastal zones of each catchment, and should be implemented by all nations in EU by 2004.

Major efforts will be needed for the years to come to fulfil the requirements of the Directive, along with other water-related environmental goals on the national level. International conventions, such as agreements made within HELCOM and OSPARCOM, define additional water quality goals. Thus, to enable efficient water management strategies, applicable control-strategies are urgently needed. Water management strategies include a variety of complex issues, which involves knowledge from a range of disciplines (e.g., Varis, 1994, 1996). These cannot be treated isolated in a piece-by-piece manner, but integrated catchment management must be applied. Stakeholders will ask for the rationality of every action and require that actions for different purposes are harmonised and effective from an over-all point of view. For example, how large is the impact on the sea from a specific part of the catchment or a point-source? Is it better to avoid autumn plowing than to construct a wetland for efficient nutrient reduction in this particular stream? What are the costs involved and how much can these measures reduce the pollution? In addition, actions aiming at local benefits should be balanced with actions needed on the large-scale to improve the water quality further down in the hydrological network.

The environmental problems that has been approached so far in water quality modelling includes e.g., eutrophication, acidification, and emission dispersion. Eutrophication of inland and coastal waters is a world-wide environmental problem and serious efforts are needed to reduce emissions and improve the situation (e.g., Ryding and Rast, 1989). It has been an environmental problem ever since the beginning of the industrial era, and it is strongly associated with urbanisation and efficient industrial and agricultural production. The effect of eutrophication is high production of plankton algae (“algal blooms”), excessive growth of weeds and macroalgae, leading to oxygen deficiency, which in turn leads to fish kills, reduced biological diversity, bottom death and toxic substances in the water. The prevailing opinion is that the eutrophication problem is caused by high nitrogen and phosphorus loads.

The problems related to acidification is mainly found in the northern hemisphere, and is caused by air-born pollutants that causes acid conditions when deposed on sensible soils. The boreal soils have low buffering capacity and acidification may lead to release of metal-compounds involving aluminium or mercury, which may be toxic when accumulated in the food-chain. They may result in fish kills, reduced biological reproduction, and poisoning. Acid atmospheric deposition is mainly caused by nitrogen and sulphur compounds released by burning of fossil fuels, however, efficient sulphur control has reduced the deposition in Europe considerable during the last two decades. Regarding dispersions of water-related pollutants, it may be important to model accidental emissions or indirect side-effects, as for pesticide treatment with solute leaching through the soil profile affecting groundwater or surface waters.

Measures against eutrophication and acidification have been introduced in Europe during the 60's - 80's, but mainly targeted the point-source emissions. The emissions have been successfully reduced for phosphorus discharge from treatment plants to surface water, and for sulphur emissions from power and heating plants to air. However, there are still large emissions from diffuse sources (such as soil leaching and traffic), which are difficult to measure "in situ". Reduction of diffuse sources is difficult to achieve as the sources are difficult to monitor and the nutrients constitute a natural part of the soil and water environment. Moreover, the measures requested to reduce diffuse sources more directly affect people's lifestyle and livelihood, asking for a policy that changes people's behaviour and involve the stakeholders in the management actions taken. For instance, the type of measures that reduce diffuse nitrogen leaching from arable land demand changed agricultural practices by the farmers.

To achieve acceptance for environmental policies and successful implementation, trustworthy methods for estimations of various sources contribution to an environmental problem are needed, as well as methods that calculate the expected and achieved effect of a measure. For such purposes, water quality models have shown to be pedagogic and powerful tools (e.g., Fig. 1 and 2). Decision makers and stakeholders benefit from the ability to run scenario simulations for optimal measure allocation to improve water quality in a catchment. The scenarios should be based on local analysis of socio-economic prerequisites and cost-efficiency for various measures. Integrating and testing of alternative management strategies, as well as judging their general feasibility and acceptance, are important steps in water management. Scenario analysis ask for a predictive model, which should be process-based and thus, normally is linked to a hydrological model for description of the transporting medium (i.e. water flow). This report presents a variety of water quality models, which are frequently used in Europe for pollutant turn-over in different compartments of the hydrological cycle. It is emphasised that this kind of models might be helpful tools when introducing the EU Water Framework Directive. Finally, the results are given from a questionnaire on the present use of process-based models in operational environmental assessment in Europe.

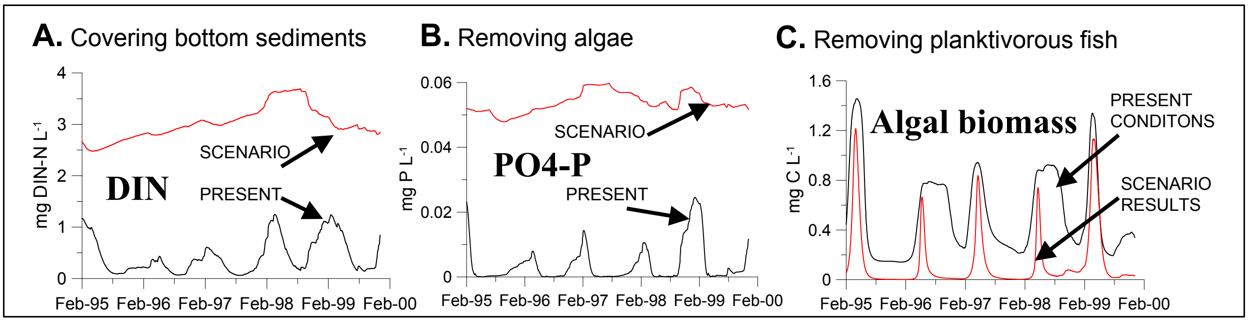

Figure 1. Modelling by using BIOLA for biogeochemical turn-over in a eutrophic lake, and analysing the effects of different in-lake methods to reduce the algal concentration. In scenario A and B the algaes were removed, but with undesired side-effects of increased nutrient load to the down-stream river system. In scenario C the algaes were reduced, but without significant side-effects on nutrient concentrations (Pers et al., to be published).

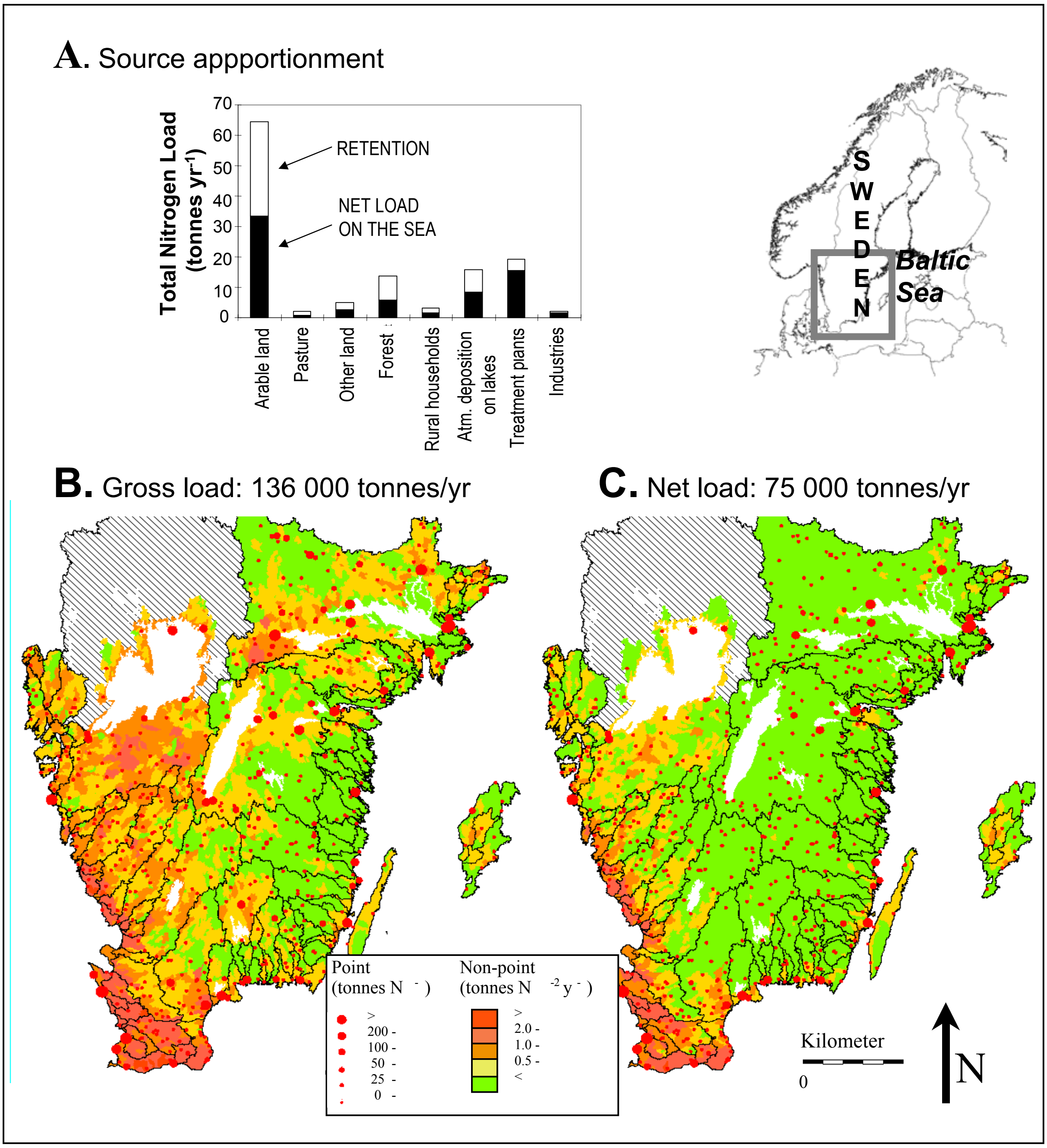

Figure 2. Model estimates of nitrogen transport from land to sea for the southern half of Sweden, using the HBV-N model: A. the contribution from various sources (i.e., source apportionment); B. gross load from diffuse and point sources, respectively; C. Net load after nitrogen removal in the fresh-water system between sources and the river outlet (modified from Arheimer and Brandt, 1998). To reduce the nitrogen load on the Baltic Sea it is important to consider the sources that contribute to the net load, to achieve the best cost-effectiveness.

2. Different approaches to model water-quality

Several ways of estimating riverine load of substances, terrestrial leakage, and retention in the aquatic system have been developed during the last decades. In environmental surveys it is important to separate the contributions from various sources and to distinguish between natural variability and anthropogenic impact, as this enables efficient environmental control and the introduction of the best management practices. It would be difficult and expensive to construct a satisfactory picture of e.g., soil leakage and water transport based only on measurements; consequently some kind of model must be applied. Modelling also enables predictions for the future by scenario simulations. A model is here defined as a numerical method to estimate water quality and transport of substances, which is based on various theoretical assumptions and generalisations. Since this field is multi-disciplinary, it includes a broad spectrum of scientists and practitioners from different backgrounds, which might be one reason for the large number of models available. In this chapter we will try to identify different kind of model approaches, independently of scale or water compartment modelled.

Water quality models may first be categorised into steady-state and dynamic models. Steady-state models have no time component but describe average temporal conditions for the period studied, while dynamic models have a time dimension with specific rates for different processes, creating time-series for temporal variability. Steady-state models may be categorised according to their spatial starts for the calculations as: 1) *imission models*, where estimated transport or concentration at the catchment outlet is related to upstream characteristics (e.g., Bauder et al., 1993; Grimvall and Stålnacke, 1996; Mattikalli, 1996), and 2) *emission models*, which summarise leakage coefficients and/or empirical emission data for different contribution classes in a catchment to reveal the outlet conditions (e.g., Haith and Shoemaker, 1987; Wendland, 1994; Johnes, 1996). Steady-state models may or may not be based on results from a hydrological model.

Dynamic N-transport models, on the other hand, are often based on a hydrological model, as water flow is the transport medium and most of the variability in substance transport is an effect of hydrological variability. As a consequence, the most frequently used hydrological models may also have a water quality routine linked to them (see, e.g., Singh, 1995). Dynamic models may be categorised according to their distribution in time and space and their degree of process description (see, e.g., Thorsen et al., 1996). Temporally, the calculations are often repeated with an hourly or daily time step. Event-based models, for example, AGNPS (Young et al., 1989), simulate transport development only during a single storm, while continuous models may simulate seasons, years, or decades. Spatially, the model may simulate the transport in one dimension, for example, a soil profile as in SOIL-N (Johnsson et al., 1987) and DAISY (Hansen et al., 1991), or it may include a full spatial distribution of transport in three dimensions, as in NELUP (Lunn et al., 1996) or NTT-Watershed (Heng and Nikolaidis, 1998). Dynamic models are often process-based and thus attempt to imitate nature by describing the physical and biogeochemical processes governing the water quality.

The fact that there is often a trade-off between a model's complexity and its predictive power has lead to a continuous debate in hydrological modelling (e.g., Abbott and Refsgaard, 1996), which is also relevant for water quality modelling. According to this discussion, dynamic models may be categorised as**:** 1) *mechanistic (i.e., physically based) models*, in which all processes are described based on physical, chemical, and biological laws (e.g., Penumalli et al., 1976; Reiche, 1994; Heng and Nikolaidis, 1998), and 2) *conceptual models*, in which only the most prominent processes are described and/or several processes may be lumped into a single expression (Knisel 1980; Christophersen *et al.* 1982; Sloan *et al.* 1994).

