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REPORT

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Selection of a watershed model used to predict the effects of management decisions on water quality based on multi-criteria comparison

Project acronym: AQUISAFE 1

by

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for

Kompetenzzentrum Wasser Berlin gGmbH

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Title

Selection of a watershed model used to predict the effects of management decisions on water quality based on multi-criteria comparison, Deliverable 2.1 of WP 2 of the Aquisafe project

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Aquisafe 1 D 2.1

Abstract

The Aquisafe project aims at mitigation of diffuse pollution from agricultural sources to protect surface water resources. The first project phase (2007-2009) focused on the review of available information and preliminary tests regarding

(i) most relevant contaminants,

(ii) system-analytical tools to assess sources and pathways of diffuse agricultural pollution,

(iii) the potential of mitigation zones, such as wetlands or riparian buffers, to reduce diffuse agricultural pollution of surface waters and

(iv) experimental setups to simulate mitigation zones under controlled conditions.

The present report deals with (ii) and aims at identifying numerical modelling tools that can assess the origin of contaminants as well as the impact of different mitigation measures regarding water quality aspects on a catchment scale.

In order to test the identified modelling tool in the further course of the Aquisafe project a case study was found in Brittany (France) in agreement with Veolia Eau: the small watershed of the river Ic. Due to intensive agricultural land use the nitrate concentration exceeds the threshold for surface water used for drinking water purpose (which is the main concern of Veolia Eau). Additionally, trace contaminants (pesticides) were detected in the surface water ever since measurements have been carried out. Therefore modelling shall mainly support the water supplier in actions aiming at reducing the nitrate concentration in the surface water. An additional task could later on be the application of the model in order to assess the effectiveness of mitigation measures against trace contamination.

In order to choose the most appropriate model a model comparison was carried out using a three step approach. The first step was a screening of different information sources and resulted in the identification of 44 existing models. The second step was a pre-selection according to essential criteria in order to identify models that fulfil the basic requirements for a) the Ic nitrate issue and b) the Aquisafe trace contaminant issue. In a third step a multi-criteria analysis was carried out using 6 additional criteria followed by a final recommendation.

The essential criteria used for the pre-selection of the models were a) the inclusion of major hydrological processes, b) the inclusion of the nitrogen cycle (for the Ic nitrate issue) or the inclusion of trace contaminants (for the Aquisafe trace contaminant issue) c) the size of catchments that can be modelled, d) the temporal and spatial resolution and e) the possibility to include management options and/or mitigation measures. For the Ic nitrate issue this resulted in the selection of the models: HBV-NP, HSPF, SWIM, SWAT, WASMOD and Mike She. For the Aquisafe trace contaminant issue only four models remained after the pre-selection process: DRIPS, HSPF, SWAT and Mike She.

Additional criteria were then applied and resulted in the recommendation to use the model SWAT for further investigations in both cases due to sufficient accuracy and included processes (full hydrological model with water quality simulation (nutrients and trace contaminants) as well as a wide range of successful applications (amongst others).

This report presents a wide range of models with their capabilities and limits. It contains criteria which were identified with the stakeholders in order to choose the most appropriate model. The approach presented in this report shall support the decision process of selecting a model for a certain problem regarding water quality and includes only a recommendation. The final decision on which model shall be applied, will be taken in agreement with the stakeholders Veolia Eau and Goel'Eaux.

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List of Abbreviations

ACRU	Model developed by the *Agricultural Catchments Research Unit* of the Department of Agricultural Engineering of the University of Natal in Pietermaritzburg, South Africa
ANIMO	Agricultural NItrogen MOdel
AGNPS	Agricultural Non-Point Source pollution model
ArcEgmo	GIS-based Catchment Model
Aquavallee/ Aquaplaine	Empirical model approaches for hot-spot identification
CAWAQS	CAtchment WAter Quality Simulator
CE-Qual-W2	United States Army Corps of Engineers 's Two Dimensional Water Quality model
Claws/Owls	Coupled Landscape and Water System / Object Watershed Link Simulation
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems
DRIPS	Drainage, Runoff and spray drift Input of Pesticides in Surface waters
EPA	Environmental Protection Agency
FOOTPRINT	Functional Tools for Pesticide Risk Assessment and Management
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
GR	Modèles Hydrologiques du Génie Rural
GUI	Graphical User Interface
HBV-NP	Hydrologiska Byråns Vattenbalansmodell for Nitrogen and Phosphorous
HSPF	Hydrological Simulation Program--Fortran
INCA	Integrated Nitrogen in CAtchments
KINEROS	KINematic Runoff and EROSion model
MAGIC	Model of Acidification of Groundwater in Catchments
MHYDAS	Modélisation HYdrologique Distribuée des AgroSystèmes
MIKE-SHE	MIKE - Système Hydrologique Européen
MONERIS	MOdelling Nutrient Emissions in RIver Systems
PEARL/GeoPEARL	Pesticide Emission Assessment at Regional and Local scales
PIK	Potsdam Institute of Climate Impact Research
PRZM	Pesticide Root Zone Model
PRZM3	Pesticide Root Zone Model 3

REM	Register of Ecological Models
REMM	Riparian Ecosystem Management Model
SACADEAU	Système d'Acquisition de Connaissances pour l'Aide à la Décision sur la qualité de l'eau
SMHI	Swedish Meteorological and Hydrological Institute
SWAT	Soil and Water Assessment Tool
SWIM	Soil and Water Integrated Model
USDA	United States Department of Agriculture
WasMod	Water and Substance Simulation Model
WASP	Water Quality Analysis Simulation Program

Chapter 1
Introduction

1.1 Background of the project

Surface water is a key element for drinking water supply in many countries. In Europe over 800 major reservoirs serve primarily this purpose. Usually, these waters do not meet drinking water standards and water treatment is needed. The best way to protect drinking water is to prevent the contaminants from entering source water. Therefore source water protection is the first and most important barrier in a multi-barrier approach to ensure safe drinking water supply.

In rural and semi-rural areas many different sources of potential pollutants contribute to source water contamination. They include agriculture (agrochemicals, biosolids application and pasture), underground or above-ground fuel storage tanks, septic systems, and storm water runoff from streets and lawns. Generally agriculture is considered as one of the major causes of surface water pollution. The discharge of nutrients (nitrogen and phosphorus) and pesticides into surface water results from crop growing while other contaminants originate primarily from animal breeding (e.g. pharmaceuticals, antibiotics, pathogens) or from human activities.

Eutrophication affects a significant number of lakes, reservoirs and rivers and is the well-known issue currently impacting drinking water resources. It has therefore been studied intensively. The presence of micro pollutants is not systematically monitored, however it is known that some substances are very mobile and tend to resist degradation. Traces (µg/L range) of such substances have been detected in numerous surface water bodies (lakes, reservoirs and rivers). As agriculture is intensifying and land use is changing in many areas, the impact of diffuse pollution on water quality is expected to be more pervasive in the future.

1.2 Aim of the Aquisafe project

1.2.1 General aim of the project

The overall research program Aquisafe aims at identifying and analyzing key processes and developing practical methods and tools for the mitigation of emerging contaminants in rural and semi rural areas for the protection of drinking water sources. The practical methods that are being tested are nature-based systems such as constructed wetlands or riparian corridors.

1.2.2 Aims and strategy of work package 2

Work package 2 within the Aquisafe project aims at identifying modelling tools that can assess the impact of different mitigation measures regarding water quality aspects on a catchment scale. The most appropriate modelling tool should facilitate the decision on the location of a mitigation zone and show how effective such a mitigation measure could be (in comparison to other measures). Common knowledge is that there is no such thing as an optimal model for universal application. Every problem, target objective and physical framework is different. The outcome of this work package shall therefore facilitate the choice for a model for given prerequisites by giving information on the focus and requirements of different models as a basic decision support.

In order to meet these aims, the strategy of work package 2 covers the following tasks:

- To analyse the characteristics, possibilities and limitations of numerous existing models regarding criteria that were defined in agreement with the stakeholders.
- To compare the models and to recommend appropriate models for certain applications.
- To implement an appropriate model on a case study (in the further course of the project).

This report presents the results of the two first tasks. The application of the selected model in the case study was initially planned to be carried out in the next phase of the Aquisafe project. Due to a strong interest of Veolia to apply the model in the Ic watershed (see Figure 1) the application commenced directly following the completion of the presented model comparison.

