Testing of harp guidelines. Final report

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Cemagref

Testing of the Harp guidelines #6 and # 9

Final report

Contract number 15533 – 1999 – 12 F1ED ISP FR

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November 2001

1. Introduction

The pollution of fresh and marine waters has a long history. The first reports of deteriorated water quality, often with hygienic problems, but also about eutrophication symptoms, can be traced back to the latter half of the 19th century. Water pollution has probably started even earlier, at least in certain regions in Europe; this has been concluded by the population and production amounts connected with the information about the old production technology (Billen, G., et al., 1999). The growing concern of water pollution launched mitigation against loading to a lesser degree already in the first half of the 20th century, but in growing extent from the 1970's onwards. Success stories have been reported particularly concerning large fresh water lakes in temperate region of Europe, e.g. Lake Geneva and Lake Constance (Anneville, O. et Pelletier, J. P., 2000, Häse, C., et al., 1998), as well as lakes in the boreal zone (e.g. (Rekolainen, S., et al., 2001)). The development has not been as successful in marine waters, examples are the Baltic Sea, the North Sea and the Adriatic Sea (Löfgren, S., et al., 1999), and the deterioration has not ceased in many freshwater lakes either. Thus, the general conclusion has been made in Europe as well as in the U.S.: Eutrophication is still considered as one of the major environmental problem (European Environment Agency, 1999, U.S. Environment Protection Agency, 1995).

The recent reductions in point source loads, municipal and industrial sewage waters, have emphasised the contribution of agricultural losses (Kronvagn, B., et al., 1995, Rekolainen, S., et al., 1997, Van Der Molen, D. T., et al., 1998). In contrast to the municipal and industrial sources, diffuse losses are by far more difficult to quantify. Moreover, the assessment of best management practices, i.e. what is the optimal set of cost-effective abatement measures to reduce these losses, is not an easy task. This has been pointed out in several international contexts, e.g. in reports produced by the OSPARCOM and HELCOM, whose task is to assess the total loads and also contributions of various human activities on these loads (Helcom, 1998, Sft, 2000). Under the OPSPAR umbrella, a scientific working group has proposed a harmonised reporting guidelines, but so far no agreement has been achieved about the most suitable methodologies for estimating nutrient losses from diffuse sources (SFT 2000).

Agricultural losses of nutrients are of a diffuse nature, having both temporal and spatial dimensions. Thus, these losses can only be assessed by studying the whole watershed over time. Long-term monitoring of the losses at the watershed outlet as well as necessary data of watershed properties, variables and management operations, are required to achieve a sufficient accuracy and precision of estimation of the losses, its possible trends and to understand the factors affecting the losses. However, monitoring requires plenty of time and resources. Integrated management, including the loss assessments over several watersheds, which often differ much in terms of natural characteristics and human activities, is usually possible only using appropriate models.

Several models have been developed in order to estimate diffuse nutrient losses from a watershed. They vary very much in terms of complexity, structure and validation status. These models may be classified in several ways, however, two main categories can be identified: conceptual and physically-based models. Conceptual models are based on observations, and do not usually simulate the processes. Physically-based models contain descriptions of relevant physical, chemical and biological processes affecting nutrient transport from soil to water. The choice of model depends on the initial objectives of the task, and also on the available data.

Within the framework of the international conventions, such as OSPARCOM, HELCOM, and also in the implementation of the EU Water Framework Directive, the criteria for model selection is an ongoing process. The objective of this study was to test, how a few existing models, which differ much from each other conceptually, and in terms of complexity, can fulfill the requirements for the OSPARCOM harmonised reporting system. In doing this, we used observed data from a few small well-monitored river basins in order to see how these models can simulate spatial and temporal variations in watersheds, where data is relatively frequent and sufficient for parameterisation of complicated models.

2. Methods

2.1. study areas

2.1.1. Location and characteristics

Field measurements done on three European watersheds have been used as a database to conduct this study. One in Finland and the two others in France. The Savijoki watershed belongs to the National monitoring network of small drainage basins and it is located in south-western Finland, about 20 km Northeast from the city of Turku (22.5E, 60.5N). It is a tributary of the River Aurajoki that discharges to the Baltic Sea at the city of Turku (Figure 1). The Coët Dan and Cétrais watersheds are located in the western part of France. Both streams are tributaries of the Blavet and the Don (itself tributary of La Vilaine), respectively, which flow into the Atlantic Ocean (Figure 2).

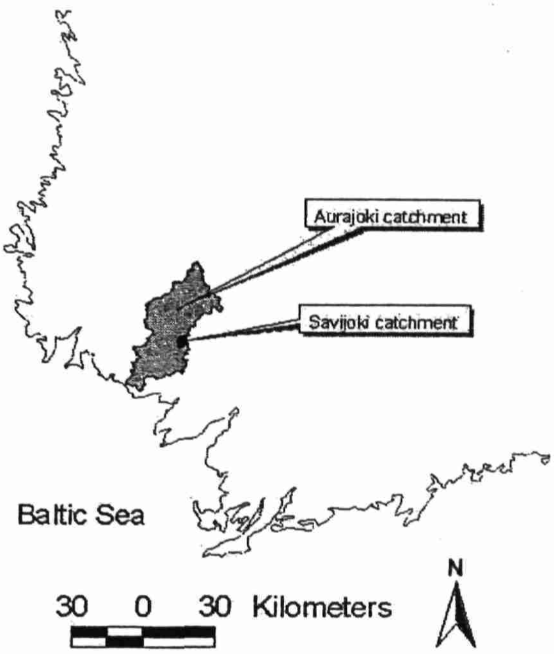
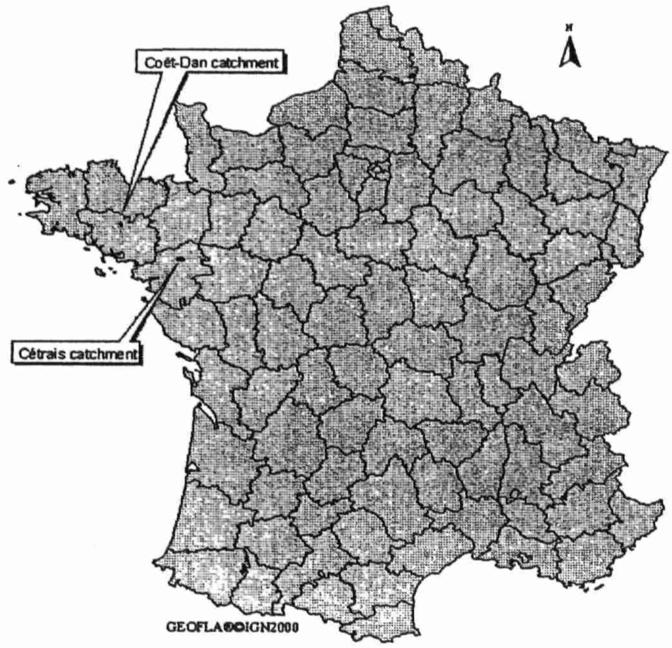


Figure 1 : Location of the Savijoki watershed in south western Finland

Figure 2 : Cétrais and Coët Dan watersheds localisation



The following developments use data and numbers summarised in Table 1. All watersheds are comparable in size, the Cétrais watershed being about 2 to 3 times as big as the other two. While agricultural lands cover most of the French watersheds, the Finnish one is mostly covered by forests. Agricultural land uses and practices are available for all three watersheds. Practices at the field scale have been recorded on the Cétrais watersheds nearly on a yearly basis, on the Coët Dan watershed four enquiries have been performed (1988, 1991, 1994 and 1999) and three on the Savijoki watershed (1987, 1999 and 2000). Missing data has been extrapolated from precise agricultural surveys performed several times in the last decade or so. Field crops are stored on a GIS for the French watersheds. In Savijoki, interview information on crop distribution and agricultural practices was available only for three years. In Finland, agricultural statistics are usually available only for administrative units, and the data is not geo-referenced. As a result, extrapolation of missing data was not possible in Savijoki.