In most mechanistic catchment models, calculations are made in grids, which are assumed to be homogenous. Conceptual models normally describe the flow paths by coupling subbasins that may be considered hydrologically heterogeneous but for which only average conditions are described. Empirical data is then used for the calibration of a few process parameters, referred to as variability parameters (Bergström and Graham, 1998).

A major advantage of conceptual models is that they demand less input data and computational effort, which makes these models suitable for large-scale studies or in catchments where there is limited background information available. However, conceptual models have been criticised, *firstly* because the equations and calibrated parameters cannot be translated into physical equivalents (Lorup and Styczen, 1996) and thus cannot be validated, and *secondly*, because there is a risk of internal parameter dependence. The first of these arguments has been used against mechanistic models as well, as even plot-scale grids include too much heterogeneity to be represented by one set of constants in physical equations (Beven, 1996). Hence, mechanistic models cannot be validated in field either.

The second argument, listed above, against conceptual models is recognised as the equifinality problem, which was defined by Beven (1993) as the phenomenon that equally good model simulations might be obtained with many different combinations of parameter values. This may be caused by poorly identified parameters or interaction between model parameters, and causes uncertainty in using the model for variables and applications outside the calibrated data range (temporal and spatial). Equifinality reflects that the model is ill-posed, i.e. the model is too complex in relation to the information in the data used for calibration (Kuczera, 1997). To summarise, the problem in process-based modelling is that advanced mechanistic models cannot be applied due to input constraints, whereas simple but applicable models may not produce reliable predictions (e.g., Kuczera and Mroczkowski, 1998). Figure 3 and 4 illustrate the model structure of two different approaches to simulate water quality in lakes, and the model to be chosen for a specific survey depend on the purpose of the study.

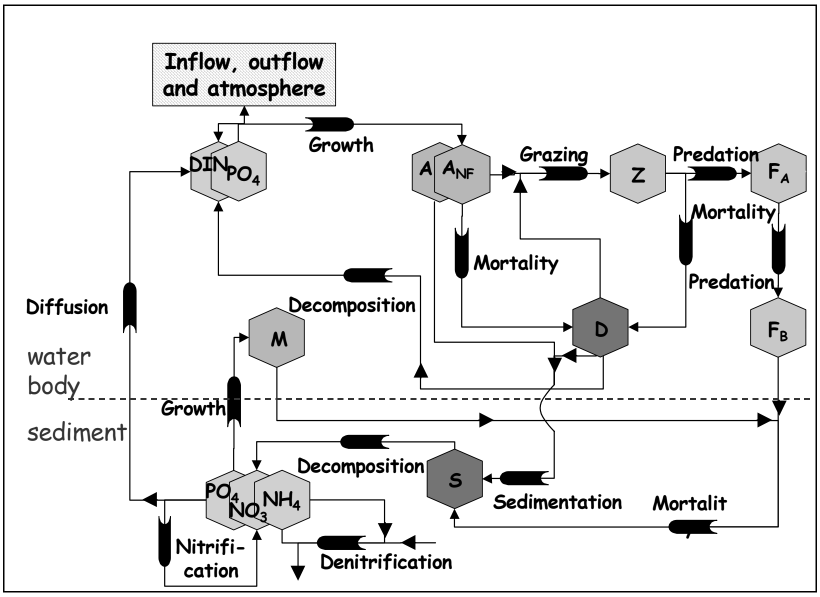

Figure 3. Schematic structure of the biogeochemical lake model BIOLA (Pers, 2002), which is linked to the hydro-physical model PROBE-lake (Svensson, 1998). The model is classified as: dynamic, one-dimensional, process-based, mechanistic (physically-based). The model calculates the state variables in the water-body in each layer (normally every meter) with a 10 minutes time-step. The compartments in the figure illustrates the storage of the following variables: DIN = dissolved inorganic nitrogen; PO_4 = phosphate; A = autotrophes (i.e., phytoplankton); Z = zooplankton; F_A = planktivorous fishes; F_B = predator fishes; D = detritus; S = sediment; M = macrophytes; NO_3 = nitrate; NH_4 = ammonium.

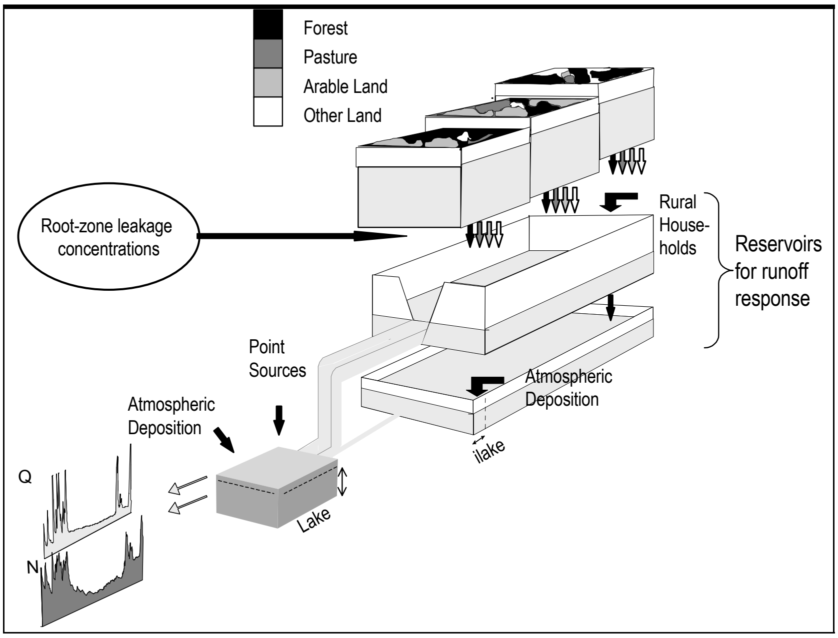

Figure 4. Schematic structure of the catchment model HBV-N (Arheimer and Brandt, 1998), which is based on the hydrological HBV model (Bergström, 1995). The model is classified as: dynamic, semi-distributed, process-based, conceptual. The model calculates water and nitrogen discharge in coupled sub-basins with a daily time-step, including nitrogen retention in groundwater, rivers and lakes.

Many models are not exclusively one kind or the other, and thus it is not always easy to categorise a specific model. In addition, model descriptions become complicated as models get more sophisticated and thereby lose transparency for the audience. The very same model may include mechanistic routines for some processes and others that are lumped. For example, the CHUM model, which is based on detailed chemical-equilibrium equations for soil micropores, lumps all the biological catchment processes (Tipping, 1996). Models are also frequently developed or put together, sometimes under the same name and sometimes under a different name, which may be confusing. For instance, the one-dimensional CREAMS model (Knisel, 1980) has been distributed in the name of SWRRB (Arnold and Williams, 1987) and AGNPS (Young et al., 1989); the NELUP N modelling system (Lunn et al., 1996) consists of EPIC (Jones et al., 1991) and SHETRAN-UK (Abbott et al., 1986; Ewen, 1990); and the SWIM model (Krysanova et al., 1998) is based on SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989).

The physical environment and purpose for which the model has been developed often limit model adaptability, and further applications may therefore demand additional development. In some cases most of the development needed for new applications include the translation and collection of adequate input data, especially for the American models, which are based on the empirical SCS Curve Number method (U.S. Department of Agriculture, 1972). This is clearly illustrated in the European adaptation of CREAMS for Finland (Rekolainen and Posch, 1993), and the modification of AGNPS for Germany (Rode and Frede, 1997).

Many model names flourish in the literature, but often the basic model equations are rather similar within a specific model category, while the interface and routines for input and output data may differ considerably. Sometimes routines for database handling are made by linking a GIS to the model (e.g., Needham and Vieux, 1989) or, if the model is not too large, the equations may even be written directly in GIS code (Potter et al., 1986) to facilitate the model's application. However, this increases the computational time considerably.

3. Survey of hydrological water-quality modelling in Europe

Several European water-quality models have been linked to hydrological models and applied for environmental assessment in different parts of Europe. We have focused on the most well-known and most frequently applied models, according to literature review, research on the WWW, contacts with model managers, and received answers to a questionnaire (Annex A). This means that there exists a whole range of other models that may be very well-posed and applicable, but which we have not included in this compilation. However, this survey gives an idea of the water-quality models available, applicable and evaluated for European conditions. The compilation is structured according to the hydrological compartment or scale modelled.

3.1. Catchment scale

A rather large variety of catchment scale models for water-quality modelling is available (Table 3.1). Several models originate from U.S. but have been modified for European conditions. The large variety for the catchment scale is probably caused by the different environmental conditions prevailing where the models have been developed. Different physiographical conditions demand different detailness on process descriptions for various hydrological compartments, and a common approach is that less important processes may be simplified. There is also a large variety of input-data available in different parts of Europe, which restricts model applicability and demands for modified approaches. Below follows a short description of each model in Table 3.1.

Table 3.1. Water-quality models for the catchment scale with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
AGNPS	USDA; 1987	AUT, BE, CH, CZ, DE, DK, ESP, FI, FR, HU, IRL, IT, LTU, NL, POL, PRT, RUS, SVK, UK	nutrients, pesticides	conceptual
HBV-N	SMHI; 1994	SE, EST	eutrophication control / nitrogen transport	conceptual
INCA	Univ. of Reading; 1998	UK, FI, NO, DE, DK, NL, FR, ESP	eutrophication control / nitrogen transport	conceptual / mechanistic
MAGIC	Univ. of Virginia; 1985	UK, NO, DE, ESP, FI	acidification control / nitrogen transport	conceptual / mechanistic
MERLIN	Univ. of Virginia; 1997	UK, SE, NL, NO	acidification control / nitrogen transport	conceptual
MIKE SHE	DHI; 1993	BE, CH, DE, DK, CZ, ESP, FR, GR, HRV, HU, IT, LTH, NL, NO, POL, SVK, SLO, SE, UK, YU	eutrophication control / pollutant transport, nitrogen transport	mechanistic
SHETRAN	Univ. of Newcastle; 1996	UK, ESP, FR, IT, PRT	pollutant control / sediment and nitrogen transport	mechanistic
SMART	Wageningen UR; 1989	FI, NL, CZ, TUR, RUS, ESP, AUT	acidification control	mechanistic
SWAT	USDA; 1993	13 European countries e.g., IT, DE, UK, BE	eutrophication and pesticide control /sediment, nutrients, pesticides	conceptual

AGNPS (AGricultural Non-Point Source pollution model)

Developer: United States Department of Agriculture (USDA); 1987

Model web site: http://www.sedlab.olemiss.edu/agnps.html
Purpose/substances: Non point source pollutant loadings (nutrients, pesticides)

Abstract: Conceptual watershed model developed to examine water quality as it is affected by soil erosion from agriculture and urban areas (Young et al., 1987). AGNPS has three major components: hydrology, soil erosion and nutrient pollution. The hydrological function provides prediction of runoff volume and peak flow rate. The soil erosion function includes soil erosion and sedimentation. The nutrient function analyses nitrogen, phosphorous and chemical oxygen demand concentration in the runoff and sediment. The model requires a total of 22 parameters for execution. These include: Digital Elevation Model (DEM) aspect and slope, soil, land use, and point source information. The model calculates information on the basis of a cell. AGNPS is a single event model for a watershed no larger than several thousand square acres. AGNPS uses another USDA developed model named CREAMS (see below) to predict nutrient/pesticide and soil particle size generation, transport and interaction.

Applications: According to the managers of the model, it has been used primarily for watershed water quality planning and for validation studies. Further it has been widely used at universities for educational purposes. Concerning European applications, the model has been downloaded in nearly every country in Europe; AUT, BE, CH, CZ, DE, DK, ESP, FI, FR, HU, IRL, IT, LTU, NL, POL, PRT, RUS, SVK, and UK. The model has been connected with a GIS-interface (GRASS) and in this version been applied in, e.g., IT and AUT.

References: Bragadin et al. (1993), Fisher et al. (1997), Klaghofer et al. (1993), Rode and Frede (1997), Young et al. (1987)

HBV-N

Developer: Swedish Meteorological and Hydrological Institute (SMHI); 1994
Model web site: http://www.smhi.se/sgn0106/if/hydrologi/hydchem.htm
http://www-nrciws.slu.se/TRK/metod_hbv.htm
Purpose/substances: Nitrogen transport and source apportionment for eutrophication management.

Abstract: The HBV-N model is semi-distributed and simulates nitrogen leakage and transport through groundwater, river and lake systems. The calculations are made for sub-basins that are coupled into larger river basins. The water balance is estimated with the rainfall-runoff model HBV, which 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 HBV model has been applied in more than 40 countries over the world and is used operationally in the Nordic countries. The nitrogen model, HBV-N, has separate routines for daily simulations of inorganic and organic nitrogen. The soil leakage from different land-use is mixed with discharge from rural household in the groundwater, runoff is mixed with contribution from upper sub-basins and lake water. In the river and lake routines, nitrogen atmospheric deposition on the water surface and load from industry and treatment plants are included. Concentration variations in due to biological and chemical processes in e.g. riparian zones and lakes, are described with simple functions mainly based on temperature, concentration and hydrology. The HBV-N model is linked to the SOILN model.

Applications: SE (operationally for the whole country, divided into 1000 basins), EST.