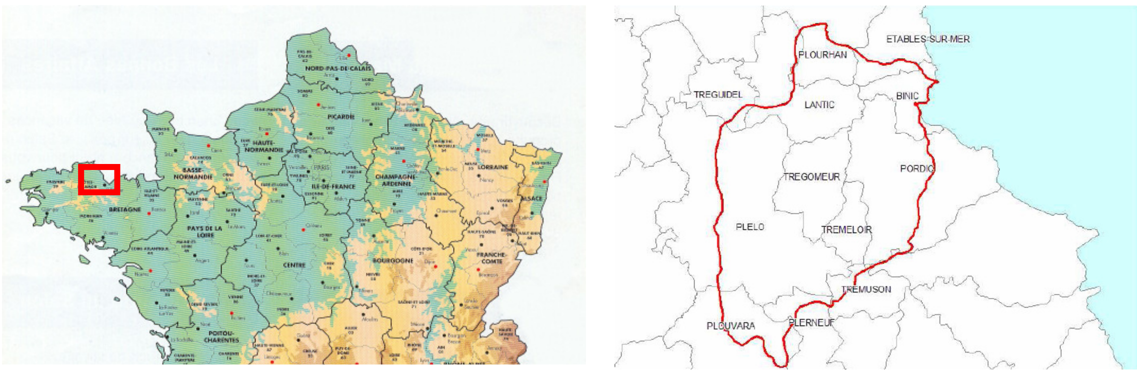

Figure 1: Location of the Ic watershed (Goel'eaux 2007) (Discover France 2007)

This report will present the results concerning the evaluation of existing models that could be possibly used in the Ic case study. Apart from other criteria that will be detailed in the report, the selected model primarily has to be able to deal with nitrate concentrations and if possible also trace contaminants in a high spatial and temporal resolution.

Due to the high priority of the nitrate issue, the criteria for choosing the model for the Ic watershed differ in part from those that will apply for the overall Aquisafe project. For transparency reasons we have therefore decided to address the two cases separately in the further course of the study: a) the Ic nitrate issue and b) the Aquisafe trace contaminant issue.

Chapter 2
Material and Methods

2.1 General issues

The models investigated were found to have a wide range of applications. For our purpose – hydrological model with nutrient cycling, trace contaminant leaching and inclusion of certain management practices (wetlands, riparian zones, etc.) – none of the models fulfilled the criteria completely. In terms of trace contaminants (e.g. pesticides) only 8 models consider this component and concurrently fail in other important criteria like nutrients (e.g. DRIPS) or catchment scale (e.g. OPUS, PEARL, PRZM). Regarding management practices some models have only wetlands included (e.g. HBV-NP); others consider a wide variety of possible management practices except wetlands.

In consequence a three step approach was used that is described in detail below. This method follows mainly the approach by Quilbé et al. (2006).

2.2 Method of the model comparison

1) Screening of models:

Different sources were screened for hydrological, ecological and nutrient load models:

1) the Register of Ecological Models (REM)[1]",
2) review papers on model comparison (major references: Quilbé et al., 2006, Arheimer & Olsson, 2005, Payraudeau, 2002).

About 320 models were found during this first screening. On the basis of personal experience at the Berlin Centre of Competence for Water, interviews with local experts (e.g. M. Bach, Uni Giessen, H. Behrends, IGB, Berlin) and under consideration of interests communicated by Veolia, 44 of these were selected for further investigation. Those models were listed and first basic information – if available - was compiled.

2) Pre-selection of models

a) Defining criteria for a pre-selection of the models that are most likely to meet the basic requirements:

The criteria in general were defined and presented to the technical committee during meetings in Rennes in July/August 2007. The application of criteria used for the pre-selection (so-called essential criteria) should exclude models from further investigations that did not meet the basic requirements. Different essential criteria were defined, according to

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[1] **http://www.wiz.uni-kassel.de/eco_model/server.html**

the different issues, target objectives and physical framework of a) the Ic-nitrate issue and b) the Aquisafe trace contaminant issue. Further information on the chosen essential criteria is given in chapter 3.2.1.

b) Application of the essential criteria:

The essential criteria for a) the Ic-nitrate issue and b) the Aquisafe trace contaminant issue were then applied to the available models found in step 1). If a model did not meet each single essential criterion it was not included in the further multi-criteria analysis. The outcome of this step was a reduced list of models for each of the two regarded issues, that could then be subject to further investigations.

3) Multi-criteria evaluation of the models:

a) Definition of criteria for the multi-criteria analysis:

For the multi-criteria analysis so-called additional criteria were defined that would enable to rank the remaining models with respect to the requirements of both issues mentioned above. Details on the criteria defined are given in chapter 3.3.1.

b) Multi-criteria evaluation of the models:

The pre-selected models were then evaluated by a ranking method depending on the level of achievement of the criteria. The evaluation is based on the information collected by literature reviews, information on the database/web and interviews with experts. For the scores we distinguished among "+", "-", "±" and "0":

"+": good agreement with the requirements of the criteria,

"-": no agreement with the requirements of the criteria,

"±": some agreement with the requirements of the criteria,

"0": no information available.

For more detailed scoring (e.g. giving points from 1 to 5 as described in Quilbé et al. 2006) sufficient information was not available. Giving scores would feign a higher accuracy of the decision basis than available.

Chapter 3
Results

3.1 Results of the model screening

Table 1 gives an overview of the models found by screening of different sources (see chapter 2.2). Models that did not fit at all were directly excluded.

Table 1: Overview of the models identified for model comparison (for further details see Appendix A)

ACRU	FOOTPRINT	MONERIS	REMM
ANIMO	GLEAMS	OPUS	SACADEAU
AGNPS	GR	PEARL / GEO-PEARL	SHETRAN
ARC/EGMO	HBV-NP	PESTAN	STONE
Aquaplaine/Aquavallee	HSPF	PLOAD	SWAT
CAWAQS	INCA	POLA	SWIM
CE-Qual-W2	KINEROS	PRZM	TELEMAC
Claws/Owls	MACRO	PRZM3	TNT(2)
CREAMS	MAGIC	QHM	WASIM-ETH
DRIPS	MHYDAS	QUAL2K	WASMOD
EPIC	MIKE SHE		WASP
			WHI Unsat

3.2 Pre-selection of models that fulfil the basic requirements

3.2.1 Definition of criteria

An overview of the essential criteria that were applied to the 44 identified models is given in Table 2. A detailed description of the different criteria can be found in the further course of the chapter.

Table 2: Overview of the essential criteria for the pre-selection of models.

Criteria	Ic nitrate issue	Aquisafe trace contaminants issue
1) Included Model Components		
a) Hydrological processes	entire hydrological cycle	
b) Hydrochemical compounds	nitrogen cycle and possibly trace contaminants	trace contaminants and possibly nitrogen cycle
2) Size of the catchment	< 100 km²	<100 - 10000 km²
3) Resolution		
a) Spatial resolution	high spatial resolution	
b) Temporal resolution	daily and/or monthly time step	
4) Inclusion of management practices / mitigation measures	yes	yes

1) Model Components

The model components are the basis for the purpose and the application of a model. Generally, hydrological models consider different processes or components, such as snow smelt, evapotranspiration, run off, subsurface flow and groundwater flow, etc. Beyond this some models deal with the nitrogen-, carbon- and phosphorus cycle, plant growth and pesticides leaching.

In order to find effective measures against high concentrations of nitrate and / or trace contaminants in the surface water it is fundamental to identify the source and the major pathways. Thus for both regarded issues the model has to consider the entire water cycle connected with different pathways for the run-off, subsurface- and groundwater (criterion 1a).

The Ic nitrate issue:

For the Ic nitrate issue the model additionally needs to comprise the nitrogen balance (criterion 1b) with the input (fertiliser), the uptake (plants growth) and leaching.

The trace contaminant issue:

For the trace contaminant issue the model will have to include the simulation of application, transport and degradation of trace contaminants (criterion 1b).

2) Size of the catchment

Hydrological models are usually developed for a certain spatial scale. Models exist for a field scale and a range between small (<100 km²)-, meso (100-20000 km²)- and large (>20000 km²) scale catchments. From such models different results can be expected: a model, which aims at comparing different catchments on a European scale regarding nutrient erosion, cannot make predictions for a small catchment and also vice versa.

The Ic nitrate issue:

The Ic-watershed covers an area of about 70 km^2, and the focus lies on assessing the effectiveness of different mitigation measures. Thus a model for a small catchment will be needed (less than 100km²). On the other hand, considering a model also applicable to larger catchments (= mesoscale) allows more flexibility for future case studies. Therefore also models for mesoscale catchments were considered.

The Aquisafe trace contaminant issue:

As the model shall be applied to different catchments the model should be able to handle a wide range of catchments sizes (from <100 km² up to 100,000 km²).

<u>3) Temporal and spatial resolution</u>

The project will investigate the effects of mitigation measures on water quality. Most of these measures target at preventing the run-off flow of nutrient/trace substances to the surface water. For such investigation it is necessary to use a model which is able to work on a high temporal and spatial resolution in order to analyse these events adequately.

The Ic nitrate/Aquisafe trace contaminants issue:

The small Ic-watershed needs a daily or monthly time step. For the modelling of meso-scale catchments with the same purpose (mitigation measures) a daily or monthly time step with a high spatial resolution would also be useful.

<u>4) Management practices / Mitigation measures</u>

It is necessary to have management tools and mitigation measures included in the model in order to assess their effect on water quality and to compare different measures.

This criterion comprises all possible measures to mitigate the nutrients' and trace contaminants' entry into the surface water like riparian zones, constructed wetlands and buffer strips but also alternative tilling, different crop schedules and options in days of application regarding fertiliser and pesticides.