Agricultural land use is very different from one watershed to the other and generally reflects agricultural intensity. In France, it seems to be highly correlated with livestock intensity on the watersheds. Spring cereals are mostly grown on the Savijoki watershed, in correlation to low livestock density. The Cétrais watershed is clearly a cattle breeding area with relatively medium intensity compared to the French and European average. As a result more than 50% of the area is covered by grasslands while cereal and corn are grown mostly as animal feed. The Naizin watershed is clearly the most intensively farmed watershed because of the high animal population raised on it. Swine, broilers and cattle are raised on the watershed, swine population accounting for most of livestock units produced. 85% of the crops produced on the watershed serve as animal feed. Grasslands are therefore less important in size than for the Cétrais watershed, while cereal and corn account for most of the difference.

Table 1 : Physical characteristics for the three watersheds

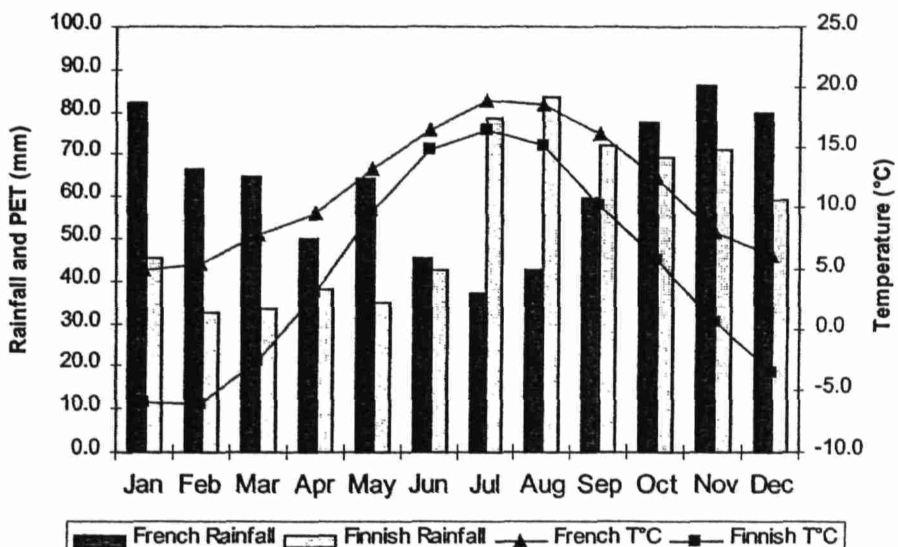
Characteristics of the watersheds	Savijoki	Coët Dan	Cétrais
Area (km²)	15.4	12.1	35.1
Land use			
Agriculture	39%	85%	74%
Forest and woods	>50%	4%	6%
urban areas	Negligeable	9%	8%
Others	-	2%	12%
Within arable lands			
Grasslands	12 %	26%	50%
Corn	-	32%	15%
Cereals	74 %	26%	20%
Others	14 %	6%	15%
Livestock density	Low	High	Medium
Soil types			
Brown soils	57% (Moraines)	83%	85%
Clay soils	34%	5%	3%
Peat	7%	0.5%	1%
Others	2%	10.5%	11%
Climate (yearly average)			
Precipitation	660 mm	755 mm	755 mm
Temperature	4.8°C	11.5°C	11.5°C
Water quality data			
Tot-N (kg/ha/yr)	8.2	46.0	22.7
Tot-P (kg/ha/yr)	0.6	0.5	only one year
Tot-N concentrations (mgl$^{1-1}$)	2.2	13.9	7.3
Tot-P concentrations (mgl$^{1-1}$)	0.17	0.16	only one year

A clear differentiation between the French and the Finnish watersheds can be made on soils. Finnish soils are the result of the aftermath of glacier retreat and can be divided into three main categories: moraines, clay and peat. Clay soils can be very deep in southern Finland, reaching as much as 28m in depth. Artificial drainage is needed to provide good conditions for management practices, especially after snowmelt in spring.

Soil covering the French watersheds are the result of alteration of granite and schist mostly and can be described as brown soils. They are usually very thin compared to the Finnish ones, rarely deeper than 1m. They tend to naturally drain relatively well, although local topography requires artificial drainage for the Cétrais watershed. Data on soil texture and organic matter content is available for all three watersheds.

2.1.2. Climatic characteristics

Figure 3 : climatic variable for the study watersheds



Over 30 years of weather data are available for all watersheds. Detailed data for mean, minimum and maximum temperatures, precipitation, relative humidity, wind speed and cloudiness are available from stations located 50 km or less for all watersheds. Figure 3 shows mean monthly climatic data for the Finnish watershed from 1961-1990 and for the French watersheds from 1978-2000.

Local rainfall data have usually been measured directly on the watershed sites. Data for the Naizin and Cétrais watersheds are not significantly different and will be assumed to be the same. In both regions, climate can be described as temperate, although there is a clear Nordic influence in Finland. With a yearly average temperature of 4.8 °C in Saviyoki, the climate is 6.7°C colder than in Brittany over the year. The average temperature is actually greatly lower due to winter months while temperatures are comparable in summer. Rainfall pattern are almost opposite with more rain or precipitation in late fall and winter in Brittany, while the precipitation peak occurs during the summer months in south-western Finland. It tends to rain more in Brittany than in Finland. Nearly a third of the total precipitation falls in the form of snow in Finland while snowfall is exceptional in Brittany.

2.1.3. Discharge measurements and water quality sampling

Discharge is measured continously on all stations by a V-notch overfall weir and a limnigraph for the Saviyoki and Naizin watersheds, while a Doppler velocity meter does the same job for the Cétrais watershed. Since the mid 1990s, water samples are mostly taken by automatic samplers often enough so that nutrient loads can be best evaluated. Grab sampling is also done as a complement.

Nutrients analysed always include NO_3-N, NH4-N, Tot-P and PO4-P in all watersheds. Total Suspended Solids are not analysed in Cétrais but are elsewhere. In Finland, many more analysis have been performed, which include Tot-N, Ca, Mg, K, Na, SO4, Cl, TOC pH, conductivity, alkalinity and turbidity.