References: Andersson and Arheimer (2001), Pettersson et al. (2001), Arheimer and Brandt (2000), Lidén et al. (1999), Arheimer and Brandt (1998), Arheimer and Wittgren (1994)

INCA (Integrated Nitrogen in CAtchments)

Developer: Aquatic Environments Research Centre, University of Reading, UK; 1998
Model web site: http://www.rdg.ac.uk/INCA/
Purpose/substances: Nitrogen transport

Abstract: Based on mass balance and reaction kinetics, the INCA model accounts for the multiple sources of N and simulates the principle N mechanisms operating, including mineralisation, immobilisation, nitrification and denitrification. The model is dynamic and N concentrations and fluxes are produced as a daily time series. Also, the model is semi-distributed. As such, it does not model the catchment land surface in a detailed manner; rather, different land use classes within sub-catchments are modelled simultaneously and the information fed sequentially into a multi-reach river model.

Applications: The INCA model underlies an EU project also named INCA. The INCA project aims to use the model to assess the nitrogen dynamics in key European ecosystems. The project, which began in April 2000, will last for three years and involves eight partners from UK, FI, NO, DE, DK, NL, FR, and ESP (see further Model web site). Outside the EU project, the INCA software has currently (March, 2002) been downloaded by some 60 institutes world-wide according to the model managers.

References: Wade et al. (2002), Whitehead et al. (1998a, b)

MAGIC (Model of Acidification of Groundwater in Catchments)

Developer: Department of Environmental Sciences, University of Virginia, USA; 1985
Purpose/substances: Steam water nitrogen transport as a result of acidification

Abstract: MAGIC is a process-oriented intermediate-complexity dynamic model by which long-term trends in soil and water acidification can be reconstructed and predicted at the catchment scale. MAGIC consists of two groups of equations. (1) Soil-soil solution equilibria equations in which the chemical composition of soil solution is assumed to be governed by simultaneous reactions involving sulphate adsorption, cation exchange, dissolution and precipitation of aluminium, and dissolution and speciation of inorganic and organic carbon. (2) Mass balance equations in which the fluxes of major ions to and from the soil and surface waters are assumed to be governed by atmospheric inputs, mineral weathering, net uptake in biomass, and loss in runoff. MAGIC produces long-term reconstructions and predictions of soil and streamwater chemistry in response to scenarios of acid deposition and land use. MAGIC uses a lumped approach in two ways. (1) A myriad of chemical and biological processes active in catchments are aggregated into a few readily described processes. (2) The spatial heterogeneity of soil properties within the catchment is lumped into one set of soil parameters.

Applications: According to model managers, MAGIC is currently used by about 20 people/institutes in Europe (e.g., in UK, NO, DE, ESP, and FI), and as a teaching tool in at least one university. Included in the EU-project DYNAMO (see Chapter 5).

References: Cosby et al. (1985, 1995, 2001), Hinderer et al. (1998), Jenkins et al. (1997)

MERLIN (Model of Ecosystem Retention and Loss of Inorganic Nitrogen)

Developer: Department of Environmental Sciences, University of Virginia, USA (?); 1997
Purpose/substances: Nitrogen transport as a result of acidification

Abstract: MERLIN is a catchment scale model of linked C and N cycling in ecosystems. The model is split in to two plant compartments, namely active (plant) and structural (wood) biomass, and two soil organic compartments termed labile (LOM) and recalcitrant organic matter (ROM). Fluxes in and out of the ecosystem as well as between compartments are regulated by processes such as atmospheric deposition, hydrological discharge, plant uptake, litterfall, wood production, microbial N-immobilisation, mineralisation, nitrification, and denitrification. The rates of fluxes are controlled by the C/N ratios of organic compartments as well as the inorganic N concentrations in the soil solutions. The physical structure of the soils and hydrological discharge are used in conjunction with the organic fluxes to determine the retention and/or leaching characteristics of inorganic nitrogen at any time in the simulation. Plant and soil organic matter pools are highly aggregated in MERLIN in keeping with the focus of the model on catchment scale dynamics. MERLIN emphasises the coupling and interaction of hydrological and abiotic processes affecting N, with the biotic cycling of N within the ecosystem.

Applications: According to model managers, MERLIN is currently in use at four institutes in Europe. MERLIN is included in the EU-project DYNAMO (see Chapter 5), and the literature contains applications in, e.g., UK, SE, NL, NO (most of these within DYNAMO).

References: Emmett et al. (1997), Kjønaas and Wright (1998), Tietema et al. (1998), Wright et al. (1998), Cosby et al. (1997)

SHE (Système Hydrologique Européen)

SHE was developed in the mid-eighties as a joint effort by Institute of Hydrology (UK), SOGREAH (France) and Danish Hydraulic Institute. It is a deterministic, fully-distributed and physically-based modelling system for describing the major flow processes of the entire land phase of the hydrological cycle. Regarding water quality modelling, SHE was first used for nitrogen simulations. The model has since then been further developed, particularly into two versions that are widely used for water quality purposes: MIKE SHE and SHETRAN.

References: Abbott et al. (1986), Christiaens et al. (1995)

MIKE SHE:

Developer: Danish Hydraulic Institute; 1993
Model web site: http://www.dhisoftware.com/mikeshe/index.htm
Purpose/substances: Catchment water quality

Abstract: MIKE SHE is a dynamic modelling tool for the analysis, planning and management of a wide range of water resources and environmental problems related to surface water and groundwater, in particular when the effect of human interference is to be assessed. MIKE SHE is an integrated modelling environment with a modular structure. Individual components can be used independently and customised to local needs depending on data availability and aims of the given study. Powerful pre-processing and results presentation tools are included in the MIKE SHE software package. Typical areas of application include conjunctive use of water, surface water groundwater interaction, water resources management, irrigation management, changes in land use practices, farming practices including fertilisers and agrochemicals, wetland protection, contaminant transport in the subsurface, and determination of well capture zones. Can as a submodel include the model DAISY for the simulation of soil water and nitrogen dynamics in the crop-soil system.

Applications: According to model managers, the total number of European users amount to some 150 in BE, CH, DE, DK, CZ, ESP, FR, GR, HRV, HU, IT, LTH, NL, NO, POL, SVK, SLO, SE, UK, and YU.

References: Refsgaard et al. (1998, 1999), Styczen et al. (1999)

SHETRAN:

Developer: Water Resource Systems Research Laboratory, University of Newcastle, UK; 1996
Model web site: http://www.ncl.ac.uk/wrgi/wrsrl/rbms/rbms.html#SHETRAN
Purpose/substances: Catchment water quality

Abstract: SHETRAN is a 3D, coupled surface/subsurface, physically-based, spatially-distributed, finite-difference model for coupled water flow, multi-fraction sediment transport and multiple, reactive solute transport in river basins. It gives a detailed description in time and space of the flow and transport in the basin, which can be visualised using animated graphical computer displays. This makes it suitable for studying the environmental impacts of land erosion, pollution, and the effects of changes in land-use and climate, and also in studying surface water and groundwater resources and management. The subsurface is treated as a variably-saturated heterogeneous porous medium and fully 3D flow and transport can be simulated for combinations of confined, unconfined and perched systems. Stream channels are simulated as a network of links, each link running along the edge of a finite-difference cell. SHETRAN has been incorporated into the NELUP nitrogen modelling system, which is a part of a decision support system for ecological and agroeconomic management.

Applications: Applications: No information has yet been provided concerning the overall application of SHETRAN, but according to the web site it has been applied in at least UK, ESP, FR, IT, and PRT.

References: Birkinshaw and Ewen (2000), Ewen et al. (2000), Lunn et al. (1996), Moxey and White (1998)

SMART (Simulation Model for Acidification's Regional Trends)

Developer: Winand Staring Centre, Wageningen UR, NL; 1989
Purpose/substances: Regional soil acidification

Abstract: SMART2 is a simple one-compartment soil acidification and nutrient cycling model that includes the major hydrological and biogeochemical processes in the vegetation, litter and mineral soil. The SMART2 model is an extension of the dynamic soil acidification model SMART (De Vries et al. 1989). The major extensions in SMART2 are the inclusion of a nutrient cycle and an improved modelling of hydrology. The SMART2 model consists of a set of mass balance equations, describing the soil input-output relationships, and a set of equations describing the rate-limited and equilibrium soil processes. Since SMART2 is a single layer soil model, neglecting vertical heterogeneity, it predicts the concentration of the soil water leaving the root zone. The annual water flux percolating from this layer is taken equal to the annual precipitation, which must be specified as a model input. The time step of the model is one year, so seasonal variations are not considered. Recently a GIS-interface has been added, and the model renamed to GISSMART.

Applications: According to model managers, the total number of European users amount to 10-15 in FI, NL, CZ, TUR, RUS, ESP, and AUT. SMART was also used by the International Co-operative Programme on Integrated Monitoring (ICP-IM) for a number of sites in Europe, and it is currently (February, 2002) used within the framework of the EU/ICP Forest Intensive Monitoring Programme for simulations on about 200 forest sites all over Europe. The model is included in the EU-project DYNAMO (see Chapter 5).

References: De Vries et al. (1989), Kämäri et al.(1998), Kros et al. (1999), Mol-Dijkstra et al. (1998), Bilaletdin et al. (2001)

SWAT (Soil and Water Assessment Tool)

Developer: United States Department of Agriculture (USDA); 1993
Model web site: http://www.brc.tamus.edu/swat/
Purpose/substances: Catchment water quality

Abstract: SWAT is a complex, conceptual model with spatially explicit parameterisation. It is a continuous time model that operates on a daily time step The objective of the model is to predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungauged river basins. To satisfy the objective, the model is physically based and uses readily available inputs. The model runs in continuous time (daily updating of the water balance, plant growth, nutrient and pesticide concentrations, etc.) and is capable of simulating long periods for computing the effects of management changes. Model components include weather, surface runoff, return flow, percolation, ET, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT is an upgrade of the model SWRRBWQ (Simulator for Water Resources in Rural Basins - Water Quality).

Applications: SWAT has been modified and extended in Europe. (1) In Belgium (Vrije University) into ESWAT, which focuses on the incorporation of a detailed river water quality module. ESWAT was developed to allow for an integral modelling of the water quantity and quality processes in river basins. (2) In Germany (Potsdam Institute for Climate Impact Research) into SWIM, which besides SWAT is based on MATSALU. SWIM includes modules from both predecessors, trying to combine their advantages (hydrological submodel and GRASS interface from SWAT; spatial disaggregation scheme and nutrient modules from MATSALU), and to avoid overparametrisation. SWIM is a continuous-time spatially distributed river basin model, simulating hydrology, vegetation, erosion and nutrients. SWAT is further included in the EU project EUROHARP (see Chapter 5). The overall application of SWAT in Europe could not be assessed, but an indication can be obtained from the participants of the SWAT conference in Giessen, Germany, August 2001. There, 50 researchers from 13 European countries participated (e.g., IT, DE, UK, BE).

References: Arnold et al. (1998), FitzHugh and Mackay (2000), Krysanova and Becker (1999), Krysanova et al. (1998), Shepherd et al. (1999)

3.2. Soil water and field scale

Similarly to the catchment scale, there is a rather large variety of models available for soil water and the field scale (Table 3.2.). Several of these are related to the agricultural sector and the environmental problems caused by leaching of pesticides and fertilisers. Some models originate from U.S. but have been modified for European conditions. The large variety of models is probably a result of differences in environmental conditions and farming practices, along with differences in input-data available. Below follows a short description of each model in Table 3.2.

Table 3.2. Water-quality models for soil water and the field scale with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
ANIMO	Wageningen UR; 1991	BE, CH, DE, DK, CZ, FR, IT, NL, NO, POL, RUS, SLO, UK	nitrogen leaching to groundwater	mechanistic
EPIC	USDA; 1984	FR, DE, UK	soil erosion, nutrient cycling, pesticide fate, agricultural economics	conceptual
GLEAMS	USDA; 1987	FI, POL, DE, SE, RUS, UK, CZ	agricultural pollutants	conceptual
HYDRUS / SWMS	USDA; 1996	AUT, BE, DK, FR, DE, IT, NL, POR, ESP, SE, CH, UK	solute transport in porous media	mechanistic
MACRO	Swe. Univ. Agric.Scien.; 1994	SE, SP, DE, UK	solute transport in arable soils	mechanistic
PEARL	Alterra, NL; 2000	NL, SE, IT	pesticide leaching	conceptual / mechanistic
PRZM	US EPA; 1984		pesticide movement	mechanistic
SOILN	Swe. Univ. Agric.Scien.; 1987	SE, NO, FI, DK, EST	nitrogen leaching from arable soils	mechanistic
WAVE	Univ. Leuven; 1995	BE, NL, TUR	soil chemical transport	mechanistic

ANIMO (Agricultural NItrogen MOdel)

Developer: Winand Staring Centre, Wageningen UR, NL; 1991
Purpose/substances: Nitrogen transport to groundwater

Abstract: ANIMO dynamically simulates the carbon, nitrogen and phosphorus cycles in unsaturated and saturated soil systems. The model was developed to analyse the leaching of nitrogen from the soil surface to groundwater and surface waters. Optional simulation of the phosphorus cycle has been added to the model. Hydrological data must be supplied by another model. The model system is a multi-layer one-dimensional soil column. The upper boundary is the soil surface, the lower boundary is the depth of the local groundwater flow and the lateral boundary is defined by the surface water system(s). Main processes included in the model are mineralisation and immobilisation, crop uptake, denitrification related to (partial and temporal) anaerobiosis and decomposing organic materials, oxygen and temperature distribution in the soil, nitrification, desorption and adsorption of ammonium and phosphorus to the soil complex, runoff, discharge to different surface water systems and leaching to groundwater.