The Ic nitrate/Aquisafe trace contaminant issue:

For both model applications the inclusion of different management practices and mitigation measures are essential. In addition, the more management practices or mitigation measures can be distinguished the better recommendations the model can provide.

3.2.2 Results of the pre-selection

The models selected for further investigations for the Ic nitrate issue were: HBV-NP, HSPF, SWIM, SWAT, WASMOD and Mike She. All other models fail in at least one of the essential criteria described above (Chapter 3.2.1). The criteria most models failed in were their limitation to field scale, the absence of nitrogen components as well as of management practices / mitigation measures.

The following models complied with the essential criteria for the trace contaminant issue: DRIPS, HSPF, SWAT and Mike She. The main elimination criterion for that issue was the trace contaminant module in the model.

If the aim of modelling was restricted to identifying sources and pathways – without including possible management practices – the models INCA and TNT would also be pre-selected.

3.3 Evaluation of models by a multi-criteria analysis

3.3.1 Definition of criteria

Table 3 gives a summary of the additional criteria used for the multi-criteria evaluation. Details are given below.

Table 3: Overview of the criteria and requirements for the two modeling issues within the Aquisafe project.

Criteria	Ic-nitrate issue	Aquisafe- trace contaminant issue
Data requirements	low (medium to high acceptable)	low
Presence of a Graphical User Interface (GUI)	yes	yes
Possibility to carry out an uncertainty analysis	yes	yes
Efforts for data acquisition, pre-/post processing and modelling	low	low
Ownership of the model for further development	open source	open source
Popularity / Support / Documentation for the model	widely used, good support	widely used, good support

1) Types of data needed (data requirements)

The modelling procedure needs data as information about the catchment (soil, land use, slope etc.), as input data (precipitation, temperature and wind speed etc.) and for calibration/verification of the modelling results (e.g. discharge, nitrate at the catchments outlet).

The types of data required can be grouped as follows:

- Meteorological data: precipitation, solar radiation, air humidity, wind speed
- Soil data: number of layers, texture, water capacity and water conductivity of each layer, land use map, as georeferenced data (GIS) or in an analogue map
- Hydrological data: Water discharge, nitrate concentrations, pesticide concentrations at the catchment outlet (calibrating/validating the model)
- Management data: Agricultural practices in the watershed (day of sowings, day of harvest, day of pesticides operation, etc.)

For application in an unknown catchment little data requirements are generally beneficial, because this reduces the risk of insufficient data availability. Additionally the effort for data acquisition and pre-processing is minimized. However, if only rough data are required, the outcomes of a model may not be sufficient for further decisions. Therefore, this criterion corresponds to the essential criteria 2 and 3 (scale of the catchment, temporal resolution); when some data are missing recommendations about those related issues are not possible (e.g. no management practices applicable when a land use map is missing).

The Ic nitrate issue:

For a small catchment as the Ic watershed accurate data are necessary in order to obtain results with a sufficient resolution: meteorological (precipitation, temperature etc.) and hydrological (discharge and nutrients) data in daily time steps; day and amount of fertiliser use and the land use schedule (remaining fertiliser in the soil, amount of uptake by the roots). Additionally, a large amount of data is available, so medium to high data requirements are acceptable, even though generally low data are positive (see above).

The Aquisafe trace contaminant issue:

Within the Aquisafe project modelling shall be applied to different catchments, where the data availability is not known. Therefore, little data requirements are generally positive, because this also reduces the effort for data acquisition and pre-processing.

Ranking:

“+” means that the data requirement is low (e.g. few, available data are necessary)

“-” means that the data requirement is high (e.g. further measurements necessary)

“±” means that the data requirement is medium (e.g. complex data, but publicly available)

2) Presence of a Graphical User Interface (GUI)

When performing modelling, several possibilities exist in term of interfaces. The most basic solution offers no proper graphical interface. Then data needs to be properly processed, transferred to the right files and an executable program will then run the modelling process. Yet, there are existing models which offer a Graphical User Interface (GUI), which means that the user is supported when performing the modelling part.

The Ic nitrate/ Aquisafe trace contaminant issue:

As several different people might use the model, it is preferable to use a model with a GUI so that a maximum number of people can fully exploit its possibilities.

Ranking:

"+" means that a GUI is existent

"-" means that a GUI is not existent

3) Accuracy vs. uncertainty of the model

Using a model implies working with simplified descriptions of real phenomena. As a result, the input as well as the output of models are never certain and must be taken with precaution. Indeed, a part of uncertainty is associated with each model, in relationship with the complexity of the model itself. Other parts are linked to the overall presence of heterogeneity of meteorological and geographical data. Thus, it is important to know how big the uncertainty is, but it is hard to define before using a model. This parameter will always have to be recalled when showing results.

The Ic nitrate/ Aquisafe trace contaminant issue:

The selected model, however, should provide the possibility of calculating the uncertainty. It should further support the modelling procedure with tools for calibration, sensitivity analysis and uncertainty analysis.

Ranking:

"+" means that there is a tool for uncertainty analysis

"-" means that there is no tool for uncertainty analysis

"0" means that there is no information available

4) Effort for data acquisition, pre- and post processing and modelling

Normally, data need to be pre-processed before being used for modelling. This operation is time-consuming and consequently expensive. The effort for modelling is strongly linked to the complexity of the model itself because each considered component (nitrogen, phosphorus or trace contaminants etc.) increases the amount of required data (input data as well as calibration data). However, this criterion is difficult to assess by a literature study because usually no information can be gained from scientific publications. The achievement of this criterion can only be given by a rough estimation.

The Ic nitrate/Aquisafe contaminants issue:

For the Ic-watershed, first results had to be delivered in February 2008 and thus, the time limit to perform modelling was short. Therefore the effort for data acquisition, pre- and post processing and modelling should be as low as possible.

The Aquisafe trace contaminant issue:

For other catchments the time limit is not so short. Nevertheless, little effort for modelling is always preferable.

Ranking:

"+" means that low effort for data acquisition and pre-processing is expected compared with other models (e.g. data publicly available)

"-" high effort for data acquisition and pre-processing (e.g. usually additional sampling necessary)

"±" means that the expected effort is medium

5) Ownership of the model for further development

Some models are not open for further developments (closed source models), others are open source. Closed source models (e.g. commercial models) do not allow changing the internal code, modifying the model or adding applications. For our purpose it would be positive to have an open source model.

The Ic nitrate/ Aquisafe trace contaminant issue:

An open source model is an advantage as first investigations have shown that enhancements regarding special pesticides or management practices (like wetlands or riparian zones) will be necessary. Thus, in both cases, an open source model and a possibility for further development would be a positive point.

Ranking:

"+" means that the model is open source and the source code can be changed

"-" means that there is a limitation in changing the source code

"±" means that the model is open source for research purpose only

6) Popularity/support/documentation of the model

For publicly available models, that have been used for many years the degree of popularity of a model can be seen as an indication of its scientific quality and reliability. In addition to that, scientific exchange with many different working groups is possible. However, it has to be considered that not only the score of references is important but also the number of applications and whether the model was used by different working groups.

Furthermore profound documentation is necessary for the implementation of a new model. This point is important for independent work and to understand the model results. Additionally, support by the developers of a model can be useful in case of problems and questions beyond the information given in the manual.

The Ic nitrate/Aquisafe trace contaminant issue:

For both cases, it is important to choose a well-known model so that potential future users of the model do not rely on only a few scientists but can obtain information from various sources.

Ranking:

"+" means that the model is popular (high number of successful applications, given support, documentation exists)

"-" means that the model has not been used frequently, low quantity of references was found and no documentation is available

"±" means medium number of references, documentation not easy available (only on demand)

3.3.2 Application of the criteria

3.3.2.1 The nitrate issue

After applying the criteria for pre-selection six models remain for further evaluation: HBV-NP, HSPF, SWIM, SWAT, WasMod and Mike-She. In a final step all these remaining models were evaluated by a multi-criteria analysis (

Table 4).

Concerning data requirements most models have medium requirements, as they all simulate the entire hydrological cycle (essential criterion 1a) and the nitrogen cycle (essential criterion 1b). HBV-NP describes some of the processes more empirically than other models therefore data requirements are low. Mike She, on the other hand is physically based and thus requires much more data than the other models – which are often not available (Quilbé et al., 2006).

The presence of a GUI facilitates the modelling including the pre- and partly the post-processing. Such a GUI exists only for the SWAT, SWIM and the Mike She models. For the HBV-NP model there is a web-interface under development but not yet available. The commercial version of the WasMod model has a GUI but the source code is not open for development. Vice versa, the open source version has no GUI included.

The criterion effort for data acquisition, pre-processing and modelling is directly linked to the criterion data requirements: The Mike-She model needs data that are normally not available (e.g. detailed maps of land use, soil, river bed geometry at different segments, high resolution data of pre¬cipitation, tempera¬ture, wind speed etc.) and thus the user has to carry out additional investigations. All other models can be used with publicly available data and the HBV-NP model requires lower effort in pre-processing due to the lower number of incorporated modules.