Mean phosphorus concentrations and loads are quite similar between the Saviyoki and the Naizin watersheds. These values are relatively low in both cases. Load and concentration values for nitrogen are very different and seem to be correlated to agricultural intensity. Total nitrogen concentrations reported for the French watersheds actually correspond to flow weighted average nitrate concentrations. While nitrogen exports from the Saviyoki watershed are rather low (around 8 kg N/ha/yr), values for the Cétrais and the Naizin watershed are medium to high (around 22 and 45 kg N/ha/yr, respectively).

2.2. Simple methods

Nutrient losses from land to surface waters depend on meteorological forces, soils, topography and land use. The most simple approaches to estimate nutrient losses are based on **regression equations**, in which one or several of the dominant factors (e.g. field percentage (FP) within the watershed) have been used to calculate the losses. Two regression models have been chosen for testing in the MicroHARP framework: Regression model (Rekolainen, S., 1989) for total nitrogen (TotN) and total phosphorus (TotP), and Ekholm model (Ekholm, P., et al., 2000) for TotP.

Another method to estimate nutrient losses is based on export coefficients. These **simple loading models** based on loading functions provide a quick method for estimating nutrient losses. Through these functions the pollutant load can be related to parameters such as climate, slope, soil type, land-use, management practices etc. Collection of the relevant export coefficients for each watershed has been started during the first year of the project. Two simple loading models have been chosen for testing: the Cemagref export coefficient model (Bioteau, T., et al., 2000) for TotN and the Johnes model (Johnes, P. J., 1996) for TotP. In the following the regression models and the simple loading models are described in more detail.

2.2.1. Regression models

Rekolainen (1989) studied diffuse nutrient loading from 23 agricultural and forest areas belonging to a network of small hydrological drainage basins in Finland. Savijoki watershed was one of the areas in the study. The network represents different climate and land-use conditions of the country. There are no lakes in the study basins and, based on the land-use, the basins were divided into three classes: forest basins (FP < 8%), mixed basins (FP 8 – 35%) and agricultural basins (FP > 35%). Both phosphorus and nitrogen loads were found to be highly dependent on the proportion of agricultural land in the basins. In the study period 1981-1985 the phosphorus load from the forest basins varied from 5.9 to 16 kg km^{-2} a^{-1} and nitrogen load from 200 to 310 kg km^{-2} a^{-1}. The load from cultivated land varied from 66 to 160 kg km^{-2} a^{-1} for phosphorus and from 640 to 1400 kg km^{-2} a^{-1} for nitrogen. Based on this data, Rekolainen (1989) calculated regression models using only land use (share of agricultural land) to predict the TotP and TotN losses. A high positive correlation (r = 0.96) was found for the following equations:

$$P_{exp} = 1.4 \cdot FP + 9.5 \qquad (1)$$

$$N_{exp} = 11.4 \cdot FP + 240 \qquad (2)$$

where

P_{exp} = TotP export [$kgkm^{-2}a^{-1}$]
N_{exp} = TotN export [$kgkm^{-2}a^{-1}$]
FP = share of all agricultural land expressed as percentage of the total drainage basin area

Since these equation are derived from data covering several years, they do not take into account the effect of variation in rainfall. To be able to estimate specific annual values, the regression model was modified by taking into account the impact of rainfall amounts by using a multiplication factor that relates the specific annual rainfall to long-term mean annual rainfall:

$$P_i = f_i \cdot P_{exp} \qquad (3)$$

$$N_i = f_i \cdot N_{exp} \qquad (4)$$

where

P_i = the annual TotP loss for the calendar year i, [$kgkm^{-2}a^{-1}$]
N_i = the annual TotN loss for the calendat year i, [$kgkm^{-2}a^{-1}$]
f_i = multiplication factor calculated as:

$$f_i = \frac{P_i}{P_m} \qquad (5)$$

where

P_i = annual precipitation for the year i [mm]
P_m = mean annual precipitation over a long period (preferably 30 years) [mm]

Ekholm et al. (2000) developed a more complicated regresssion model to estimate P losses based on results obtained from one agriculturally watershed in southern Finland. They examined the effects of watershed characteristics and riverine processes on the concentration of nutrients and total suspended solids using data from outlets of 12 tributaries (9-139 km^2) and 22 main channel sites of a river draining an intensively cropped area of 1088 km^2. Their appraoch is not only for total P (TotP) but also for dissolved reactive P (DRP), and takes into account the land use, the topography and the total size of the watershed. Using this approach the TotP loss was calculated as:

$$P_i = q_i \cdot c_i \qquad (6)$$

where
q_i = the total runoff volume for the year i [l]
c_i = the mean concentration of TotP calculated as:

$$c_i = 4.93 \cdot FP + 245 \cdot Sl - 108 \qquad (7)$$

where

FP = share of all agricultural land expressed as percentage of the total drainage basin area
Sl = mean slope of the fields [%] within the basin.

Similarly the mean DRP concentration was calculated:

$$c_i = 0.55 \cdot FP + 0.09 \cdot A + 2.34 \qquad (8)$$

where

A = total area of the above watershed [km^2]

For the equation 7 the coefficient of determination (r^2) was 0.89 and for the equation 8, it was 0.69.The mean slope of the fields can be estimated e.g. using a Digital Terrain Model and calculate the mean slope of every single (agricultural) grid from the elevation difference to all neighbouring grids.The parameters of these models (equations 7 and 8) have to be calibrated or preferably derived from the local data.

2.2.2. Simple loading models

The export coefficient model for N load developed at Cemagref (Bioteau, T., et al., 2000) is based on the idea that nutrient losses from a watershed or field can be related to parameters such as climate, soil type, land-use and management practices. Two agricultural soil units with similar physical and chemical characteristics, and located in same climatic conditions are assumed to behave similarly in terms of runoff and nutrient leaching. The first step in the modelling procedure is collecting measured N export coefficients representing similar climatic and land-use conditions to those in the study area. The bibliographic references are grouped in a matrix containing many parameters of the reported sites: land-use, location, pedological data, climatic data, system of production, management data etc. For selection of the export coefficients, the order of parameter dominance should be: land-use, place, soil type, geology, system of production, precipitation, drainage flow, management practices. The second step of the modelling procedure is linking the actual fields within the study area to the export coefficient matrix with GIS. The nitrogen losses (in Kg N per year) can then be calculated for each field unit by multiplying the selected export coefficient by the area of the unit.

The export coefficient model developed by Johnes (1996) is used to estimate P losses from MicroHARP watersheds. The model is used to calculate TotP load from each nutrient source in the watershed, the input data consisting of spatial distribution of land-use, fertilizers applied, numbers and distribution of livestock and human populations and atmospheric deposition. Export coefficients for each identifiable source are derived from literature.

The annual load of TotP is calculated as:

$$P_{\exp} = \sum_{i=1}^{n} E_i\left[A_i(I_i)\right] + p \qquad (9)$$

where

E_i = export coefficient for TotP source i
A_i = area of watershed occupied by land use type i, or number of livestock i, or of people
I_i = input of TotP to source i
p = input of TotP in precipitation

The export coefficients express the rates at which TotP is exported from each land use type in the watershed. For animals, the export coefficients express the proportion of wastes voided by the animal, which will subsequently be exported from stock houses and grazing land to the drainage network.