Applications: According to model managers, the total number of European users amount to some 70-80 in BE, CH, DE, DK, CZ, FR, IT, NL, NO, POL, RUS, SLO, and UK. Included in the EU-project EUROHARP (see Chapter 5).

References: Rijtema and Kroes (1991), Schoumans and Groenendijk (2000), Hendriks et al. (1999)

EPIC (Erosion-Productivity Impact Calculator)

Developer: United States Department of Agriculture (USDA); 1984
Home page: http://www.brc.tamus.edu/epic/

Purpose/substances: Soil erosion, nutrient cycling, pesticide fate, agricultural economics

Abstract: The model was developed to assess the effect of soil erosion on soil productivity. EPIC is a conceptual continuous simulation model that can be used to determine the effect of management strategies on agricultural production and soil and water resources. The drainage area considered by EPIC is generally a field-sized area, up to 100 ha (weather, soils, and management systems are assumed to be homogeneous). The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control. Recently, most of the EPIC model development has been focused on problems involving water quality and global climate/CO2 change. Example additions include the GLEAMS (Leonard et al., 1987) pesticide fate component, nitrification and volatilisation submodels, a new more physically based wind erosion component, optional SCS technology for estimating peak runoff rates, newly developed sediment yield equations, and mechanisms for simulating CO2 effects on crop growth and water use.

Applications: EPIC has been modified and extended in Europe. (1) In France (Centre de Recherches de Toulouse) into the EWQPTR model. The new model consider a division of the crop cycle into four development phases based on thermal time, the effect of rooting pattern on water extraction profile and a differential sensitivity of the phases to water and nitrogen stress. (2) In Germany (University of Osnabrueck) into OS-EPIC. (3) EPIC has been incorporated into the NELUP nitrogen modelling system, which is a part of a decision support system for ecological and agroeconomic management. No information has yet been provided concerning the overall application of EPIC in Europe.

References: Williams et al. (1984), Lunn et al. (1996)

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)

Developer: United States Department of Agriculture (USDA); 1987
Home page: http://sacs.cpes.peachnet.edu/sewrl/
Purpose/substances: Pollutant loading from agriculture

Abstract: GLEAMS is a conceptual, continuous simulation, field scale model, which was developed as an extension of the model Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS: Knisel, 1980; Svetlosanov and Knisel, 1982). GLEAMS assumes that a field has homogeneous land use, soils, and precipitation. It consists of four major components: hydrology, erosion/sediment yield, pesticide transport, and nutrients. GLEAMS was developed to evaluate the impact of management practices on potential pesticide and nutrient leaching within, through, and below the root zone. It also estimates surface runoff and sediment losses from the field. GLEAMS was not developed as an absolute predictor of pollutant loading. It is a tool for comparative analysis of complex pesticide chemistry, soil properties, and climate. GLEAMS can be used to assess the effect of farm level management decisions on water quality. GLEAMS can provide estimates of the impact management systems, such as planting dates, cropping systems, irrigation scheduling, and tillage operations, have on the potential for chemical movement. The model tracks movement of pesticides with percolated water, runoff, and sediment.

Applications: CREAMS has in Finland been adopted to European conditions under the name of ICECREAM. No information has yet been provided concerning the overall application of CREAMS and GLEAMS in Europe, but from the literature it is evident that the models have found widespread applications. Countries where the models have been applied include FI, POL, DE, SE, RUS, UK, and CZ.

References: Rekolainen and Posch (1993), Leonard et al. (1987), Knisel (1980), Svetlosanov and Knisel (1982), Shirmohammadi and Knisel (1994), Rankinen et al. (2001), Rekolainen et al. (2000)

HYDRUS/SWMS

Developer: United States Department of Agriculture (USDA); 1996
Model web site: http://www.ussl.ars.usda.gov/MODELS/HYDRUS.HTM
Purpose/substances: Solute transport in porous media

Abstract: HYDRUS is a modelling environment for analysis of water flow and solute transport in variably saturated porous media. HYDRUS_2D includes the two-dimensional finite element model SWMS_2D for simulating flow and solute transport in variably saturated media. The program is a finite element model for simulating movement of water, heat, and multiple solutes in variably saturated media. The program numerically solves the Richards' equation for saturated-unsaturated water flow and the Fickian-based advection-dispersion equations for heat and solute transport. The flow equation incorporates a sink term to account for water uptake by plant roots. The heat transport equation considers conduction as well as convection with flowing water. The solute transport equations consider advective-dispersive transport in the liquid phase, and diffusion in the gaseous phase. The program may be used to analyse water and solute movement in unsaturated, partially saturated, or fully saturated porous media.

Applications: According to the model managers almost 100 institutes all over Europe have acquired the model, including the countries AUT, BE, DK, FR, DE, IT, NL, POR, ESP, SE, CH, and UK. HYDRUS is included in the EU-project PEGASE (see Chapter 5).

References: Simunek et al. (1994), Mailhol et al. (2001), Persicani (1995)

MACRO

Developer: Swedish University of Agricultural Sciences; 1994
Model web site: http://www.mv.slu.se/bgf/macrohtm/macro.htm
Purpose/substances: Solute transport in arable soils

Abstract (http://www.mv.slu.se/bgf/Macrohtm/info.htm): MACRO is a physically-based, one-dimensional, numerical model of water flow and reactive solute transport in field soils. The model calculates coupled unsaturated-saturated water flow in cropped soil, including the location and extent of perched water tables, and can also deal with saturated flow to field drainage systems. The model accounts for macropore flow, with the soil porosity divided into two flow systems or domains (macropores and micropores) each characterised by a flow rate and solute concentration. Richards' equation and the convection-dispersion equation are used to model soil water flow and solute transport in the soil micropores, while a simplified capacitance type-approach is used to calculate fluxes in the macropores. Exchange between the flow domains is calculated using approximate, physically-based, expressions based on an effective aggregate half-width.

Applications: According to the model manager the model is widely used for both research and management purposes, but no detailed assessment of the applications was available. According to the literature it has been applied in SE, SP, DE, and UK. The model is included in the EU forum FOCUS and in the EU project PEGASE (see Chapter 5).

References: Jarvis (1994), Jarvis et al. (2000), Larsson and Jarvis (1999)

PEARL (Pesticide Emission Assessment at Regional and Local scales)

Developer: Alterra Green World Research and the National Institute of Public Health and the Environment, NL; 2000

Model web site: http://www.alterra.nl/models/pearl/home2.htm

Purpose/substances: Pesticide leaching

Abstract: Until 2000, two models (PESTLA and PESTRAS) were used in the Dutch pesticide registration procedure. This new model, PEARL, is the follow-up of the former two models. The PEARL model is used to evaluate the leaching of pesticide to the groundwater in support to the Dutch and European pesticide registration procedures. A regional-scale version of the model will be used for policy evaluation. PEARL describes the fate of a pesticide and relevant transformation products in the soil-plant system. The model consists of two components, i.e. a pesticide fate module and a soil water model. Pesticide fate: PEARL is a one-dimensional, dynamic, multi-layer model, which describes the fate of a pesticide and relevant transformation products in the soil-plant system. Soil water flow: Soil water flow is described with the SWAP model. SWAP (Soil, Water, Atmosphere and Plant) simulates vertical transport of water and heat in unsaturated/saturated soils. The program is designed to simulate the transport processes at field scale level and during the entire growing season

Applications: No information has yet been provided concerning the overall application of PEARL in Europe, but according to the literature it (or its predecessors) has been applied in at least SE and IT. It is included in the EU forum FOCUS (see Chapter 5), and is used in the Dutch pesticide registration procedure as a first screening tool.

References: Boesten (1994), Vollmayr et al. (1997), Brouwer (1994) Kroes et al. (2000), Leistra et al. (2000)

PRZM (Pesticide Root Zone Model)

Developer: United States Environmental Protection Agency (US EPA); 1984
Model web site: http://www.epa.gov/ceampubl/przm3.htm
Purpose/substances: Pesticide movement

Abstract: PRZM is a finite-difference model that simulates the vertical one-dimensional movement of pesticides in the unsaturated zone within and below the root zone. The model consists of hydrologic (flow) and chemical transport components to simulate runoff, erosion, plant uptake, leaching, decay, foliar washoff, and volatilisation. Pesticide transport and fate processes include advection, dispersion, molecular diffusion, and soil sorption. The model includes soil temperature effects, volatilisation and vapour phase transport in soils, irrigation simulation and a method of characteristics algorithm to eliminate numerical dispersion. Predictions can be made for daily, monthly or annual output. PRZM3 is the most recent version of a modelling system that links two subordinate models - PRZM and VADOFT (one-dimensional finite-element code which solves the Richard's equation for flow in the unsaturated zone) - in order to predict pesticide transport and transformation down through the crop root and unsaturated zone.

Applications: PRZM has been modified and extended in Germany into PELMO (PEsticide Leaching MOdel). The main modifications are that in PELMO evapotranspiration is estimated by using the Haude equation and depth dependent temperature in soil are calculated using daily air temperatures. No information has yet been provided concerning the overall application of PRZM in Europe, but according to the literature it (or its predecessors) has been applied in at least ESP and IT. PELMO is applied by the German Environmental

Protection Agency and the German Federal Biological Research Centre. Both PRZM and PELMO are included in the EU forum FOCUS (see Chapter 5).

References: Alvarez et al. (1997), Brown et al. (1996), Carsel et al.(1984), Klein et al.(2000), Trevisan et al. (2000)

SOILN (or Coup Model)

Developer: Swedish University of Agriculture; 1987
Model web site: http://www.lwr.kth.se/Vara%20Datorprogram/CoupModel/index.htm
http://www-nrciws.slu.se/TRK/metod_soilndb.htm
Purpose/substances: Estimation and scenario modelling of nitrogen leaching from arable soils

Abstract: SOILN is a one-dimension model describing nitrogen dynamics and losses in soil profiles in arable land. The hydrological SOIL model 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. SOILN includes the following processes: mineralisation of humus; mineralisation/immobilisation of carbon and nitrogen fraction in crop residue and the manure; nitrification; denitrification; nitrate leaching; plant uptake. It is also influenced by vertical redistribution and all biological processes depend on soil water and temperature conditions. The soil is divided into layers from which plants are taking nitrogen in various rates. 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. A method for assessing generalised nitrogen leaching estimates from large areas of agricultural land is developed for Sweden (SOILNDB). It is based on calculating a number of leaching estimates for different typical cropping situations using the central factors influencing the N root-zone leaching such as soils, crops and climate.

Applications: At least in SE, NO, DK, FI, EST.

References: Johnsson et al. (1987), Eckersten and Jansson (1991), Jansson (1991), Johnsson and Hoffmann (1998)

WAVE (Water and Agrochemicals in the soil, crop and Vadose Environment)

Developer: Katholieke Universiteit Leuven, BE; 1995
Model web site: http://www.agro.ucl.ac.be/geru/recherche/equip/wave/wave.htm
Purpose/substances: Soil chemical transport

Abstract: The WAVE describes the transport and transformations of matter and energy in the soil, crop and vadose environment. It is a deterministic, numerical and integrated model that simulates the behaviour of water, heat and agrochemicals in the vertical direction. The WAVE model is an integration of earlier models such as SWATRER (water module), SOILN (nitrogen module), LEACHN (heat and solute modules) and SUCROS (crop growth module). WAVE describes mass and energy fluxes according to the vertical direction. The soil profile is composed of soil layers which are subdivided into equally spaced intervals (the compartments). The water transport module is based on Richards equation. The solute transport module relies on a two-region convection-dispersion concept. The heat transport module uses the 1D heat flow equation. The nitrogen describes the transformation processes for the organic and inorganic nitrogen present in the soil.

Applications: According to the model manager the model is widely used, but no detailed assessment of the applications was available. According to the literature it has been applied in at least BE, NL, and TUR. WAVE is included in the EU project PEGASE (see Chapter 5).

References: Munoz-Carpena et al. (1999), Meiresonne et al. (1999), Vanclooster et al. (1995, 2000), Droogers et al. (2000)

3.3. Groundwater

Rather few models for water-quality simulations in groundwater were found (Table 3.3). The models available are all mechanistic and simulates any pollutants dispersion in groundwater aquifers. Several on-going efforts are presently made to link this kind of models to soil leaching models. In addition to the models presented here, there are several efforts with stochastic modelling for solute transport in groundwater. Below follows a short description of the two models in Table 3.3.

Table 3.3. Water-quality models for groundwater with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
ASM/ASMWIN	ETH; 1986	CH	pollution dispersion	mechanistic
MODFLOW /MT3D/RT3D	USGS; 1988	e.g. NL, DE, FR, IT, SE, UK	groundwater flow, solute transport	mechanistic

ASM/ASMWIN (Aquifer Simulation Model/for WINdows)

Developer: Swiss Federal Institute of Technology (ETH); 1986
Model web site: http://www.baum.ethz.ch/ihw/soft/welcome_e.html
Purpose/substances: Groundwater pollution

Abstract: ASM (Aquifer Simulation Model) is a horizontally or vertically, two-dimensional groundwater flow and transport model. The solution of the flow equation uses a finite difference method. The system equations can alternatively be solved with the method of preconditioned conjugate gradients (PCG) or the IADI-method (Iterative alternative direction implicit procedure). Pathlines and isochrones are computed by Euler-integration. The interpolation of the velocity alternatively uses the methods by Prickett or Pollock. Solute transport simulation uses random walk method based on Fokker-Planck theory. Pathline and isochrone calculations as well as transport simulation are possible for steady state flow fields only. ASM runs under MS-DOS, the MS Windows version is called ASMWIN.