Except for the Mike She model all of the models are open source. The Mike She model needs the Mike11 model for simulating the river routing through the catchment. Both models are relatively expensive (up to 11,000 € for Mike She and up to 10,000 € for Mike11). The HBV-NP model is available free of charge for research purpose but not for commercial use. In latter case it is not known whether the source code is available.

Table 4: Ranking of the 6 most suitable models for the Ic nitrate issue according to the additional criteria (details on the ranking within the criteria is given in chapter 3.3.1).

	HBV-NP	HSPF	SWIM	SWAT	WasMod	Mike-She
Data requirements + low data requirement - high data requirement ± medium data requirement	+	±	±	±	±	-
Graphical User Interface (GUI) + GUI exists - GUI not exists	+	-	+	+	-	+
Effort for model-ling + low effort - high effort ± medium effort	+	±	±	±	±	-
Ownership of the model + open source model - closed source model ± open source only for research purpose	±	+	+	+	+	-
Popularity of the model + very popular - minor use ± medium use	- 6 references for HBV-NP, one user group in Sweden (SMHI), insufficient manual, no support	+ 146 references, different user groups, user manual available	± 19 references, one user group in Germany (PIK), comprehensive manual, no support	+ 685 references, wide range of application, different user groups, comprehensive manual, support can be given	± 12 references, little user group (about 3 groups only in Germany), only a insufficient manual available	+ 10 references, using all over in Europe, user manual available
Tools for estimating the uncertainty + existing tool - no existing tool 0 no information	0	0	+	+	-	+

The most popular model is SWAT, due to its more than 600 publications with a wide range of applications and user groups around the world. Moreover there is comprehensive manual available and an annual conference to contact experts. The Mike-She model has a wide range of applications especially in Europe: it has been used in 20 European countries. The HBV-NP model is based on the well-known hydrological model HBV and has only just recently been established. Thus the references as well as the range of application are few. All papers found deal with one catchment in Sweden. The SWIM-model is a spin-off of the SWAT model and is only used by one research group in Germany. The model is used for simulations in the context of the EU Water Framework Directive and a user manual is available. For WasMod only an insufficient manual is available. There is a small user group in Germany (University of Jena, University of Kiel) with about 10 successful applications in Germany.

For the last criterion “tools for estimating the uncertainty” it was difficult to obtain reliable information. There are applications found in the literature for the models SWIM, SWAT and Mike-She with special regard to this issue. For the HBV-NP model and the HSPF no information was found and the WasMod model has no tool available. Nevertheless, in terms of uncertainty it is important to keep in mind, that the uncertainty resulting from uncertain data usually exceeds the uncertainty resulting from the modelling procedure itself.

Summary: Without weighing the different criteria, the SWIM and the SWAT model seem to fit best to the requirements of the lc-nitrate issue. The only difference is the popularity of the model, which is much higher for the SWAT model. As this is an important factor, due to limited own experience at KWB and due to the need for scientific exchange in the context of Aquisafe, we recommend to simulate the lc-nitrate issue with the model SWAT.

3.3.2.2 The trace contaminant issue

Beside the nitrate issue for the Ic watershed trace contaminants are in the main focus of the Aquisafe project. After applying the essential criteria (chapter 3.2.2) four models remain for further investigation: DRIPS, HSPF, SWAT and Mike She. An overview of the ranking according to the additional criteria is given in Table 5. In the previous chapter 3.3.2.1 only the DRIPS model was not discussed so only the DRIPS model will be detailed in the following.

Table 5: Ranking of the 4 most suitable models for the trace contaminant issue according to the additional criteria.

	DRIPS	HSPF	SWAT	Mike She
Data requirements + low data requirement - high data requirement ± medium data requirement	±	±	±	-
Graphical User Interface (GUI) + GUI exists - GUI not exists **0** no information	+	-	+	+
Effort for model-ling + low effort - high effort ± medium effort	±	±	±	-
Ownership of the model + open source model - closed source model	+	+	+	-
Popularity of the model + very popular - minor use ± medium use	- 6 references, one user group in Germany, no user manual	+ 146 references, different user groups, user manual available	+ 685 references, wide range of application, different user groups, comprehensive manual, support can be given	+ 10 references, using all over in Europe, user manual available
Tools regarding uncertainty + existing tool - no existing tool 0 no information	+	0	+	+

The DRIPS model requires medium data comparable to HSPF and SWAT. It has a graphical user interface included which allows a user-friendly pre-processing of data (medium effort for modelling). The source code of the model is available (open source). However, it needs a noteworthy time to becoming familiar (like in all other cases). The popularity is lower than all other models because of their minor use and the limited user group (only Germany). Numerous management practices are available and a tool for assessing uncertainty is included in DRIPS.

Summary: After applying the additional criteria to the pre-selected models without weighing only the DRIPS and the SWAT model seem to be appropriate. They differ only in the criterion popularity, with SWAT the being the by far more popular model. We would therefore recommend testing the SWAT model in the further course of the Aquisafe project.

Chapter 4
Summary and Conclusions

The Aquisafe project aims at identifying key processes and developing practical methods for mitigation of emerging contaminants in rural and semi-rural environments for the protection of surface water resources. Modelling can assist in finding major sources and key processes as well as in simulating the effectiveness of different mitigation measures. It was therefore the aim of work package 2 within the Aquisafe project to identify available tools for modelling and – if available – to apply these to a case study.

For this purpose the Ic case study was identified together with Veolia Eau. The Ic catchment is dominated by agriculture and thus high concentrations of nitrate and trace contaminants occur. Due to a possible closure of the water intake from the river Ic the nitrate issue is of high priority for Veolia Eau and will therefore be considered first in the course of model application. Therefore modelling shall mainly support the water supplier in decisions on the most effective actions for reducing the nitrate concentration in the surface water. An additional task could later on be the application of the model in order to assess the effectiveness of mitigation measures against trace pollution contamination.

In a three step approach six and four models were found to fulfil the basic requirements for the Ic nitrate issue and the Aquisafe trace contaminant issue, respectively. Each of these models has advantages and drawbacks. The **HBV-NP** model includes nutrients for the Ic nitrate issue as well as wetlands but fails in contaminants. Furthermore it was developed only recently and is thus not frequently applied. The **HSPF** model includes both nutrients and contaminants. It is widely used which is shown by the heterogeneous user community. The main drawback of the model is the missing graphical user interface. The **SWIM** and **SWAT** models are very well documented, include nutrients and are open source models. The SWIM model includes wetlands while the SWAT model considers pesticides and offers numerous management options. Both models come with a graphical user interface which leads the user through the complete data pre-processing. However, the developer of the SWIM model recommends the SWAT model for external users due to the better support. The **WasMod** model covers nutrient components like nitrogen, phosphorus and carbon but has no contaminants module included. A graphical user interface is not available and the user community is only situated in Germany. All these models need medium or low data compared to the **Mike She** model. This model includes nutrients as well as contaminants, is physically based, and thus, requires much more data some of which are not publicly available. Further it is expensive compared to the other models. The **DRIPS** model focuses only on contaminants, not nutrients, but all other criteria were achieved, similar to the SWAT model. However, a noteworthy drawback of the model is the minor international use.

We have to note that the ranking for this report should not be interpreted as a universal intercomparison study of models. One model is not better than another but only more suitable with respect to our specific needs. An application of these multi-criteria analysis regarding other issues would be probably lead to a different ranking (Quilbé et al., 2006).

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Appendix A

Comparison of the 44 hydrological models

Table 6: Basic information on 44 hydrological models

Model	Objectives	Modelling Approach	Limitations	Scale	Components		Management Practices	Requirements	Pre-selection yes/no (why)	Main references, number of references in SCOPUS
					Nutrients	Contaminants				
ACRU University of Natal, South Africa, public domain	modelling floods in South Africa; impact of afforestation in stream flow reduction, South Africa	agro-hydrological model considering stream flow, evaporation and land use management options		small to large catchments; daily time step	no	no	no	maps of land cover, soil, topography and rainfall data	no (no nutrients)	Jewitt & Schulze, 1999, Smithers et al., 2001 ACRU: 26
ANIMO DLO Winand Staring Centre (SC-DLO), Wageningen, Netherlands	effects of land use changes and nitrogen application on nitrate concentration in the groundwater	modelling the leaching of nitrogen into the river, water fluxes within the soil	Catchment is not included	field scale	C-, P-, N-cycle	no	no	soil physical properties, soil, chemical properties, using of fertilizer, boundary and initial conditions	no (only field scale)	Sonneveld & Bouma, 2003 Animo: 11