The human input is calculated as:

$$E_h = D_{ca} \cdot H \cdot 365 \cdot M \cdot B \cdot R_s \cdot C \qquad (10)$$

where

E_h = annual export of TotP from human population [kg a^{-1}]
Dca = daily output of TotP per person [kg d^{-1}]
H = number of people in watershed
M = coefficient for mechanical removal of TotP during treatment
B = coefficient for biological removal of TotP during treatment
R = retention coefficient of the filter bed
C = coefficient for removal of TotP if TotP stripping takes place.

The nutrient load through precipitation is calculated as:

$$p = c \cdot a \cdot Q \qquad (11)$$

where

c = concentration of TotP in precipitation [gm^{-3}]
a = amount of rainfall per year [in m over the watershed]
Q = percentage of the total annual rainfall lost to runoff

The model is then calibrated against the observed TotP load determined in the field monitoring programme, and the accuracy of the predicted nutrient losses is assessed. Johnes (1996) constructed the model for the year 1989 in Windrush watershed in UK. After calibration of the export coefficients, the deviation between the measured and calculated TotP loss was within 0.5%. The Windrush model was validated for the period 1925-1989 using independent records of changes in the input data for e.g. land use, livestock numbers, fertiliser application rates, human population and atmospheric deposition.

2.3. Mid-range models

The extension services in France have developed a method to help the farmers to adapt their fertilisation. A balance has been built on a yearly basis (Comifer, 1995) to assess the amount of inorganic nitrogen (X) to apply :

X = Re + PluiN + Mhb + Mha + Mhp + Mr + Xa + Rest + Fix + (Nf – Ne) – Rf

with :

X amount on inorganic nitrogen to applied

Re initial content of inorganic nitrogen in the soil

PluiN inorganic nitrogen in rain

Mhb basal mineralisation from the soil

Mha defer effect of previous spreads of organic nitrogen

Mhp defer effect of previous plowing of grasslands

Mr defer effect of previous crop

Xa direct effect of manures

Rest amount of inorganic nitrogen spread during grazing periods

Fix fixation by legumes

Nf – Ne crops requirements

Rf final content of inorganic nitrogen in the soil

With this method, the N cycle is roughly simulated, with annual coefficients produced by extension services in each area (see annex for coefficients used in Loire Atlantique).

The idea of this method is to estimate ex post the amount of nitrogen in the soil, Rf, each year, using surveys for inorganic nitrogen spread and yields, and the previous equation. Because the fertilisation equation was built on cropping period, and it is now used for autumn and winter time, some parameters have been added :

(12)

Rf = Re + PluiN + Mhb + Mha + Mhp + Mr + X + Xa + Rest + Fix + (Nf – Ne) – **Reorgn – Reorgpra - Denit – Volat +Ev**

(13)

with :

Rf to Ne parameters of eq. 12

and with new parameters :

Reorgn fixation of nitrogen from crop residue for C/N >50

Reorgpra amount of nitrogen organised under grassland (Scholefield, D., et al., 1991)

Denit denitrification during autumn and winter

Volat volatilisation for slurries (Moal, J. F., 1995)

Ev sampling of N if intermediate crop is sowed after harvesting

see annex1 for estimation of these parameters.

For the following year, the initial amount of nitrogen is estimated from this Rf and simple leaching models. Here, Burns model (Burns, I. G., 1975) has been used.

2.4. - physically based models :

2.4.1. ICECREAM

The selected model, ICECREAM (Tattari, S., et al., 2000), is a field-scale mathematical simulation model predicting water, soil, phosphorus (P) and nitrogen (N) losses at the edge of fields and out of the root zone. It is an extension of the CREAMS/GLEAMS models (Knisel, W. G., et al., 1995, Knisel, W. G. E., 1980) originally developed in the U.S. to assess and compare the impact of different management practices on soil and nutrient losses.The hydrology, crop growth, and partly also the erosion calculations have been further developed by (Rekolainen, S. et Posch, M., 1993).

The hydrology component of ICECREAM simulates daily runoff using a modification of the SCS Curve Number method (Wischmeier, W. H. et Smith, D. D., 1978), which relates to soil texture and structure, land use and management practice. The matrix flow in soil is described by a simple 'tipping bucket' system using the user-defined hydraulic conductivity and pF-curve values for porosity, field capacity and wilting point. Evaporation is calculated by a model presented by (Ritchie, J. T., 1972). Erosion is computed using the modified Universal Soil Loss Equation, MUSLE (Foster, G. R., et al., 1981).

The submodels for P and N are mainly taken from the GLEAMS model with a few adaptations to achieve a better fit to local conditions. The P cycle in the soil is described by three inorganic and two organic pools, and flows between these and the biomass. The most active inorganic pool is the plant available P, which has been defined as anion exchange extractable P (Sharpley, A. N., et al., 1994). Chemical fertiliser P is added to plant available P at the day of fertilisation, and crops are assumed to take up P from this pool only. The loss of soluble P with surface runoff also originates only from this pool, whilst the loss of particulate P (attached to soil particles) takes place from all soil P pools.

The nitrogen submodel includes the significant pools and flows of the nitrogen cycle in soil. Nitrate (NO_3^-) and ammonium (NH_4^+) constitute the plant-available inorganic nitrogen. Plant uptake of nitrogen is calculated on the basis of biomass demand and supply. The model considers two sources of mineralisation from organic N pools: fast-cycling fresh organic N pool (litter N), associated with crop residues and microbial biomass, and the more stable organic N pool, associated with the soil humus. Organic N associated with humus is further divided into two pools, active and stable.

The nitrogen pools are connected by reactions such as mineralisation and immobilisation. Most of the reactions are controlled by moisture content and temperature of soil layers. Inorganic or organic fertilisers and the atmospheric deposition constitute the input of nitrogen to the model. Nitrogen losses take place from the topsoil by erosion and in soluble form by surface runoff. Nitrate and ammonium are also percolated from the lowest simulated soil layer. Soil nitrate can be reduced to nitrogen gases by denitrification. Volatilisation, the loss of ammonium N to the atmosphere, is estimated simultaneously with nitrification.

2.4.2. BMP1-GLEAMS

GLEAMS v.2.10 (Groundwater Loading Effects of Agricultural Management Systems) is a mathematical model to simulate the complex climate-soil-management interactions for fields-size area. GLEAMS operates in a daily time step. It does not simulate movement at groundwater level. The main aim of BMP1-GLEAMS is to use GLEAMS for all homogeneous surface units coming from GIS (see method 2) and coupled it with a hydrologic model.

BMP1-GLEAMS simulates in detail most of nitrogen movements in soil and particularly flows between both organic and mineral nitrogen pools.

A detailed and complete description of the model is given in the user manual provided with the model (Knisel, W. G. E., 1993). Knisel also proposes a summarised description and model modifications. GLEAMS v. 2.10 is composed of four components operating simultaneously: hydrology, erosion/sediment yield, pesticides and plant nutrients. However the model can operate without using all modules and the module pesticides can be disconnected particularly.