Applications: According to the model manager the model is widely acquired and used, but no detailed assessment of the applications was available.

References: Kinzelbach and Rausch (1995), Kinzelbach (1986)

MODFLOW/MT3D/RT3D

Developer: United States Geological Survey (USGS); 1988
Model web site: http://www.modflow.com
Purpose/substances: Groundwater flow, solute transport

Abstract: MODFLOW is the name that has been given the USGS modular 3D groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering. Groundwater flow within the aquifer is simulated using a block-centred finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated. MT3D is a comprehensive three-dimensional numerical model for simulating solute transport in complex hydrogeologic settings. MT3D accommodates advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and non-linear sorption. RT3D is a software package for simulating three-dimensional, multispecies, reactive transport in groundwater. RT3D is based on M3TD, but is more flexible in terms of reaction frameworks and scenario modelling.

Applications: No information has yet been provided concerning the overall application of MODFLOW in Europe, but it appears widely applied mainly for quantitative modelling but also for qualitative assessments. The literature includes applications in e.g. FR, IT, and UK. Further, MODFLOW is routinely used by the German Federal Institute of Hydrology and Amsterdam Water Supply.

References: McDonald and Harbaugh (1988), Lasserre et al. (1999), Olsthoorn (1999), Ashley (1994), Chen and Soulsby (1997), Clement et al. (1998)

3.4. River channels

Several models are available for water-quality simulations within rivers (Table 3.4). Normally, the description of substance transformation in the river channel is mechanistic, and the transport calculations are based on hydraulics. Below follows a short description of each model in Table 3.4.

Table 3.4. Water-quality models for river channels with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
AQUASIM	EAWAG; 1994	BE, DK, DE, FI, FR, GR, UK, IRL, IT, NL, NO, AUT, POL, PRT, ROM, SE, CH, SLO, ESP, CZ, TUR, HU	substance transport and transformation in open channels	mechanistic
CE-QUAL	USACE; 1982	POR, DE, ESP, BE, CZ, UK, TUR	substance transport and dispersion	mechanistic
MIKE11	DHI; 1999	distributed to all European countries, but unclear if used for water quality modelling	water quality and sediment transport	mechanistic
PC-QUASAR	Centre for Ecol. & Hydr.; UK; 1997	10 users in e.g., UK, DE, CH, NL	river flow, ammonia, PH, nitrate, temperature, E.coli, biochemical oxygen demand, dissolved oxygen, and conservative pollutant or tracer	conceptual / mechanistic
QUAL2E	US EPA; 1987	widely used in e.g. UK, GR, BE, ESP, SLO	nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration, dissolved oxygen balance. 15 water quality concentrations.	conceptual / mechanistic
TELEMAC	Centre for Ecol. & Hydr.; UK; 1991	FR, UK, DE, IT, ESP.	environmental impact of reclamations and dredging schemes, strategic water quality planning, outfall design and pollutant dispersion, dredged material disposal, coastal defence design, port and harbour design, navigation and design of shipping channels, and wave activity including harbour resonance	conceptual / mechanistic

AQUASIM

Developer: Swiss Federal Institute of Technology (EAWAG); 1994
Model web site: http://www.aquasim.eawag.ch/
Purpose/substances: General framework for modelling of aquatic systems

Abstract: AQUASIM defines the spatial configuration of the system to be investigated as a set of compartments, which can be connected to each other by links. Currently, the available compartment types include mixed reactors, biofilm reactors (consisting of a biofilm and a bulk fluid phase), advective-diffusive reactors (e.g. plug flow with or without dispersion) and river sections (describing water flow and substance transport and transformation in open channels). Compartments can be connected by two types of links. Advective links represent water flow and advective substance transport between compartments, including bifurcations and junctions. Diffusive links represent boundary layers or membranes, which can be penetrated selectively by certain substances. For the model as defined by the user, the program is able to perform simulations, sensitivity analyses and parameter estimations using measured data.

Applications: AQUASIM is widely applied at Swiss Federal Institute of Technology and all over Europe. According to the model manager there, at present (February, 2002) 121 AQUASIM licenses have been issued in BE, DK, DE, FI, FR, GR, UK, IRL, IT, NL, NO, AUT, POL, PRT, ROM, SE, CH, SLO, ESP, CZ, TUR, and HU. Besides for rivers, the system has also been applied for quality modelling in e.g. porous media and lakes.

References: Reichert (1994), Fesch et al. (1998), Uehlinger et al. (2000)

CE-QUAL

Developer: United States Army Corps of Engineers (USACE); 1982
Model web site: http://www.wes.army.mil/el/elmodels/index.html#wqmodels
Purpose/substances: Water quality in reservoirs and rivers

Abstract: The CE-QUAL family comprises three models. CE-QUAL-R1 is a spatially one-dimensional and horizontally averaged model for reservoirs; temperature and concentration gradients are computed only in the vertical direction. The reservoir is conceptualised as a vertical sequence of horizontal layers where thermal energy and materials are uniformly distributed in each layer. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. CE-QUAL-RIV1 is a one-dimensional (cross-sectionally averaged) hydrodynamic and water quality model, meaning that the model resolves longitudinal variations in hydraulic and quality characteristics and is applicable where lateral and vertical variations are small. It can be used to predict one-dimensional hydraulic and water quality variations in streams and rivers with highly unsteady flows, although it can also be used for prediction under steady flow conditions.

Applications: No information has yet been provided concerning the overall application of CE-QUAL-R1 and CE-QUAL-RIV1 in Europe. According to the model manager of CE-QUAL-W2, it is widely used in Europe, including in POR, DE, ESP, BE, CZ, UK, and TUR.

References: Wells (2000), Robey and Stein (1982), Guenduez et al. (1998)

MIKE 11

Developer: Danish Hydraulic Institute; 1999 (latest version)
Model web site: http://www.dhisoftware.com/mike11/index.htm
Purpose/substances: Water flow and quality in rivers

Abstract: MIKE 11 is a engineering software package for the simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. It is a dynamic one-dimensional modelling tool for the detailed design, management and operation of both simple and complex river and channel systems. The rainfall-runoff module contains three different models that can be used to estimate catchment runoff. The hydrodynamic module contains an implicit, finite difference computation of unsteady flows in rivers and estuaries. The advection-dispersion module is based on the one-dimensional equation of conservation of mass of a dissolved or suspended material. The water quality module is coupled to the advection-dispersion module and simulates the reaction processes of multi-compound systems including the degradation of organic matter, the photosynthesis and respiration of plants, nitrification and the exchange of oxygen with the atmosphere. A non-cohesive sediment transport module can be used to study the sediment transport and morphological conditions in rivers.

Applications: According to model managers, the total number of European users amount to some 500 distributed over virtually all European countries. It is, however, unclear how much of this application that concerns water quality.

References: Hanley et al. (1998), Crabtree et al. (1994)

PC-QUASAR (UK)

Developer: Centre for Ecology & Hydrology, Wallingford, UK; 1997
Model web site: http://www.nwl.ac.uk/ih/www/products/mswpcquasar.html
Purpose/substances: Water flow and quality in rivers

Abstract: PC-QUASAR is a water quality and flow model for river networks. It is designed to be used by river regulatory authorities and water/sewerage utility companies to help manage river water quality. PC-QUASAR can provide distributions of flow and quality at key sites, allowing river regulators to set effluent consent levels designed to meet river quality objectives. PC-QUASAR can also provide river flow and water quality estimates at each reach boundary over a period of time, allowing proposed changes in the river's use, flow or quality to be assessed. The following determinants can be modelled: river flow, ammonia, PH, nitrate, temperature, E.coli, biochemical oxygen demand, dissolved oxygen, and conservative pollutant or tracer.

Applications: According to model managers, the total number of European organisational users is around 10 in e.g. UK, DE, CH, and NL.

References: Lewis et al. (1997), Whitehead et al. (1997), Eatherall et al. (1998)

QUAL2E (Enhanced Stream Water Quality Model)

Developer: United States Environmental Protection Agency (US EPA); 1987
Model web site: http://www.epa.gov/docs/QUAL2E_WINDOWS/index.html
Purpose/substances: Water flow and quality in rivers

Abstract: QUAL2E is applicable to well mixed, dendritic streams. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It can predict up to 15 water quality constituent concentrations. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. By operating the model dynamically, the user can study diurnal dissolved oxygen variations and algal growth. However, the effects of dynamic forcing functions, such as headwater flows or point source loads, cannot be modelled with QUAL2E. QUAL2EU is an enhancement allowing users to perform three types of uncertainty analyses: sensitivity analysis, first order error analysis, and Monte Carlo simulation.

Applications: No information has yet been provided concerning the overall application of QUAL2E in Europe, but from the literature and the web the model has been rather widely used in e.g. UK, GR, BE, ESP, and SLO.

References: Brown (1987), Barnwell et al. (1987), Drolc and Koncan (1999), Cubillo et al. (1992)

TELEMAC

Developer: Laboratoire National d'Hydraulique, FR, and Centre for Ecology & Hydrology, Wallingford, UK; 1991
Model web site: http://www.hrwallingford.co.uk/software/telemac/
Purpose/substances: Water flow and quality in rivers

Abstract: TELEMAC is a finite element based modelling system for simulation of physical processes associated with rivers, estuaries and coastal waters. TELEMAC uses an unstructured triangular grid allowing realistic representations of complicated coastlines and bathymetries. TELEMAC comprises modules for hydrodynamics (TELEMAC-2D/TELEMAC-3D), water quality (WQ 2D/3D), sediment transport (SUBIEF, SEDPLUME 3D), dispersion of pollutants (PLUME-RW, SISYPHE), wave dynamics (ARTEMIS, BOUSSINESQ, COWADIS), and pre- and post-processing (MATISSE, RUBENS). Applications include environmental impact of reclamations and dredging schemes, strategic water quality planning, outfall design and pollutant dispersion, dredged material disposal, coastal defence design, port and harbour design, navigation and design of shipping channels, and wave activity including harbour resonance.

Applications: "Current Users" on the model web site include institutions in FR, UK, DE, IT, and ESP.

References: Lucille et al. (2000), Kopmann and Markofsky (2000), Ciffroy et al. (2000), Galland et al. (1991)

3.5. Lakes

There are many models available for specific lakes in Europe, and well-known examples of deterministic models can be found in e.g., Jørgensen (1983). In the literature specific process-descriptions are repeated or compared and evaluated, but few general full-scale lake models seem to be available or well-spread over Europe. The most frequently applied models for lake management are simple empirical and statistical models. For instance, average values of lake depth, inflow, outflow and phosphorus concentration of inflow gives the eutrophication level (e.g., Vollenweider, 1968; OECD, 1982). Regional and national coefficients for this kind of regressions are often applied (e.g., Håkansson, 1995) and may also be found for nitrogen (e.g., Jensen et al., 1990 and 1992). More complex dynamic and mechanistic models have been developed to simulate the acidification processes (Small and Sutton, 1986) or for eutrophication management (cf. a few examples in Table 3.5), but each model seem to be applied only locally in Europe.

Table 3.5. Water-quality models for lakes with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
DELWAQ-BLOOM-SWITCH (DBS)	RIZA; 1994	NL, Danube countries	eutrophication management	mechanistic
DYRESM	Centre for Water Research, University of Western Australia; 1980	BIH, FI, FR, DE, GR, IT, NL, NO, POL, PRT, ESP, SE, CH, TUR, UK	hydrodynamics and water quality in lakes and reservoirs	mechanistic
LIMNOD	Eldgenössische Technische Hochschule, Zürich, Switzerland; 1992	CH	lake management and scenario modelling	mechanistic
PC-LAKE (PCLOOS)	LWD; 1992	NL	eutrophication management	mechanistic
PH-ALA	Univ. of Rome, Italy; 1996 (?).	IT	eutrophication trend analysis	mechanistic

DELWAQ-BLOOM-SWITCH (DBS)

Developer: Inst. for Inland Water Management and Waste Water Treatment (RIZA), The Netherlands; 1994
Model web site: (DELWAQ) http://www.netcoast.nl/tools/rikz/DELWAQ.htm
Purpose/substances: Eutrophication management

Abstract: The goal of DBS is to increase understanding of the eutrophication process and to be an operational tool for decision making. Rather than 'complex', the model may be described as 'large': the model contains about 45 state variables and 17 files with parameters in the water, the sediment and a boundary layer. Time-variable inputs are the hydraulic in and outflows, nutrient loading specified for several fractions, irradiation, water temperature, background extinctions and grazing rates. Calculations are carried out with a time-step depending on rate of the fastest process. Output of all variables and fluxes can be produced daily. The model may be applied to one compartment, or to a network of compartments. Initially, DBS was applied only to freshwater lakes, but later on (parts of) the model was also used for rivers, estuaries and oceans.

Applications: Mainly in NL, according to literature. The sub-model DELWAQ formed the basis of the Danube Water Quality Model (DWQM), that is used for assessment of eutrophication in the Black Sea.