Model	Objectives	Modelling Approach	Limita-tions	Scale	Components		Manage-ment Practices	Requirements	Pre-selection yes/no (why)	Main references, number of references in SCOPUS
					Nutri-ents	Conta-minants				
AGNPS United Stated Department of Agriculture (USDA)	modelling nutrients and pesticides fate		single event model	small scale catch-ment	yes	no	?	?	no (only single events)	Register of Ecological Models
ArcEgmo Potsdam Institute of climate impact research (PIK), costs depending on selected modules	modelling impacts on river basin management; impact of land use changes on water dynamics	hydrological model		meso to large catch-ments; daily time step	no	no	no	maps of land cover, topography, soil, rainfall data, temperature, discharge at the (sub)basins outlet	no (no nutrients)	Klöcking & Haberlandt, 2002, Haberlandt et al., 2001 ArcEgmo: 6
Aquavallee (Aquaplaine)	Risk assessment for pesticide mobilization	empirical, spatially distributed, multi-criteria analysis for hot-spot identification	no hy-drolo-gic mode-ling	catch-ment scale (field scale)	no	yes	yes	topography, land use, soil type, rainfall data, pesticide application	no (no hydrologic model)	www.agriperon.fr/aquavallee_en.html

CAWAQS	assessment of nitrate losses at catchment scale	partly conceptual and partly physically based; fully distributed; coupling of a fluvial hydrodynamic and biogeochemical model with a quasi 3D hydrogeological model; Division into sub basins; Water production units		Daily time step	N	no	no	precipitation, potential Evapotranspirati on For water production units: land use, soil texture Possibly more.	no (management practices not included)	Flipo et al., 2007
CE-Qual-W2 US Army corps of engineers, USA, public domain	modelling the water quality and algae in lakes and reservoirs	2-D lake and reservoir model	only for lakes	small and large lakes	N, P, O_2, bac-teria, Algae	no	no	2 dimensional data sets necessary (calibration), weather data, nutrient input, hydrology	no (only for lakes)	Wells, 2000, Cole, 2000 Ce-Qual-W2: 42

Claws/Owls	Hydrological simulation of the Bear Brook watershed	Modelling hydrological and geomorphological processes with forest dynamics		?	no	no	no	?	no (no nutrients)	Chen & Beschta, 1999 Claws: 1
CREAMS United States Department of Agriculture (1980)	Prediction of runoff, erosion, and chemical transport from agricultural management systems	Physically based; hydrologic component: with daily rainfall data: SCS curve number model; with hourly data: infiltration based models …		Field scale; Individual storms to long term averages	yes	yes	yes		no (basic equations are integrated into recent model developments e.g. SWAT and SWIM)	REM
DRIPS University of Gießen, public domain	modelling non-point sources of pesticides in Germany	drainage runoff input of pesticides in surface water		small to large catch-ments; monthly time step	no	yes	yes	maps of soil, land cover, topography, rainfall data (incl. frequency of storm water events), details on application of pesticides	**yes** **-** **for Aquisafe contaminants issue**	Huber et al., 2000; Bach et al., 2001; Röpke et al., 2004 DRIPS: 6

EPIC USDA	modelling soil erosion, nutrient cycling and pesticide fate			field scale	yes	yes	?	?	no (only field scale)	EPIC: 117
FOOT—CRS developed by EU project FOOTPRINT, coordination BRGM (2006 – 2009)	Identification of pesticide pathways in the landscape; Estimation of pesticide levels in surface and groundwater; Specific recommendations to be made to reduce contamination by pesticides	not completed	Available from the end of 2008	Small catchments to regional levels	no	yes	yes	not completed	no (not completed)	http://www.eu-footprint.org/ataglance.html http://www.eu-footprint.org/FOOT_CRS.html
GLEAMS USDA	modelling agriculture pollutants			field scale	yes	yes	?	?	no (only field scale)	Gleams: 37

GR	Flood estimation; reservoir design; management of single- or multi-purpose reservoirs (for flood allaviation, low flow augmentation, etc.); flood forecasting, trend detection in hydrological time series	Catchment as lumped unit; empirical	Daily, monthly and yearly time step		no		no	Precipitation; air water demand	no (no hydrochemistry)	http://www.cemagref.fr/webgr/IndexGB.htm http://www.cemagref.fr/webgr/Historiquegb.htm
HBV-NP Swedish Meteorological and Hydrological Institute (SMHI)	catchment modelling for nutrient reduction, establishing measuring plans, flash flood forecast	Hydrological model including crops, nitrogen and phosphorus		small to large catch-ments	yes	no	yes	maps of land cover, topography, soil, river length, lakes depth, weather data, (prec., sol. rad., wind veloc., temp.), water qual./ discharge data (sub) basins outlet	**yes** **-** **for Ic-nitrate issue**	Arheimer et al., 2005, Anders-son et al., 2005, Arheimer & Wittgren, 2002, Arhei-mer & Brandt, 1998, Pettersson et al., 2001 HBV: 83 HBV-NP: 6

HSPF EPA, Purdue University; USA		modelling non-point source hydrology	no tile drain-age flow	small to large catch-ments	yes	yes	yes	maps of land use, topo-graphy, soils, hydrology, weather data (precipitation, solar radiation, wind velocity, temperature), water quality data/ discharge data at the (sub)basins outlet	**yes** **-** **for lc-nitrate and Aquisafe conta-minant issue**	Lee, 2007 HSPF: 146
INCA University of Reading, UK, USARQ-Institut national de la recherche agronomique, Rennes, France	modelling the nitrogen dynamics in different catchments	integrated nitrogen in catchments model, export nitrate from diffuse land use types, nitrogen cycle within the plant/soil system		small to large catch-ments	N (point/ non-point source s)	no	no	maps of land cover, topography, soils, weather data, discharge data at the (sub)basins outlet, nitrate- and ammonium-load	no (no Management practices available)	Wade et al., 2002 Inca: 45

KINEROS USDA, public domain	simulation of watershed erosion	event based hydrological model, erosion	no long term periods	small scale	no	no	yes	maps of land cover, topography, soils, rainfall data (incl. storm water events)	no (no nutrients)	Smith et al., 1995 Kineros: 181
MACRO Swedish University of Agriculture (SLU)	modelling solute transport in arable soils			field scale	yes	?	?	?	no (only field scale)	Macro: 52
MAGIC University of Virginia, USA	acidification control, nitrogen transport		no nitrogen		yes (sulfate)	no	no	?	no (no nitrogen/ contaminants)	Magic: 50
MHYDAS	Model processes at local discontinuity scale or at catchment integration scale		Single events; only hourly time step	Small catchments, hourly time step	no	yes	?		no (time scale not sufficient)	http://www.umr-lisah.fr/mhydas/index.php?page=oview&lang=en

MIKE SHE Danish Hydrological Institute, DK	eutrophication control, pollutant and nitrogen transport	physically based model, coupling with MIKE 11 (hydrodynamic model for river flow) for catchments studies		small water-sheds	yes	yes	yes	detailed maps of land use, soil, river bed geometry at different segments, high resolution input data (pre-cipitation, temperature, wind speed etc.)	**yes** **-** **for Ic-nitrate and Aquisafe conta-minant issue**	Thompson et al., 2004 Mike She: 61
MONERIS Leibniz-Institute of freshwater Ecology and Inland Fisheries (IGB), Germany	modelling water and nutrients balances, nutrient emissions into river basins in Germany	modelling nutrient emissions in river systems considering different diffuse pathways and point sources of nutrients		large catch-ments, annual time step	N, P	no	yes	maps of soils, topography, land use, tile drainage, hydrology, weather data, water quality data and discharge data at the (sub)basins outlet	no (only large catchments, yearly time step)	Behrendt & Bachor, 1998 Moneris: 17

OPUS USDA, University of Georgia, USA	studying different pollutions from agriculture	transport model for material in soil and water	the catch-ment is not inc-luded	field scale, daily time step	C, N, P-cycle	yes	yes	?	no (only field scale)	Smith & Ferreira. 1992; Ma et al., 1999 Opus: 10
PEARL/ **GeoPEARL** Alterra Green World Research, The Netherlands	fate of pesticides in soils	leaching of pesticides to groundwater and drainage	no run-off conside red	field scale	no	yes	yes	?	no (only field scale)	Boesten, 2004 Pearl: 16
PESTAN	Initial screening to estimate the vertical migration of dissolved org. solutes through the vadose zone to groundwater	based on a closed-form analytical solution of the advective-dispersive-reactive transport equation.	Very simplifie d, Steady-state flow conditio ns assume d	no spatial dimen-sioning	no	yes	no		no (no spatial approach)	http://www.epa.gov/ada/download/models/pestan.pdf

Pload Environmental Protection Agency (EPA), USA		modelling pollution loads for watersheds, point and non-point sources, including "best managing practices"		annual average	yes	yes	yes	maps of soils, topography, land use, hydrology, weather data, pollution loading	no (only annual average)	Endreny et al., 2003 Pload: 7
POLA (1997)	Predicting Agricultural Diffuse Pollution Fate	continuous		Small catchments, daily time step	yes	yes	no		no (no recent developments)	Quilbé et al. 2006
PRZM	modelling the pesticide movement		field scale		no	yes	?	?	no (only field scale)	PRZM: 96
PRZM3	Predict pesticide transport and transformation down through the crop root and unsaturated soil zones.	Finite-difference model; Hydrologic and chemical transport components		Daily, monthly or annual time steps	yes	yes	yes		no (no watershed scale)	http://www.epa.gov/ceampubl/gwater/przm3/przm3123/ABSTRACT.TXT REM