2.4.3. SWAT

SWAT is a spatially distributed model developed to predict the effects of management (Climate and vegetative changes, reservoir management, groundwater withdrawals, water transfer) on water sediment and chemical yields on large river basins. SWAT can analyse watersheds and river basins of 100 square miles by subdividing the area into homogenous units. The model simulates hydrology, pesticide and nutrient cycling, erosion and sediment transport. Water, nutrients and sediment quantities predicted at the field scale are routed in the hydraulic network. Information required on the inputs can be obtained from existing databases. A linkage will be done using data already available in the existing GIS on the Cétrais and Coët Dan watersheds and SWAT.

Description provided herein is mostly taken from available descriptions of SWAT, especially that available at http://www.wiz.uni-kassel.de/model_db/models.html. The model was developed by modifying the SWRRB, (Arnold et al, 1990) and ROTO (Arnold et al., 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, running simultaneously in several hundred subbasins.

The SWAT hydrology model is based on the water balance equation. A SCS curve number is generated for the computation of overland flow runoff volume, given by the standard SCS runoff equation (USDA, 1972). A soil database is used to obtain information on soil type, texture, depth, and hydrologic classification. In SWAT, soil profiles can be divided into ten layers. Infiltration is defined in SWAT as precipitation minus runoff. Infiltration moves into the soil profile where it is routed through the soil layers.

A storage routing flow coefficient is used to predict flow through each soil layer, with flow occurring when soil moisture in 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, J. G., et al., 1993).

Based on surface runoff calculated using the SCS runoff equation, excess surface runoff not lost to other functions makes its way to the channels where it is routed downstream. Sediment yield used for in-stream transport is determined from the Modified Universal Soil Loss Equation (MUSLE) (Arnold, J. G., 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. Sediment size is estimated from the primary particle size distribution (Foster and others, 1980) for soils the SWAT model obtains from the STATSGO (USDA 1992) database. 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.

2.5. Statistics

One component of a model evaluation exercise is to define criteria by which the agreement between observation and prediction can be assessed. As part of this research programme, various statistical indices were either taken from the literature or identified in discussions with statisticians. A description of the indices selected is given below. They were not all used in the subsequent modelling exercises, but they are listed here to give an indication of the types of index that are available.

The simplest way to assess model performance is to plot the predicted and observed values on a suitable diagram; this method represents an essential starting point for any model evaluation exercise. The visual method, although useful, needs to be backed up by some appropriate statistical evaluation so that relative model performance can be assessed in different situations. What is required is a system that enables us to estimate the fit (or the lack of fit) that is expressed graphically in the diagrams.

The criteria used in selection of the statistical indices were purposely chosen in relation to our specific context. Many alternatives were available, but only those with a simple and straightforward application were selected.

2.5.1. The Set of Indices

An index calculated from observed and predicted data can be used to express an overall fit of the model simulation or the fit of a particular aspect of the phenomenon we are modelling.

2.5.2. Notation

The evaluation process in the current research project deals mainly with the prediction of annual nutrient loads in rivers. The adopted notation is as follows:

Given a sample of N annual observations and their N corresponding annual predictions

O_i Observed nutrient loss in the i-th year $i=1,..,N$

P_i Predicted nutrient in the i-th year $i=1,..,N$

$\{O_i\}$ Sample of observations

$\{P_i\}$ Sample of predictions

iff *"if and only if"* (logical equivalence: biconditional)

if...then... logical implication.

$\forall i$ For all values ($i = 1,...,N$)

We will refer to the *graph* $\{(i,P_i)\}$ as the *Predicted Curve* (the plot of predicted values against time), and similarly the *Observed Curve* refers to the plot of observed data against time.

2.5.3. Evaluation of Overall Fit

2.5.3.1. Scaled Total Error

$$TE = \frac{\sum_{i=1}^{N} |P_i - O_i|}{\sum_{i=1}^{N} O_i} \qquad (14)$$

The numerator of the above ratio represents the ***total discrepancy*** between predicted and observed values. The reason for dividing by the total of the observed values is to scale the total error in relation to the size of the experiment. This enables us to use the same index (1) for comparison between different modelling approaches.

Properties

Two properties follow by the definition of TE:

$TE \geq 0$;

$TE = 0$ *iff* $\forall i \ (P_i = O_i)$.

2.5.3.2. Scaled Root Mean Squared Error

$$SRMSE = \frac{1}{\overline{O}} \bullet \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}} \qquad (15)$$

This quantity (2) is a measure of the *Spread* around the ideal case of $P_i = O_i \ \forall i$:

With a perfect fit, the value $(P_i - O_i)$ would be zero. The left-hand factor in (2) is included in order to *scale* the *Root Mean Square Error* in a similar way to that used for Index (14).

Properties

Again, from the definition of (15) it follows that:

$SRMSE \geq 0$

$SRMSE = 0$ *iff* $\forall i \, (P_i = O_i)$.

2.5.3.3. Model Efficiency

$$ME = \frac{\sum_{1}^{N} (O_i - \bar{O})^2 - \sum_{1}^{N} (P_i - O_i)^2}{\sum_{1}^{N} (O_i - \bar{O})^2} \quad (16)$$

This quantity is widely used in Model Evaluation exercises and is based on more sophisticated considerations than the previous indices.

In order to understand its behaviour, *ME* can be rearranged as follows (*ME* in this form is known as *Sutton-Rathcliffe's Coefficient*):

$$1 - \frac{\sum_{1}^{N} (P_i - O_i)^2}{\sum_{1}^{N} (O_i - \bar{O})^2} \quad (16a)$$

Properties

The following observations can be made:

$ME \in \,]-\infty; +1]$ (*ME* has no lower bound and its upper bound is 1)

$ME = 1$ *iff* $P_i = O_i \; \forall i$

ME # 0 *iff*

$$\left(\sum_{1}^{N} (P_i - O_i)^2\right) / \left(\sum_{1}^{N} (O_i - \bar{O})^2\right) \leq 1$$

The third property suggests that when *ME* becomes negative the fit is unacceptably poor. Under these conditions, the statistical sample variance of $(P_i\text{-}O_i)$ is less than (or equal to) the sample variance of $(O_i\text{-})$. Therefore accepting the model predictions is no better than simply using the mean of the observed data.

2.5.3.4. Coefficient of Determination

$$CD = \frac{\sum_{1}^{N} (O_i - \bar{O})^2}{\sum_{1}^{N} (P_i - \bar{O})^2} \quad (17)$$

This is the ratio between the spread of the observed values around their mean and the spread of the predicted values around the observed mean.

Properties

$CD \geq 0$

if $\{P_i\} = \{O_i\}$ *then* $CD = 1$

In general, the closer CD is to 1, the better the fit. When CD = 1, the statistical variance does not change if we use the predicted rather than the observed values. There are therefore reasons to believe that there is good agreement between observed and predicted data.