References: van der Molen (1999), van der Molen et al. (1994)

DYRESM-CAEDYM (DYnamic REservoir Simulation Model - Computational Aquatic Ecosystem DYnamics Model)

Developer: Centre for Water Research, University of Western Australia; 1980
Model web site: http://www.cwr.uwa.edu.au/~ttfadmin/model/dyresm1d/
Purpose/substances: Hydrodynamics and water quality in lakes and reservoirs

Abstract: DYRESM is a one-dimensional hydrodynamics model for predicting the vertical distribution of temperature, salinity and density in lakes and reservoirs. It is assumed that the water bodies comply with the one-dimensional approximation in that the destabilising forcing variables (wind, surface cooling, and plunging inflows) do not act over prolonged periods of time. DYRESM has been used for simulation periods extending from weeks to decades. Thus the model provides a means of predicting seasonal and inter-annual variation in lakes and reservoirs, as well as sensitivity testing to long term changes in environmental factors or watershed properties. DYRESM can be run either in isolation, for hydrodynamic studies, or coupled to CAEDYM for investigations involving biological and chemical processes. CAEDYM is an aquatic ecological model that may be run independently or coupled with hydrodynamic models DYRESM or ELCOM. CAEDYM consists of a series of mathematical equations representing the major biogeochemical processes influencing water quality. At its most basic, CAEDYM is a set of library subroutines that contain process descriptions for primary production, secondary production, nutrient and metal cycling, and oxygen dynamics and the movement of sediment.

Applications: According to the model web site, DYRESM is currently being used in BIH, FI, FR, DE, GR, IT, NL, NO, POL, PRT, ESP, SE, CH, TUR, and UK (in the literature an application in CZ was also found). It is not known how many of the applications concern water quality.

References: Imberger and Patterson (1980), Han et al. (2000), Hamilton and Schladow (1997), Schladow and Hamilton (1997), Hejzlar et al. (1993)

LIMNOD

Developer: Lab. of Hydraulics, Hydrology and Glaciology, Eldgenössische Technische Hochschule, Zürich, Switzerland; 1992
Model web site: http://eco.wiz.uni-kassel.de/model_db/mdb/limnod.html
Purpose/substances: Long-term prediction of water quality in lakes. The effects of restoration

measures such as oxygenation, deep water drainage and artificial mixing can also be studied. The model is adaptable to most lakes by adjusting some lake specific parameters or by adding new state variables.

Abstract: LIMNOD is a one-dimensional vertical lake model which considers coupled physical, biochemical and sedimentation processes. For the physical description (state variables are temperature and conductivity), the lake is divided into fully mixed epilimnion and a hypolimnion with a sharp thermocline between these layers. The thermocline depth is calculated daily by means of an energy-balance considering heat and radiation exchange with the atmosphere and energy input by the wind. In the hypolimnion the turbulent mixing processes are expressed by the concept of a time and depth dependent eddy diffusion. Based on the physical processes a cycle of nutrients is calculated with phosphorus as limiting nutrient (state variables are the concentrations of particular organic carbon (biomass), dissolved oxygen and dissolved and particular phosphorus). In the sediment two types of organic phosphorus, inorganic phosphorus and organic carbon are considered. In this coupled system, transport of chemical species is governed by the physical model. Inversely, biochemical processes influence the stability of the water column due to light extinction by biomass reducing the penetration depth of the incoming short wave radiation and due to dissolution of settling particles from the epilimnion, enhancing the concentration of dissolved species in the hypolimnion.

References: Jørgensen et al. (1996), Karagounis (1992), Karagounis et al. (1993)

PC-LAKE (former PCLOOS)

Developer The Laboratory for Water and Drinking Water Research (LWD), The Netherlands; 1992
Model web site: http://www.rivm.nl/aboutrivm/labs/lwd.html
Purpose/substances: Eutrophication management

Abstract: The PCLake model specifies the food web in shallow lakes. The complete food chain is simulated in this model in order to predict the effect of measures such as reduced nutrient load, dredging, chemical manipulation, active biological management, and food chain interventions. The model combines a description of the internal nutrient cycles with a food-web approach. Applications include: combined calibration on a multi-lake data set, the effects of increasing vs. decreasing loading, evaluation of different restoration scenarios in several lakes in The Netherlands. PCLake is operational and can be linked to a water transport model called DUFLOW. Another model, PCDitch, shows how external nutrient load affects plant growth in ditches, often leading to excessive duckweed. Because water in ditches, as compared to lakes, has a relatively short staying retention time, linkage to a water transport model is essential.

Applications: NL

References: Janse (1997), Janse and van Liere (1995), Janse et al. (1998), Janse et al. (1992).

PH-ALA

Developer: Dept. Hydraulic, Transportation and Roads, Faculty of Engineering, University of Rome "La Sapienza", Italy; 1996 (?)
Model web site: http://eco.wiz.uni-kassel.de/model_db/mdb/ph-ala.html
Purpose/substances: To analyse over many years the eutrophication trend in a lake taking in account the three-dimensional characteristics of the hydrodynamic field.
Abstract: The system is composed by two different models, a hydrodynamic model and a mass balance model: Hydrodynamic model parameters: velocity components, temperature, baroclinic component of the pressure, density anomaly. Mass balance model parameters: phytoplankton concentration, phosphorus concentration, rate of phosphorus release from the bottom sediment, phosphorus concentration in the bottom sediment, residual components of the velocity, phytoplankton growth rate, phosphorus fraction in the algal biomass, sedimentation velocity. Forcing functions: wind action Necessary input: wind velocity and direction over long periods, initial temperature distribution in the lake, pollutant injection location and mass injection, daily hours of sunshine.

Applications: IT

References: Jørgensen et al. (1996)

3.6. Urban stormwater

Rather few models for water-quality simulations of urban stormwater were found (Table 3.6). The models available are all mechanistic and simulates any pollutants storm-runoff from the urban environment. In addition to the models presented here, there are several efforts with stochastic modelling for solute transport in urban stormwater. Below follows a short description of the two models in Table 3.6.

Table 3.6. Water-quality models for urban stormwater with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
MOUSE	DHI; 1980's	distributed to all European countries, but unclear if used for water quality modelling	water quality and sediment transport modelling package for urban drainage systems, storm water sewers and sanitary sewers	mechanistic
SWMM	US EPA; 1970's	CZ, DK, FR, IT, ROM, ESP, SE, but unclear if used for water-quality modelling	all aspects of the urban hydrologic and quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through drainage network, storage and treatment	mechanistic

MOUSE (Modelling Of Urban SEwers)

Developer: Danish Hydraulic Institute; 1980s (?)
Model web site: http://www.dhisoftware.com/mouse/index.htm
Purpose/substances: Water flow and quality in urban systems

Abstract: MOUSE is a comprehensive surface runoff, open channel flow, pipe flow, water quality and sediment transport modelling package for urban drainage systems, storm water sewers and sanitary sewers. MOUSE combines complex hydrology, hydraulics, water quality and sediment transport in a completely graphical interface. Typical applications of MOUSE include studies of combined sewer overflows (CSO), sanitary sewer overflows (SSO), complex RTC schemes development and analysis, design of new site developments, regulatory consenting procedures and analysis & diagnosis of existing storm water and sanitary sewer systems. MOUSE is supplied with routines for water quality in both surface and pipe runoff.

Applications: According to model managers, the total number of European users amount to some 500 distributed over virtually all European countries. It is not known how many are applying the model for water quality purposes.

References: Jensen and Linde-Jensen (1992), Entem et al. (1998), Schaarup-Jensen and Hvitved-Jacobsen (1994)

SWMM (Storm Water Management Model)

Developer: United States Environmental Protection Agency (USEPA); 1970s (?)
Model web site: http://www.ccee.orst.edu/swmm/
Purpose/substances: Water flow and quality in urban systems

Abstract: USEPA's SWMM is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Extran Block solves complete dynamic flow routing equations (St. Venant equations) for accurate simulation of backwater, looped connections, surcharging, and pressure flow. The modeller can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through drainage network, storage and treatment. Statistical analyses can be performed on long-term precipitation data and on output from continuous simulation. SWMM can be used for planning and design. Planning mode is used for an overall assessment of urban runoff problem or proposed abatement options.

Applications: No information has yet been provided concerning the overall application of SWMM in Europe, and from the literature it is difficult to estimate. At Danish Hydraulic Institute, SWMM has been combined with an interface into MIKE SWMM. According to the managers of MIKE SWMM, the total number of European users amount to some 40-50 in CZ, DK, FR, IT, ROM, ESP, and SE. It is not known how many are applying the model for water quality purposes.

References: Huber et al. (1985), Huber and Dickinson (1988), Tsihrintzis and Hamid (1998)

3.7. Coastal zone

The EU Water Framework Directive also include the coastal zone of the marine ecosystem, since this is highly influenced by land-based activities. Thus, we give a few examples of European modelling of the coastal zone (Table 3.7) even though this is outside the discipline of hydrology.

Table 3.7. Water-quality models for the coastal zone with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
BSHdmod	FMHA; 1990	DE (North and Baltic Sea countries)	dispersion and water quality modelling for coastal protection	mechanistic
DELFT3D	DH; 1970's	BE, DE, ESP, FR, IT, NL, POL, UK	modelling of coastal, river and estuarine areas	mechanistic
MIKE 21	DHI; 1980's	BUL, BE, HRV, CZ, DE, DK, EST, FR, GR, IRL, IT, LIT, NL, POL, PRT, RUS, SLO, SVK, ESP, SE, UK	modelling of estuaries, coastal waters and seas	mechanistic
SCOOBI	SMHI; 1999	SE (North and Baltic Sea countries)	eutrophication management	mechanistic

BSHdmod (Lagrangian and Eulerian)

Developer: Federal Maritime and Hydrographic Agency, Hamburg, DE; 1990 (?)
Model web site: http://www.wsv.de/cis/computer/computer.htm (Lagrangian)
Purpose/substances: Dispersion and water quality modelling for coastal protection

Abstract: The model exists in two versions, one Lagrangian and one Eulerian. To simulate the drift and dispersion of a substance in the Lagrangian Dispersion Model, the particular substance is represented by a particle cloud drifting with the current. Drift and dispersion forecasts are based on wind predictions of the DWD'S (German Weather Service) atmospheric models and on currents predicted by the BSH's Operational Circulation Model of the North Sea and Baltic Sea. In the dispersion model, also turbulence is taken into account. Sub-scale motion is simulated by a Monte Carlo method. In simulations of oil dispersion, the physical behaviour of different oil types on the water surface and in the water column is taken into account as well. The BSH's oil drift model simulates wind and current-induced drift, spreading, horizontal and vertical dispersion, evaporation, emulsification, sinking, beaching as well as the deposition of oil on the sea bed. The model is frequently used to trace back harmful substances and is thus a valuable tool in identifying environmental polluters.

Applications: Used in DE for the North and Baltic Seas.

References: Dick and Soetje (1990), Schönfeld (1995), Müller-Navarra et al. (1999)

DELFT3D

Developer: Delft Hydraulics, The Netherlands; 1970s (?)
Model web site: http://www.wldelft.nl/soft/d3d/index.html
Purpose/substances: Modelling of coastal, river and estuarine areas

Abstract: Delft3D simulates the time and space variations of six phenomena and their interconnections. While principally suitable for a variety of conditions, the package is mostly used for the modelling of coastal, river and estuarine areas. Delft3D is mainly the product of the WL / Delft hydraulics and the FLOW module of Delft3D is a multi-dimensional (2D or 3D) hydrodynamic (and sediment transport) simulation program which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary fitted grid. Delft3D consists of a modelling environment for six modules that are linked to one-another: hydrodynamics [Delft3D-FLOW], waves [Delft3D-WAVE], water quality [Delft3D-WAQ], morphology [Delft3D-MOR], sediment transport [Delft3D-SED], and ecology [Delft3D-ECO]. Delft Hydraulics have also developed a 1-D flow and water quality model named SOBEK.

Applications: According to model managers, the total number of European users of the DELFT3D water quality module amount to some 35 in BE, DE, ESP, FR, IT, NL, POL, and UK. The SOBEK water quality module is used by around 15 institutes, mainly in NL.

References: Postma et al. (1999), Uittenbogaard and Blumberg (2000)

MIKE 21

Developer: Danish Hydraulic Institute; 1980s (?)
Model web site: http://www.dhisoftware.com/mike21/
Purpose/substances: Modelling of estuaries, coastal waters and seas

Abstract: MIKE 21 is a professional engineering software package containing a comprehensive modelling system for 2D free-surface flows. MIKE 21 is applicable to the simulation of hydraulic and related phenomena in lakes, estuaries, bays, coastal areas and seas where stratification can be neglected. MIKE 21 offers two modules for coastal hydraulics and oceanographic studies, the hydrodynamic module and the nested grid hydrodynamic module. The group of environmental modules include the fundamental advection-dispersion module, plus process modules for water quality, eutrophication, heavy metals, and spill analysis. Sediment transport modelling include transport of sand, mud, and solutes or suspended matter. A range of wave modules are included in MIKE 21, based on wave action or momentum.

Applications: According to model managers, the total number of European users amount to some 200 in BUL, BE, HRV, CZ, DE, DK, EST, FR, GR, IRL, IT, LIT, NL, POL, PRT, RUS, SLO, SVK, ESP, SE, and UK. It is not known how many are applying the model for water quality purposes.