QHM	Watershed management and stormwater design	Continuous, water quality and quantity		5 min to 24 h, watershed scale	?	yes	yes	precipitation, temperature, flow	no (no nutrient simulation)	http://www.scisoftware.com/products/qhm_detailed/qhm_detailed.html
Qual2k (2e) EPA, USA		river and stream water quality model	steady state model, no diffuse inputs and no catchment considered	small to large rivers, daily time step	N, P, C, O2, Peri-phyton, Pathogens	no	no	?	no (no catchment)	Jun et al., 2007 Qual2e:106
REMM USDA	erosion and sediment transport through riparian forest buffers	riparian ecosystem management model, quantifies water quality benefits of riparian zones	con-siders buffer strips only	hill slope, field scale, daily time step	C, N, P	no	yes	weather data, contributing field/upland input, riparian zone size, soil information, riparian vegetation data	no (only field scale)	Bhat et al., 2007 Remm: 28

SACADEAU	Simulate pesticide transfer through the catchment and provide decision aid	Biophysical transfer model coupled with 3 sub models (a management model, a climate model and a spatial model)		5-100 km² catchment Daily time step	no (?)	yes	yes		no (no nutrients, more DSS than model)	http://www.cemagref.fr/webgr/IndexGB.htm http://www.umr-lisah.fr/mhydas/index.php?page=oview&lang=en
SHETRAN University of Newcastle, UK	pollution control, sediment and nitrogen transport		only hourly time step	small to meso scale water-sheds	yes	yes	?	?	no (only hourly time step)	Lunn et al., 1996 Shetran: 36
STONE Alterra, Department of soil and Land use, The Netherlands	modelling the nutrient emissions from agriculture	nutrient emission modelling system		national and regional scale, annual time step	N, P	no	yes	?	no (only annual average)	Wolf et al., 2003 Stone: 5

SWAT USDA, USA;, public domain	integrated hydrological modelling of nitrate load, impact of water quality plans	modelling hydrology, pesticide and nutrient cycle, erosion and sediment transport		Small to large catch-ments, daily time step	N, P	yes	yes	maps of land use, topography, soils, hydrology, weather data (precipitation, solar radiation, wind velocity, temperature), water quality data/discharge data at the (sub)basins outlet	**yes** **-** **for lc-nitrate and Aquisafe conta-minant issue**	Santhi et al., 2005; Schuol & Abbaspour, 2006 SWAT: 685
SWIM PIK, Germany; USDA, USA; public domain	integrating wetlands and riparian zones in river basin modelling, global change impacts in the Elbe basin	modelling the hydrological cycle, vegetation growth, erosion, nutrient transport		meso-scale water-sheds (100-20000 km^2), daily time step	N-, P-cycle	no	yes	maps of land use, soils, hydrology, weather data (prec., sol. rad., wind vel., temp.), water quality data/ discharge data at the (sub-) basins outlet	**yes** **-** **for lc-nitrate issue**	Post et al., 2007; Hatter-mann et al., 2005, 2006 SWIM: 19

TELEMAC EDF, France	dam break simulation in France, modelling sediment transport in the Loire Estuary, France	hydrodynamics, water quality, sediment transport in rivers	the catch-ment is not in-cluded	small to large rivers	yes	no	no	river geometry (hydraulic gradient, roughness etc.), river discharge etc.	no (no catchment)	Hervouet, 2000, Normant, 2000 Telemac: 25 (for rivers/ channels)
TNT(2) INRA Rennes France	studying nitrate fluxes on small catchments	fully distributed hydrological model		small catch-ments	N	no	no	maps of land use, topo-graphy, soils, hydrology, weather data (precipitation, solar radiation, wind velocity, temperature), water quality data/ discharge data at the (sub)basins outlet	no (no management practices available)	Beaujouan et al. 2001 TNT: 2

WASIM-ETH ETH Zurich, Switzerland	modelling the hydrology of glacier catchments, impact of land use changes to the water balance	hydrological model	no nu-trients/ con-tami-nants in-cluded	small to large catch-ments	no	no	no	maps of land cover, soils, topography, hydrology, weather data	no (no nutrients)	Kleinn et al., 2005; Jasper et al., 2004 Wasim: 38
WasMod University of Jena, Germany	modelling impacts of land use changes for watershed management	WAter and Substance simulation MODel		meso-scale catch-ments	N, P, C	no	yes	maps of land cover, soils, topography, hydrology, weather data, water quality /discharge data at the (sub)basins outlet	**yes - for lc-nitrate issue**	Widen-Nilsson et al., 2007 WasMod: 12
WASP EPA, USA; public domain	examination of eutrophication of the Tampa Bay, phosphorus loa-ding to Lake Okeechobee	Water Analysis Simulation Program for aquatic systems	the catch-ment is not in-cluded	small to large river systems	N, P, O_2, detritu s, phyto-plankt on	no	no	external nutrient loads, temperature, solar radiation	no (no catchment)	James et al., 1997 Wasp: 33

WHI Unsat	Compilation of 5 one-dimensional groundwater flow and contaminant transport models	graphic environment for combination of different models	no catchm ent model	one-dimensio nal	no	yes	no	diverse	no (one-dimensional)	http://www.sciso ftware.com/prod ucts/whiunsat_o verview/whiunsa t_overview.html

Appendix B

Fact Sheets on the 7 pre-selected models

Name: Drainage, Runoff and Spraydrift Input of Pesticides in Surface Waters
Acronym: DRIPS

General Information

Main medium	terrestrial
Main subject	hydrology, ecotoxicology
Type of model	not specified
Main application	decision support
Data requirements	thematic maps: land use, soil type and grain size, annual precipitation, frequency of heavy rain, river basin districts and subbasins, frequency of receiving waters, proportion of drained agricultural fields, administrative units databases: amount and timing of pesticide application, areas under cultivation, physico-chemical properties of active agents measured concentrations of pesticides in surface waters
Graphical User Interface	yes
GIS	yes
Ownership	open source
Uncertainty analysis	existing tool
Institution/Authors	University of Giessen, Institute for resource management Röpke, B., Bach, M., Frede, Prof. Dr. H.-G.
Homepage	no
Year, Country	2004, Germany
Keywords	watershed, management, basin scale, spatially distributed, runoff, water quality, pollutant transport, climate change, vegetative changes, resevoir management, groundwater withdrawals, water transfer, nutrient cycling, erosion, sediment transport, continuous-time, multiple subbasins, capacity

	cascade soil water model , Priestley-Taylor evapotranspiration, Curve-Number-runoff, GIS-interface, soil database
Model Objectives	Risk assessment concerning predicted environmental concentrations (PEC) of pesticides caused by diffuse pollution (surface runoff, tile drainage and spraydrift). The model works on a catchment scale with a special resolution of 1km².
Approach	DRIPS is based on different models which quantify diffuse pollution from pesticides. Runoff, tile drainage and spraydrift are simulated in different independent modules. Leaching: The model PELMO is used to assess the amount of pesticides transported by leaching. Here only drained areas are considered to influence surface waters, since the contamination of surface water by contaminated groundwater is assumed to be minor.
Processes	modelled processes are surface runoff, tile drainage and spraydrift.

References

Röpke, B., Bach, M. and Frede, H.G., 2004. DRIPS – a decision support system estimating the quantity of diffuse pesticide pollution in German river basins. Water Science and Technology. 49(3):149-156.

All information compiled from Röpke et al., 2004

Name: HBV-NP

Acronym: HBV-NP

General Information

Main medium	terrestrial. aquatic
Main subject:	hydrology, biogeochmistry
Type of model	dynamic mass-balance model
Main application	research
Data requirements	Subbasin division and coupling, altitude and land cover distribution, precipitation and temperature data, soil leaching concentration for each landcover type, lake depths, atmospheric N-deposition on water surfaces, emissions from rural households and point-sources (i.e., wastewater treatment plants, industries). time-series of observed water discharge and concentrations at some site),
Graphical User Interface	yes
GIS	yes
Ownership	open source only for research purpose
Uncertainty analysis	no information
Institution/Authors	Swedish Meteorological and Hydrological Institute (SMHI)
Homepage	www.smhi.se/sgn0106/if/hydrologi/hbv_np.htm
Year, Country	1994, Sweden
Keywords	watershed, basin scale, management, nutrient transport, landuse changes, climate change
Model Objectives	Simulation of nitrogen (N) and phosphorus (P) transport and transformation at catchment scale (from 1 to > 1 000 000 km^2). Estimation of transport, retention and source apportionment,

separation of natural impact from anthropogenic and evaluation of climate and management scenarios.