2.5.3.5. Coefficient of Shape

$$CS = \frac{\sum_{1}^{N} (O_i - \bar{O})^2}{\sum_{1}^{N} (P_i - \bar{P})^2} \quad (18)$$

This quantity (similar to *CD*) represents the ratio between the spread around their respective means of both the predicted and the observed values (i.e. ratio between the sample variance of the two sets). In graphical terms, this is reflected by a similarity in the shape of the predicted and observed curves.

Properties

Same properties as *CD*

$CS = 0$ ***iff*** $\forall$ constant $K > 0$ so that $\forall i$ $(P_i = O_i \; \forall \; K)$

The second property means that when the predicted amounts differ from the observed amounts by a certain constant *K*, *CS* does not vary. This behaviour will be characterised visually as a predicted curve similar to the observed **but** shifted upwards or downwards by a constant factor. In this situation, the simulation is likely to be responsible for the overall lack of fit.

NOTE: As any index calculation is carried out on an equal number *N* (number of years) of observations O_i against their predictions P_i, the condition of *good fit* for loss (ΣP_i . ΣO_i) renders *CD* . *CS*. With these conditions, the information given by *CS* will be identical to that from *CD*.

3. Results :

3.1. simple methods

3.1.1. application of the simple methods for nutrient loads estimation

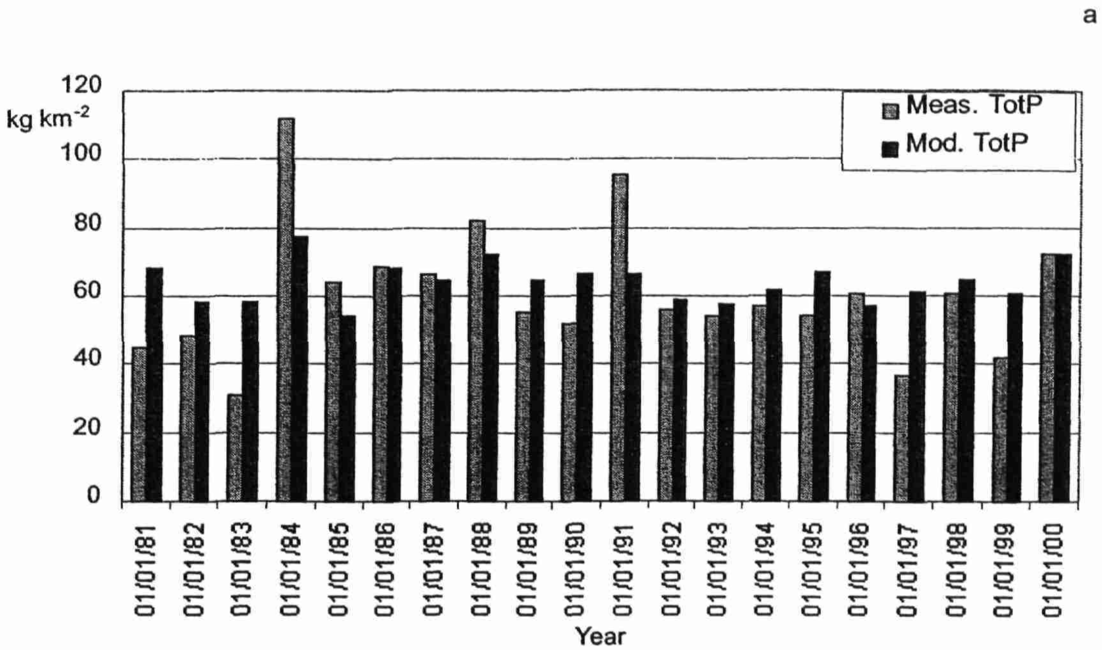
3.1.1.1. Regression models on the Savijoki watershed

In the first phase of the modelling procedure the simple regression model by Rekolainen (1989) was applied at Savijoki watershed. The TotN and TotP loads were calculated with equations 1 and 2. The only parameter needed is field percentage, which for Savijoki is 39% during the study period 1981-2000. The TotP export from the Savijoki watershed calculated by the equation (1) is 64 kgkm-2a-1 which is very close to the measured mean annual TotP load for the period 1981-1997 (61 kgkm-2a-1). The TotN export calculated by the equation (2) is 685 kgkm-2a-1, which is somewhat lower than the measured mean value 819 kgkm-2a-1 .

To be able to model specific annual load values, the impact of precipitation was taken into account by using a multiplication factor that relates the specific annual rainfall to long-term mean annual rainfall (equations 3-5). Measured precipitation values were corrected to account for measuring errors. The measured and modelled annual TotP and TotN loads are presented in Fig.1. For TotP the model either over-or underestimated the load while for TotN it was more common that the model underestimated the load (80% of the cases). The mean modelled loads for the period 1981-2000 were 64 kgkm-2a-1 for TotP and 685 kgkm-2a-1 for TotN. In the year 1984 both TotP and TotN loads were highly underestimated. This is probably due to the high amount of precipitation (946 mm) in 1984.

Next, TotP was estimated with the model developed by Ekholm et al. (2000) (equations 6 and 7). Two parameters are needed for the model, namely field percentage (FP) and mean slope (Sl) of the fields. For Savijoki FP is 39% and Sl is 0.5%, as estimated from the DTM. The annual mean concentration of TotP in the river Savijoki calculated by the equation 7 was 206.8 mg l-1. The annual TotP loads for the years 1981-2000 where then calculated by multiplying the mean concentration by the total annual runoff volume. The modelled and measured annual TotP loads are shown in Figure 4. The model overestimated TotP load in 80% of the cases. The mean modelled annual TotP load for the period 1981-1997 was 76 kg km^{-2} a^{-1}.