References: Joergensen and Edelvang (2000), Baretta et al. (1994), Malmgren-Hansen et al. (1984)

SCOBI

Developer: Swedish Meteorological and Hydrological Institute; 1999
Model web site: http://www.smhi.se/sgn0106/if/oceanografi/general.htm
Purpose/substances: Eutrophication management

Abstract: The SCOBI model is a coupled one-dimensional model with high vertical resolution. Horizontal variations are taken into account by dividing the area into smaller boxes. The model includes primary phytoplankton production, nitrogen fixation and secondary zooplankton production. It estimates ammonia, nitrate, phosphate, oxygen, phytoplankton, zooplankton and detritus. This work is a part of an integrated atmospheric-riverine-marine biogeochemical model system that is under development at the SMHI. The model is used for operational coastal management under establishment in Sweden.

Applications: Used in SE for the North and Baltic Seas.

References: Marmefelt et al. (1999), Marmefeldt et al. (2000)

4. Decision Support Systems applied in Europe

Several user-friendly interfaces for model applications exist in Europe. These usually include several process-based models (or may be adopted for different model approaches) for water-quality modelling in various compartments of the hydrological cycle. We mention a few well-known and frequently applied systems below.

BASINS (Better Assessment Science Integrating point and Nonpoint Sources)

Developer: United States Environmental Protection Agency (USEPA); 1996
Model web site: http://www.epa.gov/OST/BASINS/
Purpose/substances: GIS-based environmental modelling system

Abstract: The U.S. Environmental Protection Agency's water programs and their counterparts in states and pollution control agencies are increasingly emphasising watershed- and water-quality-based assessment and integrated analysis of point and nonpoint sources. BASINS is a system developed to meet the needs of such agencies. It integrates a geographic information system (GIS), national watershed data, and state-of-the-art environmental assessment and modelling tools into one package. It also supports the development of total maximum daily loads (TMDLs), which require a watershed-based approach that integrates both point and nonpoint sources. BASINS can support this type of approach for the analysis of a variety of pollutants. It can also support analysis at a variety of scales, using tools that range from simple to sophisticated. BASINS contains e.g. QUAL2E and SWAT (see above) as integrated submodels.

Applications: According to model managers the total number of European users is around 40, in e.g. SE, SLO, and FR. Most users appear to have acquired the model for purposes of testing, evaluation, and education.

References: Whittemore (1998), Whittemore and Beebe (2000)

MIKE BASIN (DK)

Developer: Danish Hydraulic Institute, 1999 (?)
Model web site: http://www.dhisoftware.com/mikebasin/index.htm
Purpose/substances: Catchment water quality

Abstract: In general terms, MIKE BASIN is a mathematical representation of the river basin encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing as well as potential major schemes and their various demands of water. MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. With the WQ module, MIKE BASIN can simulate transport and degradation of the most important substances affecting water quality in rivers: ammonia, nitrate, oxygen, total phosphorus, E. coli, COD, BOD, and a user-defined substance (e.g., salinity). The degradation process for all substances is described including reactive transformations (e.g., ammonia <> nitrate, oxygen <> BOD). Point sources as well as non-point pollution can be modelled. Point sources are generally water supplies with associated treatment plants. Non-point pollution includes total nitrogen and phosphorus loads, including their seasonal variation. Water quality in reservoirs and groundwater is modelled as well, assuming perfect mixing. MIKE BASIN WQ has facilities for calibration of non-point pollution loads and transport times in rivers.

Applications: According to model managers, the total number of European users amount to some 70-80 in DE, DK, CZ, ESP, FR, HRV, HU, IT, NL, POL, SE, and UK.

References: Krejcik and Vanecek (2000)

NELUP (NERC/ESRC Land Use Programme)

Developer: Water Resource Systems Research Laboratory, University of Newcastle, UK; 1995
Model web site: http://www.ncl.ac.uk/wrgi/wrsrl/projects/nelup/nelup.html
Purpose/substances: GIS-based environmental decision support system

Abstract: The NELUP decision support system (DSS) for predicting the impacts of agricultural land use change and analysing their implications at the river-basin scale, is the outcome of a 5-year multi-disciplinary research programme. The utility of the DSS can be summarised under three headings. (1) Description. A wide variety of spatial, temporal and relational data, describing the characteristics of the river basin, are stored in the system. (2) Prediction. Several models are installed within the DSS; these can be used to establish the characteristics of the river basin under a wide range of scenarios. The links between environmental- economic policy and the physical-ecological systems pertaining to a river basin are described. These links have been formalised through the integration of models, database and user-interface. (3) Presentation. The system provides visual statements of model results in graphical and tabular form to illustrate the consequences of land use change. The results are presented in formats that are of direct value to land use planners. NELUP contains e.g. SHETRAN and EPIC (see above) as integrated submodels.

Applications: It is unclear how much NELUP has been used (or is intended to be used) outside of the research project within which it was developed.

References: Haslam and Newson (1995), Dunn et al. (1996), O'Callaghan (1995)

5. On-going model comparison in Europe

The EU 5th Programme for Research and Development encouraged model benchmarking and comparison between different national modelling systems. Especially the section "Integrated catchment modelling" focused water-quality models and their benefits when implementing of the Water Framework Directive. Additionally, concerted actions were started. Below we mention a few on-going EU projects, with the objectives to apply and compare different water-quality models in Europe.

DYNAMO (DYNAmic MOdels to predict and scale-up the impact of environmental change on biogeochemical cycling)

Co-ordinating institute: The Macaulay Institute, Aberdeen, UK
Number of participating institutes: 5 (NO, UK, NL, FI)
Project web site: http://www.mluri.sari.ac.uk/dynamo/
Models included: NUCSAM, MAGIC, MERLIN, SMART, WANDA

Objectives: At present various acidification models are available ranging from simple steady-state lumped empirical models to complex dynamic distributed process orientated models. Most acidification models are process orientated. Soil and/or surface water acidification is predicted by describing processes in the soil system that have a major influence on soil and water quality responses. DYNAMO has three overall objectives. (1) Apply and evaluate dynamic biogeochemical models at intensively-studied catchments/large forest stands. (2) Use these models to scale up in space from the catchment/stand to the regional and continental scale. (3) Use these models to scale up in time from observations over several years to predict future impacts over decades under scenarios of global change, acid deposition and land use. Within DYNAMO the single and interactive effects of three dominant environmental driving variables on biogeochemical cycling in natural terrestrial and aquatic ecosystems are assessed by the models. (1) Acidic deposition denotes acidifying compounds derived from emissions of SO_x, NO_x and NH_4 to the atmosphere. (2) Global change denotes changes in atmospheric composition, in particular CO_2, and changes in temperature and precipitation. (3) Land use denotes primary changes in forest management practices, including commercial forestry.

EUROHARP (towards EUROpean HARmonised Procedures for quantification of nutrient losses from diffuse sources)

Co-ordinating institute: The Norwegian Institute for Water Research (NIVA)
Number of participating institutes: 22 (NO, UK, NL, IT, DK, FI, GR, SE, FR, IRL, LTU, DE, CZ, LUX, AUT, HU, ESP)
Project web site: http://www.euroharp.org/index.htm
Models included: ANIMO, Irish method, N-LESS, MONERIS, TRK (i.e., HBV-N and SOILN), SWAT, NEAP-N, NOPOLU

Objectives: The methodologies that are currently used in EC Member States and candidate countries for quantifying diffuse nitrogen (N) and phosphorus (P) losses have been developed at a national level. They differ profoundly in (1) their level of complexity, (2) their representation of system processes and pathways, and (3) resource (data and time) requirements. With many nations using different approaches/methodologies, there is now an urgent need for an intercomparison of these contrasting methodologies in order to form an objective judgement of their performance and cost-effectiveness under different agricultural, geophysical and hydrological conditions throughout Europe. The primary objective of EUROHARP is two-fold. (1) Provide end-users (national and international European environmental policy-makers) with a thorough scientific evaluation of nine contemporary quantification tools and their ability to estimate diffuse nutrient (N, P) losses to surface freshwater systems and coastal waters, and thereby facilitate the implementation of the EC Water Framework Directive. (2) Develop an electronic decision support system (toolbox) for the identification of benchmarking methodologies with respect to both costs and benefits, for the quantification of diffuse nutrient losses under different environmental conditions across Europe.

FOCUS (FOrum for the Co-ordination of pesticide fate models and their USe)

Workgroup web site: http://arno.ei.jrc.it:8181/focus/
Models included: PEARL, PELMO, PRZM, MACRO

Objectives: Plant protection products have an important role in agricultural production and food security, and ensuring their safety to man and the environment is of paramount importance. The FOCUS groundwater scenarios are used to assess the potential movement of active substances and metabolites of plant protection products to groundwater. They form a part of the review process for active substances in the EU. The FOCUS groundwater scenarios are a set of nine standard combinations of weather, soil and cropping data which collectively represent agriculture in the EU for the purposes of a Tier 1 EU-level assessment of leaching potential. The scenarios and their derivation are described in detail in a published report. The scenarios have been implemented as sets of input files for four simulation models - MACRO, PEARL, PELMO & PRZM. These input files and the simulation models which are needed to run them, form an important part of the leaching assessment process. In addition to the FOCUS groundwater scenarios also FOCUS surface water scenarios are under development.

PEGASE (Pesticides in European Groundwaters: detailed study of representative Aquifers and Simulation of possible Evolution scenarios)

Co-ordinating institute: Bureau de Recherches Géologiques et Minières (BRGM), FR
Number of participating institutes: 11 (FR, DE, NL, SE, DK, CH, IT, UK)
Project web site: http://www.brgm.fr/pegase/
Models included: AGRIFLUX, ANSWERS, HYDRUS, PESTAQ, MACRO, WAVE, MARTHE, TRACE/PARTRACE

Objectives: Production of high quality data sets with intensive and extensive 32-months monitoring of contrasted aquifers: (1) detailed land use and pesticide applications, (2) soil, vadose zone and aquifer characterisation, (3) long term (> 10 months) degradation studies, (4) pesticide monitoring of the ground water (GW), at least monthly sampling frequency. Development of mechanistic and semi-empirical tools dedicated to the modelling of pesticide contamination of GW: (1) operating links between root zone models (RZMs) outputs and aquifer models (AQMs) inputs, (2) modelling of pesticide GW concentrations, (3) spatialisation of the tools by coupling with GIS, (4) screening tool for preliminary assessment. Performance assessment of those tools: (1) calibration of the water balance, (2) calibration of GW pesticide concentrations, (3) assessment of the predictive capacity of the tools, (4) revision of the tools. Socio-economic assessment of alternative scenarios: (1) development of an interactive ICT format, (2) exploitation of his tool as a part of the scenario generation and evaluation process, (3) final delivery of the tool for other research and educational applications.

6. Survey by inquiry and establishment of meta database

To start up this survey a questionnaire was sent out to 154 scientists and water authorities in Europe (Annex 1). However, there was a rather weak interest in answering to the questionnaire and it was doubtful weather the answers achieved actually reflected the models most frequently used in Europe (Table 6.1). Therefore the literature review was performed to complete the survey. The original objective was firstly, to make a compilation of water-quality models that are used operationally for environmental assessment in Europe, and secondly, to establish a meta database for such models on the WWW. The second goal will not be full-filled as a result of the weak interest from authorities, along with the fact that there already exists a web-based database (called REM or ECOBAS), which also includes water-quality models. This database is not limited to European modelling, but is managed from Europe. It is under development and has attracted many modellers lately. It would thus not be fruitful to construct a competitive web-site. Instead, it is highly recommended to all model owners to include information about their models at the existing site.

Web site: http://eco.wiz.uni-kassel.de/ecobas.html

Abstract: REM: The Register of Ecological Models (REM) is a meta-database for existing mathematical models in ecology. REM is a co-operative service of the University of Kassel and the GSF - National Research Center for Environment and Health.
ECOBAS: The ECOBAS project provides a system for documentation of mathematical descriptions of ecological processes. In particular ECOBAS focuses on i) convenient access to information, ii) complete and precise documentation of mathematical formulations including the limits of validity wherever feasible and, iii) standardisation of documentation.

Table 6.1. Received answers on the questionnaire to authorities and researchers in Europe, considering their use of water-quality models for environmental assessment (cf. Annex A).