HBV-NP runs at a daily time-step, including all sources in the catchment coupled to the water balance

Approach

It is based on the hydrological HBV model, which gradually has been extended to simulate N transport (Bergström et al. 1987, Brandt 1990, Arheimer & Wittgren 1994, Arheimer & Brandt, 1998). VASTRA - the Swedish Water Management Research Programme – has recently come up with the P routine.

The river basin may be separated into a number of coupled subbasins, for which the calculations are made independently, which gives the spatial distribution of the model results.

Processes

hydrological part (i.e. HBV-96): snowmelt and accumulation of snow, soil moisture, lake routing and runoff response, free parameters (calibrated against observed time-series of river discharge and riverine nutrient concentrations).

nutrient routine: soil leaching concentrations are assigned to the water percolating from the unsaturated zone to the response reservoir of the hydrological HBV model. Field scale models (e.g. SOILN or ICECREAM) extended with macropore flow are used to simulate nutrient leakage from different kinds of crops and management practices. For P soil surface erosion and water transport is considered as well, applying a GIS-based model component (e.g. DelPi).

Nutrient load from point-sources (rural households, industries, and wastewater treatment plants) is considered.

Atmospheric deposition is considered over lake surfaces, whereas deposition on land is implicitly included in the soil-leaching. Residence, transformation and transport of N and P in groundwater, rivers, wetlands and lakes are simulated. Stream bank erosion, as well as sedimentation and suspension processes in the rivers are taken into consideration. Equations for the nutrient turnover processes are largely based on empirical relations between physical parameters and concentration dynamics. Modelled fractions are: dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), particulate phosphorus (PP), and soluble reactive phosphorus (SRP). Simultaneous calibration of water balance and nutrient concentrations is possible (Pettersson et al., 2001).

Applications large-scale studies, covering southern Sweden (145 000 km^2 divided into 3700 catchments; Arheimer and Brandt, 1998), the country of Sweden (450 000 km^2 divided into 1000 subbasins; the TRK project), and the Baltic Sea drainage basin (~1 720 000 km^2 divided into 30 subbasins; Pettersson et al., 2000).

more detailed studies, as for the Genevadsån River (200 km^2 divided into 70 subbasins; Arheimer & Wittgren, 2002; Arheimer et al, 2003). Additionally, the model has been applied in Matsalu River in Estonia (Lidén et al., 1999), and in the rivers Neckar and Warnow in Germany (Fogelberg, 2003).

Costs Application to one catchment requires about 2 weeks work of an experienced modeller if necessary database is already available. Database setup may be time-consuming. (Field-scale models of arable root-zone leaching may take an additional 2 months to set-up.)

Technical Information

Operating System: IHMS interface in a Windows environment.

Source-code: programming languages: Fortran

References

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All information compiled from Register of Ecological Models (http://eco.wiz.uni-kassel.de/model_db/mdb/hspf.html) and www.smhi.se/sgn0106/if/hydrologi/hbv_np.htm

Name: Hydrological Simulation Program - FORTRAN

Acronym: HSPF

General Information

Main medium	aquatic, terrestrial
Main subject	hydrology
Type of model	partial differential equations, ordinary differential equations
Data requirements	input data: DEM, meteorological data (precipitation, solar radiation, wind velocity, temperature, relative humidity), time series of P application, maps: land use map, soil map validation data: discharge data and P concentrations management data
Graphical User Interface	no
GIS	yes
Ownership	open source
Uncertainty analysis	no information
Institution/Authors	United States Environmental Protection Agency (USEPA) Center for Exposure Assessment Modeling (CEAM) Johansen, N.B., J.C. Imhoff, J.C. Kittle, and A.S. Donigian
Homepage	www.epa.gov/ceampubl/swater/hspf/index.htm
Year, Country	1997, USA
Keywords	basin, watershed, hydrology, pollutants, contaminant runoff, fate, transport, water quality, sediment, organic chemicals, biodegradation, continuous-time, spatially distributed, multiple subbasins, process based, toxicity
Model Objectives:	Johansen et al. (1984) developed the Hydrological Simulation Program - FORTRAN (HSPF) model to simulate both basin hydrology and water quality.

continuous-time model

Approach: HSPF simulates watershed hydrology and water quality for conventional and toxic organic pollutants by simulating contaminant runoff, instream water quality and sediment interactions. The watershed-scale ARM and NPS models are integrated into a basin-scale analysis framework which includes fate and transport in one dimensional stream channels.

The catchment is divided into smaller sections based on the land use type, which can each consist of pervious and impervious sections with different hydrological properties.

The model consists of 3 main modules and 5 utility modules:

- PERLND: hydrology and water quality processes on pervious land
- IMPLND: hydrology and water quality processes on impervious land
- RCHRES: processes on a single reach of an open channel or well mixed impoundment

The drawback of HSPF is that it is quite data intensive. An expert system for HSPF-parameters has been developed in order to facilitate parameter acquisition and model calibration. HSPF can be applied in basins up to about 180 000 km^2, and the watershed can be divided into smaller subbasins. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.

Processes - Instream component: nitrogen and phosphorus movement, algae, phytoplankton, zooplankton, chemical processes (hydrolysis, biodegradation, and oxidation)

- Integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions (only model that can do that)

- results: time history of the runoff flow rate, sediment load, nutrient and pesticide concentrations, water quantity and quality at any point in a watershed.

Technical Information:

Executables: Operating System: 16-bit MS-DOS

Source-code: programming language: FORTRAN

Manuals: www.epa.gov/ceampubl/swater/hspf/index.htm

References

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All information compiled from Register of Ecological Models (http://eco.wiz.uni-kassel.de/model_db/mdb/hspf.html) and www.epa.gov/ceampubl/swater/hspf/index.htm

Name: MIKE Système Hydrologique Européen
Acronym: MIKE SHE

General Information

Main medium	terrestrial
Main subject	hydrology, agriculture
Type of model	deterministic, fully distributed, physically based
Graphical User Interface	yes
GIS	yes
Ownership	closed source
Uncertainty analysis	existing tool
Institution/Authors	Danish Hydraulic Institute
Homepage	ww.dhigroup.com/Software/WaterResources/MIKESHE .aspx
Year, Country	1993, Denmark
Keywords	watershed, basin scale, water resources management, human impact on water resources, irrigation management, land use changes, contaminant transport, nitrogen dynamics, DAISY
Model Objectives	Analysis, planning and management of water resources, especially with respect to human impact catchment water quality.
Approach	MIKE SHE is a dynamic modelling tool with a modular structure, which allows independent use of each module and adjustment to local conditions and data availability. The model is applied for conjunctive use of water, surface water groundwater interactions, water resources management, irrigation management, land use changes, agricultural practices, wetland protection, contaminant transport and the investigation of well capture zones. Soil water and nitrogen dynamics can be simulated by the model DAISY.

	The catchment is divided horizontally into a network of grid squares, which allows the inclusion of spatially varying parameters. Vertical variation is represented by different horizontal layers.
Processes	Interception/evapotranspiration, overland/channel flow, unsaturated zone, saturated zone, snow melt and the exchange between aquifers and rivers are modelled
Application	about 150 applications all over Europe

References (selection of most recent publications)

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All information compiled from Arheimer & Olsson, 2005 and Thompson et al. 2004

Name: Soil and Water Assessment Tool
Acronym: SWAT

General Information

Main medium	terrestrial
Main subject	hydrology, biogeochmistry
Type of model	deterministic, semi-distributed
Main application	decision support/expert system, research
Data requirements	<u>input data</u>: precipitation, temperature, solar radiation, air humidity, wind speed <u>maps</u>: land use, soil, topography <u>validation data</u>: discharge data, nitrate measurements <u>management data</u>: amount of fertilizer/pesticide, days of operation
Graphical User Interface	yes
GIS	yes
Ownership	open source
Uncertainty analysis	existing tool
Institution/Authors	United States Department of Agriculture, Agricultural Research Service and Texas A&M University Arnold, Allen, Bernhardt, Srinivasan, Muttiah, Walker,Dyke
Homepage	www.brc.tamus.edu/swat/index.html
Year, Country	1993, USA
Keywords	watershed, management, basin scale, spatially distributed, runoff, water quality, pollutant transport, climate change, vegetative changes, reservoir management, groundwater withdrawals, water transfer, nutrient cycling, erosion, sediment

transport, continuous-time, multiple subbasins, capacity cascade soil water model , Priestley-Taylor evapotranspiration, Curve-Number-runoff, GIS-interface, soil database

Model Objectives prediction of management effects (Climate and vegetative changes, reservoir management, groundwater withdrawals, water transfer) on water, sediment and chemical yields in large catchments. Analysis of watersheds and river basins of 100 square miles. Uses daily time step, continuous for 1-100 years.

Approach subdivision of large river basins into homogenous parts, then analysis of each section and its interaction with the whole catchment. SWAT is spatially distributed, so that these parts can interact. Input consists of files, information from databases and information from a GIS interface.