Figure 4 : regression model results for 1981-200 on Savijoki watershed



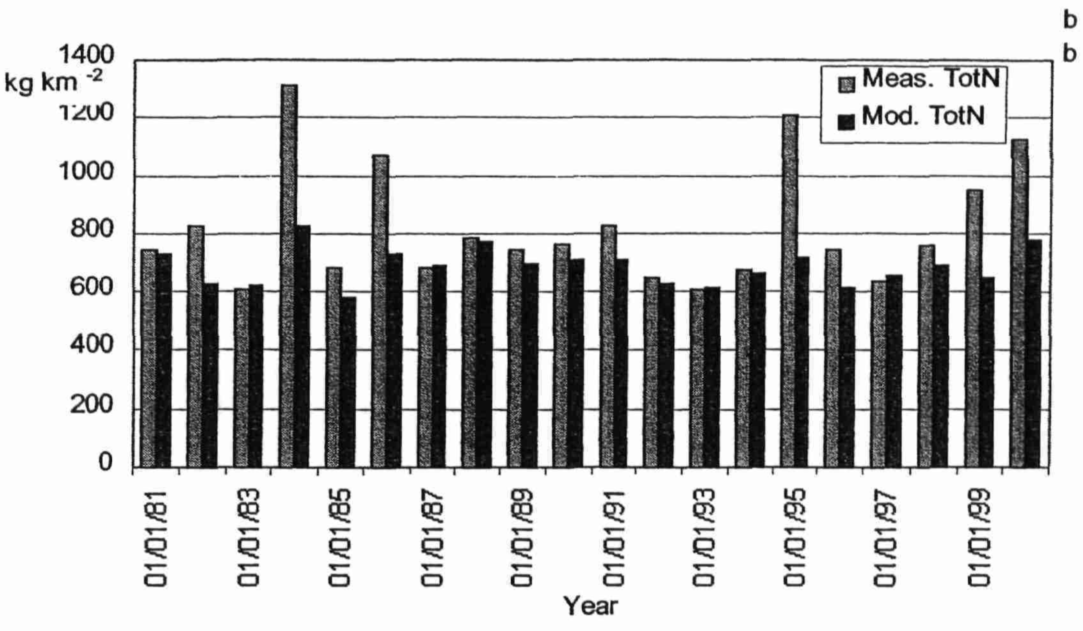
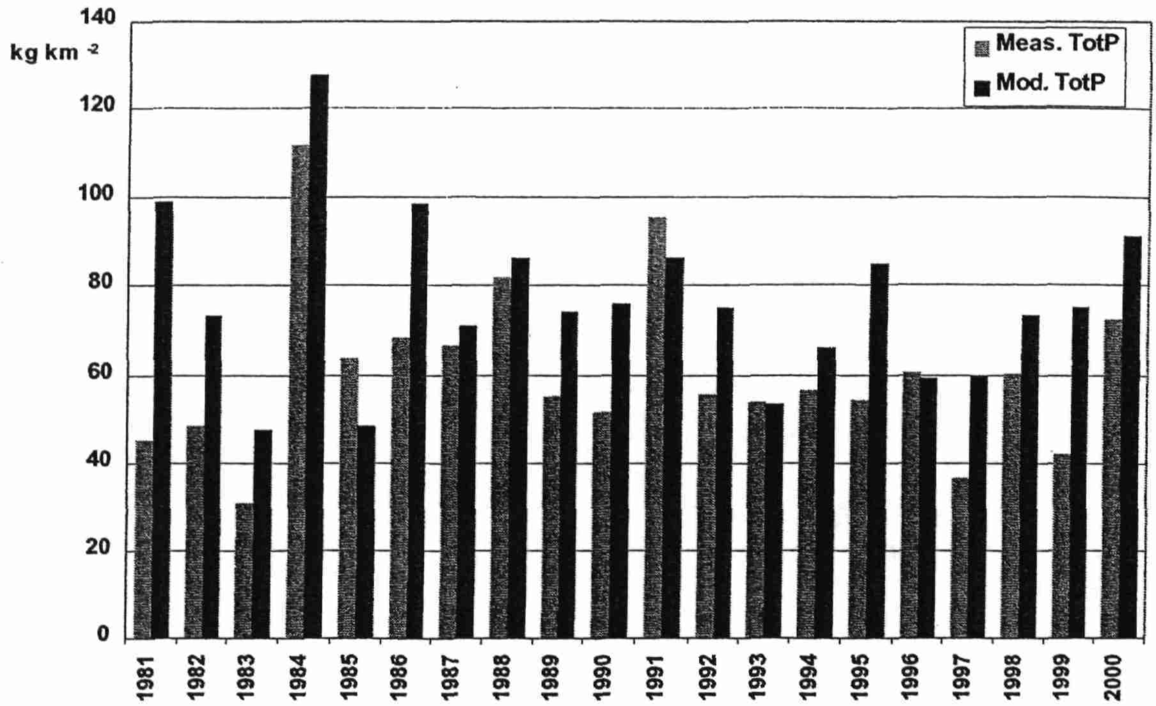


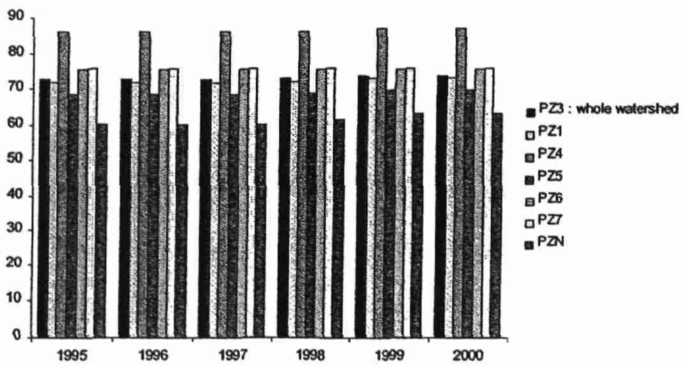
Figure 5 : Measured and modelled annual total phosphorus load (TotP) in the Savijoki catchment. Model: Ekholm et al. (2000).



3.1.1.2. Regression models on the Cétrais watershed

The simple regression model (Rekolainen, 1989) was applied on the Cetrais watershed, and each sub-watershed. The tot N and tot P loads were calculated with equations 1 and 2. The only parameter needed is the field percentage, which changes slightly from one year to the other and more from one subs-watershed to the other (see Figure 6).

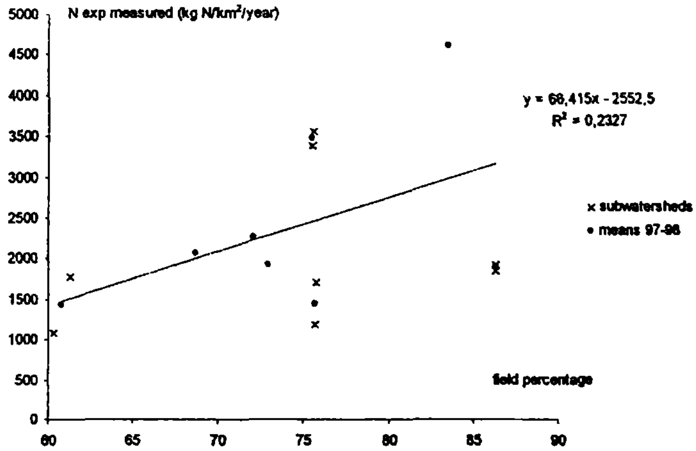
Figure 6 : field percentage on Cétrais subwatersheds



Only nitrogen loads have been measured on the Cétrais sub-watersheds. Total N loads estimated with regression model are highly underestimated : the tot N export calculated with equation 1 is 10,7 kg N/ha/year (mean for every points and every years, $\sigma = 0.7$) and the measured value is 22,7 kg N/ha/year ($\sigma = 7.5$).

We have tried to calibrate this regression model, with data from 1997 and 1998, because we have measurements for these years on all the stations. The Figure 7 shows Nexp measured (mean 97-98) on each station including Naizin watershed, compared to the field percentage.