COUNTRY (Institute) **DOMAIN**	**MODEL NAME**		**SUBSTANCES MODELLED**	**APPLICATIONS IN ENV. ASSESSMENT**			**MAJOR REFERENCES**
	Hydrology part	**Water quality model**		**Purpose**	**SPACE resolution coverage**	**TIME step period**	**(Publications)**
AUT(BOKU) **Soil profile**	LEACHM	LEACHM	NaCl	Breakthrough curve	25 mm 1 m	0.01 d 1 d	Taxenbacher (1993), Diploma Thesis at University of Agriculture Sciences, Vienna, AUT
AUT(BOKU) **Groundwater**	MOC	MOC	1,1,1-Trichlorethane	Expert opinion	50 m 5×7 km	5 h 6 y	Kammerer et al. (1996), in: Zannetti & Brebbia (eds.), Development and Application of Computer Techniques to Environmental Studies VI, Southampton: Computational Mechanics Publications
AUT(BOKU) **Soil profile**	HYDRUS CHAIN_2D	HYDRUS CHAIN_2D	Metamitron, bromide	Model validation Tracer experiment (lysimeter)	5 mm 1.2 m 10 cm 4 m	0.1 d 450 d - 2 y	Klepsch et al. (2000), in: Bentley et al. (eds), Computational Methods in Water Resources XIII, Rotterdam: Balkema
AUT(BOKU) **Groundwater**	EPIC	EPIC	N	Groundwater recovery	(soilmap) 80 000 km	1 d 20 y	Tuller and Cepuder (1995), Wiener Mitteilungen, Band 109, 33-63; Cepuder et al. (1997), Proc. 11th World Fertilizer Congress, Gent (BE), 2, 451-465
DE (GFIH) **River channel**	QSIM	QSIM	Temp, pH, seston, C, N, P, Si, O_2, algae biomass, zoo-plankton, mussels	Water quality, biological interactions	0.1-2 km 5-500 km	1 h 1 y	Müller and Kirchesch (1990), Water Sci. Tech., 22, 69-78; Schöl et al. (1999), Hydrobiologia, 410, 167-176
DE (GFIH) **Groundwater**	MODFLOW	MT3D/ RT3D	Multi-species (hydrocarbon, oxygen)	Environmental impact of construction and maintenance of federal waterways	10 m²-1 km² 10-100 km²	1 min 1 y	http://bioprocess.pnl.gov
DE (FMHA) **Sea (North Sea, Baltic Sea)**	BSHcmod	BSHdmod.L or BSHdmod.E	Oil, floating subst., conservative subst., suspended matter	Water quality, drift and dispersion prognoses for coastal protection	1.8-10 km 10^6 km²	15 min days/years	Schönfeld (1995), J. Mar. Systems, 6, 529-544; Müller-Navarra et al. (1999), Acta Hydrochim. Hydrobiol., 27, 364-373

Table 6.1. Continued...

COUNTRY (Institute) DOMAIN	MODEL NAME		SUBSTANCES MODELLED	APPLICATIONS IN ENV. ASSESSMENT			MAJOR REFERENCES
	Hydrology part	**Water quality model**		**Purpose**	**SPACE resolution coverage**	**TIME step period**	**(Publications)**
DK (?) **Catchment (prec.-runoff)**	NAM	NAM	Stream hydrograph (quick/intermediate/base flow), coupled to N, P measurements	Trends of nutrient concentrations from different hydrological pathways	Catchment 3-58 km²	1 d 10 y	Andersen et al. (2001), Water Sci. Tech., in press
DK (?) **Soil profile**	EVACROP	N-LES	Nitrate	Agricultural nitrate leaching	Field 3-58 km²	1 y 10 y	Andersen et al. (1999), Water Sci. Tech., 39, 257-264; Simmelsgaard et al. (2000), DJF rapport nr. 32, Danmarks Jordbrugs Forskning
FI (FEI) **Catchment** **FI** (FEI) **Catchment** **FI** (FEI) **Groundwater**	HBV-FEI INCA/ WSFS HST3D	CATCH-LOAD/PIR INCA HST3D	P Inorganic N Chloride	Diffuse load Simulate and predict N transport, processes and retention Simulate road salt transport	10-100 km² 100-10^5 km² 1-100 km² 1-10^5 km² 400-2000 m² 1 km²	1 d years 1 d years 2 min-10 d 50 y	Bilaletdin et al. (1994), Publ. Acad. of Finland 1/94, Helsinki, pp.128-133 Wade et al. (2002), Hydrol. Earth System Sci. (submitted) Nystén et al. (1995), Tielaitoksen selvityksiä 29/1995 (in Finnish with English abstract.)
FI (FEI) **Groundwater**	MODFLOW	MODPATH MT3D RT3D		Modelling artificial groundwater	400-10^4 m² 3-10 km²	Steady state	Kivimäki et al. (1998), In: Peters et al. (ed.), Proc. 3rd Int. Symp. on Artificial Recharge of Groundwater - TISAR 98, Amsterdam, Sep. 21-25, 1998.
FI (FEI) **River channel**	1Dflow-FEI HBV-FEI	1Dsed-FEI 1Dqual-FEI	SS, Hg, PCDD/F, BOD, O2, TOTN, TOTP, PO4, NO2, NH4, phytoplankton biomass	Transport of contaminants	100 m 100 km	1 h decades	Malve et al. (2000), 9th Int. Symp. on the Interaction Between Sediments and Water, IASWS, Canada, May 5-10 (submitted)
FI (FEI) **Lake**	(HBV-FEI) PROBE – SMHI 1Dflow-FEI 3Dflow – YVA Oy	Water quality model – FEI AQUASIM 3Dqual – YVA Oy	Oxygen, nutrients and phytoplankton biomass	Estimation of respiration and dimensioning of restoration measures	- 6-25 km²	1 d 30 y	Frisk et al. (1999), Hydrobiologia, 414, 59-69; Malve et al. (2001), Ecol. Modelling (submitted)

Table 6.1. Continued...

COUNTRY (Institute) DOMAIN	MODEL NAME		SUBSTANCES MODELLED	APPLICATIONS IN ENV. ASSESSMENT			MAJOR REFERENCES
	Hydrology part	**Water quality model**		**Purpose**	**SPACE resolution coverage**	**TIME step period**	**(Publications)**
N.IRL (EHS) **River channel**	Estimates based on Low flow study of N. Ireland and Micro Low Flows	Mass balance: 1.Warn and Brew (1980) 2.Monte Carlo	Biochemical oxygen demand (BOD) Ammoniacal Nitrogen Suspended solids Heavy metals	Calculating discharge standards Assessing impact of discharges on river water quality	>1 km² 1-5500 km²	1 d 10 y	Warn and Brew (1980), Water Res., 14, 1427-1434; IoH reports: Low flow studies (1980), Low flow study of Northern Ireland (1986), Low flow estimation in the UK (1992)
NL (RIZA) **River systems**	POLFLOW	POLFLOW	N, P	Quantification of average pollutant fluxes	1- 10^3 km² 10^4-10^6 km²	5 y 5-50 y	De Wit et al. (2000), Hydrol. Proc., 14, 1707-1723; De Wit (2001), Hydrol. Proc., 15, 743-759; De Wit and Pebesma (2001), Hydrol. Proc., 15, 761-775
NL (RIZA) **River channel**	RHINE ALARM	RHINE ALARM	Arbitrary (conservative or first-order decay)	Downstream travel time and concentration of incidental pollution	10-100 m Rhine (Lake Boden - North Sea)	Arbitrary (analytical) Case dependent (~1 month)	Mazjik (1996), Ph.D. thesis, Univ. Of Tech., Delft
ROM (NIMH) **River channel**	PROGRES (DANU-BUIS)	POLAC	Inorganic subst.	Concentration following accidental pollution	1 km Arbitrary	1 h 5 y	Serban et al. (1998) and Raducu (1998), Proc. XIXth Danube Conference, Osijek, Croatia
SE (SMHI) **Catchment (prec.-runoff)**	HBV	HBV-N	Nitrogen (inorg.N and org.N)	Mapping of nutrient source areas, source apportionment, management scenarios	5-400 km^2 5-400 000 km^2	1 day several years	Arheimer, B., and Brandt, M. (1998) *Ambio, Vol. 27* (6), pp. 471-480. Bergström, S. (1995) In Singh, V. P. (ed.) Water Resources Publications, Littleton, Colorado, pp. 443-476.
UK (WRSRL) **Catchment**	SHETRAN	SHETRAN	Solutes, N, sediment	Flow/transport for impact assessment of changes in env./climate/land-use	0.01-2 km 0.1-10^3 km²	10 min-1 d 1 d-100 y	Ewen et al. (2000), J. Hydrol. Eng., 5, 250-258

Table 6.1. Continued...

COUNTRY (Institute) **DOMAIN**	**MODEL NAME**		**SUBSTANCES MODELLED**	**APPLICATIONS IN ENV. ASSESSMENT**			**MAJOR REFERENCES**
	Hydrology part	**Water quality model**		**Purpose**	**SPACE resolution coverage**	**TIME step period**	**(Publications)**
BUL (NIMH) ***No modelling***							
LIT (LHS) ***No modelling***							
ESP (?) ***No modelling***							

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ANNEX A: The questionnaire and its distribution list

Dr. Berit Arheimer (rapporteur)
Working group on hydrology of RA VI (Europe)
World Meteorological Organisation (WMO)
Norrköping, Sweden, 09/01/01

Integration and Coupling of Hydrological Models with Water Quality Models

Dear Ms/Mr/Mme/Sir,

this is a questionnaire to make a first scanning of hydrological models, which are equipped with a water quality routine and have been used in Europe for environmental assessment. An overview of such models and their present applications would be very useful for efficient water quality management within the new European Water Framwork Directive. This kind of compilation does not exist at present, but it will be available to us all, if you could please;

1) fill in the table below (next page) and send it back to me;
2) send me the most relevant publications/documentation (in English) describing each model and its applications in environmental assessment;
3) inform me even if you do **not** apply any water quality models operationally.

I am rapporteur of the working group within WMO RA VI (Europe) called "*Integration and Coupling of Hydrological Models with Water Quality Models*". The result of this work will be a review of hydrological water-quality models and their applications in environmental management, planning and surveys in Europe. You will find the resulting documents in the form of a report and on Internet. This will be forwarded to you free of charge if you choose to deliver your information. To include your models in the review and to complete the compilation of European models, please send the requested material to:

Dr. Berit Arheimer
Head of hydrology group
Research and Development
Swedish Meteorological and Hydrological Institute
SE-601 76 Norrköping
SWEDEN

Please, also forward this questionnaire to colleagues at other institutes that might have this information in your country! To be included in the register I will need your information at latest the 31 of Mars 2001, and you will then get the gathered information, the report and web-address in August. Thank you very much for you co-operation.

Yours Sincerely,

Berit Arheimer

If you have any further questions, you may also reach me on:

phone: + 46 11 495 82 60
fax:+ 46 11 495 80 01
e-mail: Berit.Arheimer@smhi.se

ANNEX A: The questionnaire and its distribution list

Questionnaire on Integration and Coupling of Hydrological Models with Water Quality Models

Contact person (name, adress, e-mail):

Institute:

DOMAIN	MODEL NAME		SUBSTANCES MODELLED	APPLICATIONS IN ENVIRONMENT. ASSESSMENT						MAJOR REFERENCES
	hydrology part	water quality model		Purpose	Spatial resolution	Time -step	Spatial coverage	Time- period	Country	(Publications)
Groundwater										
Soil profile										
River channel										
Lake:										
* biogeochemical										
* emission/dispersion										
Catchment:										
* precipitation-runoff										
* hydrodynamic										
* statistical / coefficients										
Others (specify!)										
EXAMPLE:										
Catchment: * precipitation-runoff	HBV	HBV-N	Nitrogen (inorg.N and org.N)	*Mapping and estimation in river-basins of gross load, net load to the sea and retention *Source apportion ment	5-400 km^2	1 day	5-400 000 km^2	often 10 years	Sweden	Arheimer, B., and Brandt, M. (1998) Modelling nitrogen transport and retention in the catchments of southern Sweden, *Ambio, Vol. 27* (6), pp. 471-480. Bergström, S. (1995) The HBV model. In Singh, V. P. (ed.) *Computer Models of Watershed Hydrology*, Water Resources Publications, Littleton, Colorado, pp. 443-476.

ANNEX A: The questionnaire and its distribution list

Distribution was mainly made by e-mail to the following adressess:

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peeter@ekm.envir.ee	geus@geus.dk;	kcooreman@unicall.be;
wolfram.schrimpf@jrc.it;	Mikael.Hilden@vyh.fi;	jbj@mst.dk; hpk@mst.dk;
eeva-liisa.poutanen@vyh.fi;	daniel.roux@meteo.fr;	anita.kuenitzer@eea.eu.int;
antti.raike@vyh.fi;	hydro@environnement.gouv.fr;	alain.peloux@diplomatie.fr;
pentti.kangas@vyh.fi;	posteingang@bafg.de;	philippe.maire@environnement.
imhoff.heike@bmu.de;	info@opw.ie;	gouv.fr;
heike.herata@uba.de;	webmaster@dstn.it;	hartmut.heinrich@bsh.d400.de;
dagmar.kallweit@uba.de;	riza@riza.rws.minvenw.nl;	marina.carstens@uba.de;
manfred.rolke@bsh.d400.de;	inforag@inag.pt;	heyerkarin@t-online.de;
andreas.roepke@um.mv-	jinx@ceh.ac.uk;	neuhoff.hans-georg@bmu.de;
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guenther.nausch@io-	lhmt@meteo.lt;	boelensr@enterprise-ireland.com;
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norka@vvi.gov.lv;	SHMU-GR@shmu.sk;	r.h.dekker@hkw.rws.minvenw.nl;
ilze.kirstuka@vdc.lv;	webmaster@imgw.pl;	e.l.enserink@rikz.rws.minvenw.nl;
aivars@monit.lu.lv;	adrian.jakob@bwg.admin.ch;	rune.vistad@sft.telemax.no;
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tadas.navickas@aplinkuma.lt;	webmaster@meteo.yu;	hgn@md.dep.no;
skh@rzgw.gda.pl;	dhmz@cirus.dhz.hr;	teresa.vinhas@dga.min-amb.pt;
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imgw_ka_wsigw@gapp.pl;	etudplan@dsi.gov.tr	argeo.rodriguez@md.ieo.es
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