Background the model was developed by modifying the SWRRB, (Arnold et al, 1990) and ROTO (Arnold, 1990) models for application to large, complex rural basins. SWRRB is a distributed version of CREAMS, which can be applied to a basin with a maximum of 10 subbasins, and SWAT is an extended and improved version of SWRRB (several hundred subbasins)

Processes - simulation of hydrology, pesticide and nutrient cycling, erosion and sediment transport.

- hydrology model is based on water balance equation.

- overland flow runoff volume: distributed SCS curve number generated given by the standard SCS runoff equation (USDA, 1986).

- soil type, texture, depth and hydrologic classification: from soil database

- soil profiles can be divided into ten layers.

- Infiltration = precipitation – runoff

- storage routing flow coefficient used to predict flow through each soil layer, with flow occurring when a layer exceeds field capacity. When water percolates past the bottom layer, it enters the shallow aquifer zone (Arnold et al., 1993).

- Channel transmission loss and pond/reservoir seepage replenishes the shallow aquifer while the shallow aquifer interacts directly with the stream. Flow to the deep aquifer system is effectively lost and cannot return to the stream (Arnold et al., 1993).

- irrigation algorithm developed for SWAT allows irrigation water to be transferred from any reach or reservoir to any other in the watershed.

- Sediment yield used for instream transport is determined from the Modified Universal Soil Loss Equation (MUSLE) (Arnold, 1992). For sediment routing in SWAT, deposition calculation is based on fall velocities of various sediment sizes.

- Rates of channel degradation are determined from Bagnold's (1977) stream power equation. Stream power also is accounted for in the sediment routing routine, and is used for calculation of re-entrainment of loose and deposited material in the system until all of the material has been removed.

Applications currently adapted only for US watersheds. The SWAT represents a component of the HUMUS project, where it is applied for 350 6-digit hydrologic unit areas in the 18 major river basins in the U.S. (Srinivasan et al., 1993b).

Krysanova et. al (1996) adopted large parts of SWAT for their model SWIM which they designed for the Elbe river basin in Northern Germany.

Processing The SWAT/GRASS interface (Srinivasan, Arnold, 1993, Srinivasan et al., 1993a) extracts spatially distributed parameters of elevation, land use, soil types, and groundwater table. The interface creates a number of input files for the basin and subbasins, including the subbasin routing structure file.

Advanced visualization tools are capable of statistical analysis of output data. ArcGIS interface available.

Technical Information:

Executables Operating System: UNIX (Solaris), PC (DOS, Windows)

Source-code: programming languages: Fortran

Manuals: http://www.brc.tamus.edu/swat/doc.html

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All information compiled from Register of Ecological Models (http://eco.wiz.uni-kassel.de/model_db/mdb/hspf.html) and www.brc.tamus.edu/swat/index.html

Name: Soil and Water Integrated Model
Acronym: SWIM

General Information

Main medium: terrestrial

Main subject: hydrology, biogeochmistry

Type of model: not specified

Main application: research

Data requirements: spatial data: Digital Elevation Model with an appropriate resolution, land use, soil map, ground water recession map

relational data: climate data (daily precipitation, average, minimum and maximum air temperature, solar radiation, rainfall intensity parameters); hydrological data (river runoff in the basin outlet, river cross-sections or mean river width and depth in subbasin outlets, hydraulic structure (for regulated rivers)); soil data base (depth of the layer, clay, silt and sand content, bulk density, porosity, available water capacity, field capacity, organic carbon content, organic N content, saturated conductivity); crop management parameters (day of operation, operation code (planting, fertilization, irrigation, harvesting, etc.), crop number (from crop data base), day of fertilization, amount of N and P applied per hectare, irrigation code)

Graphical User Interface: yes

GIS yes

Ownership: open source

Uncertainty analysis: existing tool

Institution/Authors Potsdam Institute for Climate Impact Research (PIK)

SWIM: V. Krysanova, D.-I. Müller-Wohlfeil, A.Becker (PIK)

	SWAT-Modules: J.G. Arnold, P.M. Allen, G.T. Bernhardt, R. Srinivasan, R.S. Muttiah, C. Walker, P.T. Dyke, 1993, USDA & Texas A&M University MATSALU-Modules: V. Krysanova, A. Meiner, J. Roosaare, A. Vasilyev, 1989, Estonian Ac. Sci.
Year, Country	2000, Germany
Keywords	watershed, basin scale, spatially distributed, runoff, groundwater, water quality, crop growth, nutrient cycling, nutrient transport, erosion, sediment transport, climate change, land use change, continuous-time, multiple subbasins, multiple hydrotops, three level spatial disaggregation, Priestley-Taylor evapotranspiration, modified Curve-Number-runoff, GIS, GRASS interface, soil database, SWAT
Model Objectives	Simulation of the hydrological cycle, erosion, vegetation growth and nutrient transport in mesoscale watersheds (100 to 20,000 km^2); Analysis of climate change and land use change impacts on hydrology and water quality at a regional scale. A daily time step is used. SWIM can be used either for hydrological modelling only, or for integrated hydrological/crop, hydrological/erosion, hydrological/water quality modelling.
Approach	A three-level scheme of spatial disaggregation "basin - subbasins - hydrotops" is implemented. SWIM/GRASS interface is used to initialize the model by extracting distributed parameters of elevation, land use, soil (maximum 10 soil layers), climate, and to create hydrotop structure and routing structure files. 1. subdivision of the basin into subbasins (10-100km^2). Boundaries can be obtained from existing maps or created in GIS 2. hydrotops are sketched within every subbasin, based on land use and soil types (hydrotop = units in a subbasin with unique land use and soil type).

3. SWAT/GRASS interface is adopted and modified (Steps 3 & 4) to extract spatially distributed parameters of elevation, land use, soil types, groundwater table and to generate hydrotop structure and routing structure files. A number of input files for the basin and subbasins is obtained.

Three-step modelling procedure:

1. water and nutrient balance are calculated for every hydrotop
2. outputs are averaged (weighted average) to estimate the subbasin output, (not accounting for lag time in the case of surface runoff, and assuming average for subbasin lag time for subsurface flow)
3. routing procedure is applied to the subbasin outputs, taking into account transmission losses.

Background: SWIM is based on two previously developed models – SWAT and MATSALU. Both models could not be applied at German watersheds to several reasons. The main reason is connection of SWAT to specific American data sets (especially for soil, weather, and crop rotation parameters), and not sufficient transferability of MATSALU (a system of four coupled models disigned for the Matsalu Bay watershed in Estonia). SWIM contains modules from both models and tries to combine their benefits (hydrological submodel and GRASS interface from SWAT; spatial disaggregation scheme and nutrient modules from MATSALU), while avoiding overparametrization.

Processes: hydrological processes: precipitation, snow melt, evapotranspiration, surface runoff, lateral subsurface flow (interflow), percolation to ground water, ground water contribution to streamflow, streamflow routing.

geo- and hydrochemical processes: input of fertilizers, mineralization, denitrification and nitrification, sorption/desorption (for phosphorus), crop uptake of nutrients, leaching to ground water, transport with surface flow, transport with subsurface flow.

For more information on each process see http://eco.wiz.uni-kassel.de/model_db/mdb/swim.html.

Technical Information:

Executables: Operating System: UNIX uses the Geo Information System GRASS.

Source-code: programming languages**:**

- SWIM/GRASS interface: C
- SWIM: Fortran

Manual: www.pik-potsdam.de/research/publications/pikreports/.files/pr69.pdf

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All information compiled from Register of Ecological Models:
http://eco.wiz.uni-kassel.de/model_db/mdb/hspf.html

Name: Water and Substance Simulation Model

Acronym: WASMOD

General Information

Main medium	aquatic, terrestrial
Main subject	biogeochemistry, hydrology, (eco)toxicology
Type of model	ordinary differential equations, partial differential equations, difference equations
Main application	research
Data requirements	Climate data, GIS layers of soil, relief, land use, river network, sub-catchments and relief units
Graphical User Interface	no
GIS	yes
Ownership	open source
Uncertainty analysis	no existing tool
Institution/Authors	Christian-Albrechts-University, Kiel Ernst-Walter Reiche
Year, Country	1994, Germany
Keywords	soil water dynamics, groundwater, carbon dynamics, nitrogen dynamics, soil temperature, eco-system research, pesticides, heavy metals, GIS, Bornhöveder Seenkette
Model Objectives	Simulation of water and nutrient dynamics at local scale or regional scale for whole catchments.
Approach	WASMOD is based on modules. Parameters are allocated to different spatial sections in order to label vegetation, relief and soil characteristics as well as agricultural techniques. Depending on that the process description takes place in a variety of hierarchical organized spatial units.

	The coupling with GIS results in simulations with high spatial and temporal resolution (http://www.pz-oekosys.uni-kiel.de/~ernst/wasmod/wasmod.html)
Processes	The description of the different transport and transformation processes is related to the vegetation, the soil surface, the rooted soil layers as well as the saturated and unsaturated zones. The simulation of the transport processes is done 'quasi-3-dimensional', i.e. vertical and lateral transport processes are simulated successively per time step. In this model lateral transport happens only at the soil surface and in the aquifer.

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