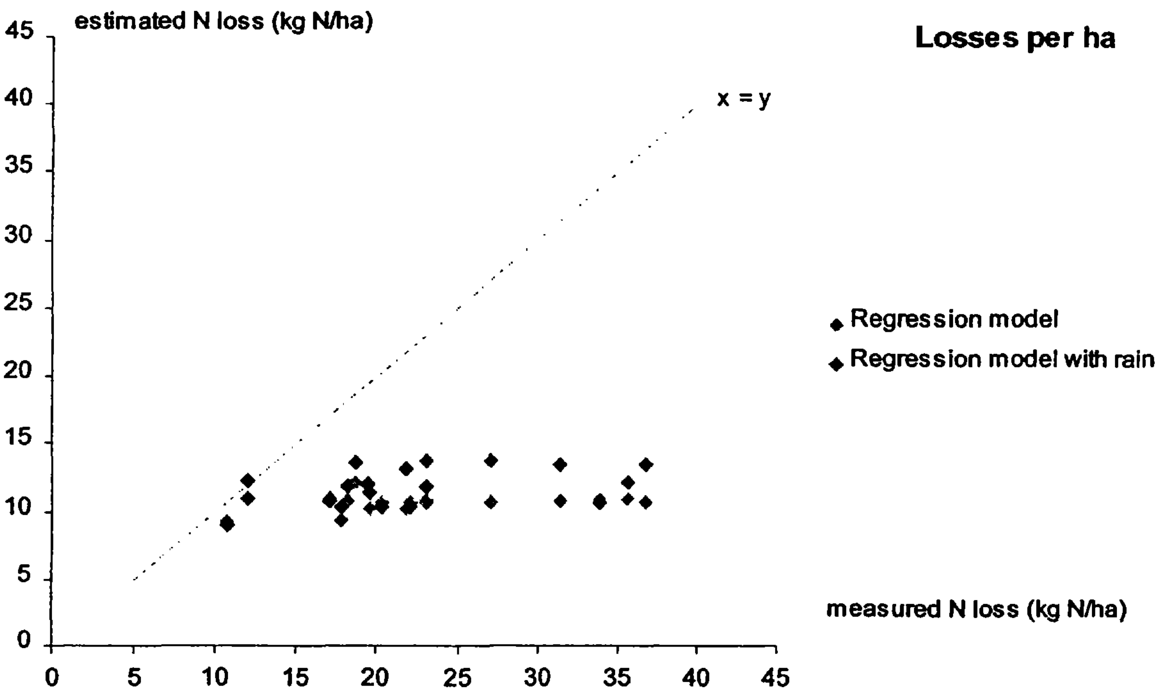
Figure 7 : Nexp measured (mean 1997-1998) as a function of field percent



We do not have enough points for calibrating this regression equation (correlation between these two variables is very bad). In fact, in the western part of France, one can observe very different ranges of animal density (and thus of nutrient losses) from one area to the other : the field percent is not enough to estimate the loads.

For improving annual loads values around the range, we considered the impact of annual precipitation compared to long-term mean annual rainfall (data coming from Météo France). For tot N the model underestimates the loads as soon as they are greater than 10 kg/ha (see Figure 8).

Figure 8 : estimated N loads compared to measured ones – regression models on Cétrais watershed



3.1.1.3. Regression models on the Coët Dan watershed

The simple regression model (Rekolainen 1989) was applied on the Naizin watershed. The field percentage varies slightly on this watershed from 82 to 85% on the 1993-2000 period.

As observed on the Cétrais watershed, the tot Nexp are greatly underestimated (see Figure 9) : the tot Nexp mean is 15.9 tons and the mean measured value is 63.2 tons.

On the contrary, this model overestimates tot P loads (see Figure 10).
Taking into account the precipitation for annual estimation gives no improvement.

On Naizin watershed, Ekholm (2000) model was applied for totP loads. This model overestimates the measured loads too : the mean totP load estimated with Ekholm model on Naizin watershed is 5.9 tons / year and the mean measured tot P load is 0.5 ton / year.

Figure 9 : estimated N loads compared to measured ones – regression models on Naizin watershed

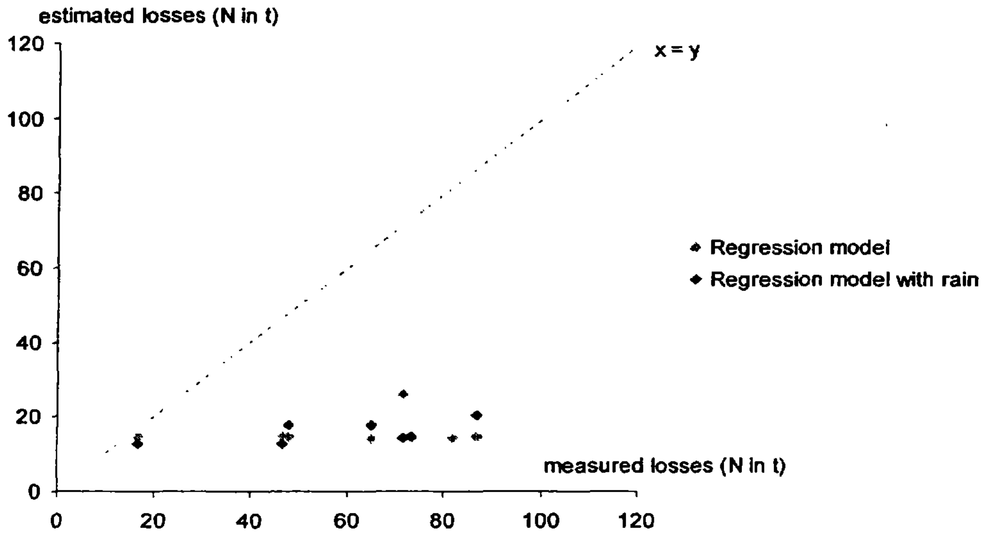
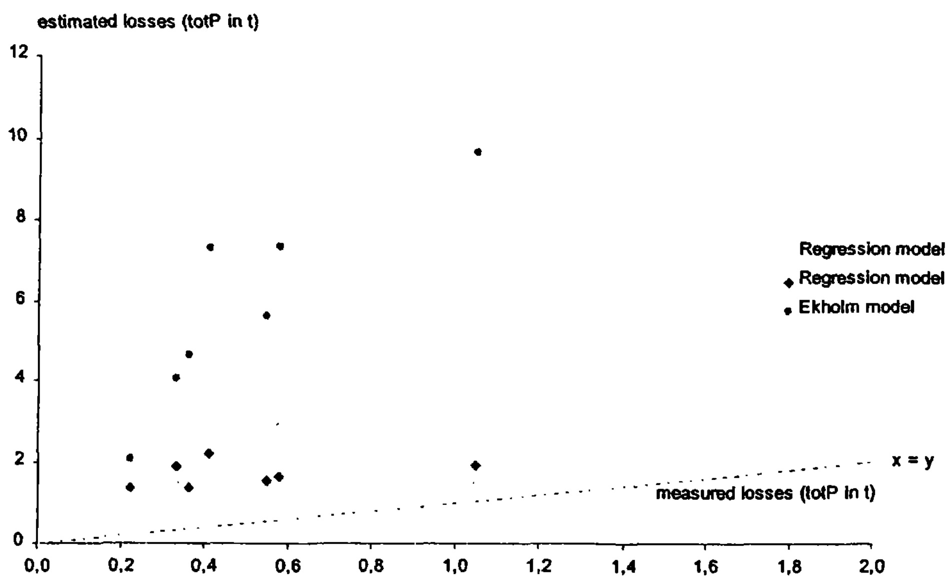


Figure 10 : estimated totP loads compared to measured ones – regression models on Naizin watershed



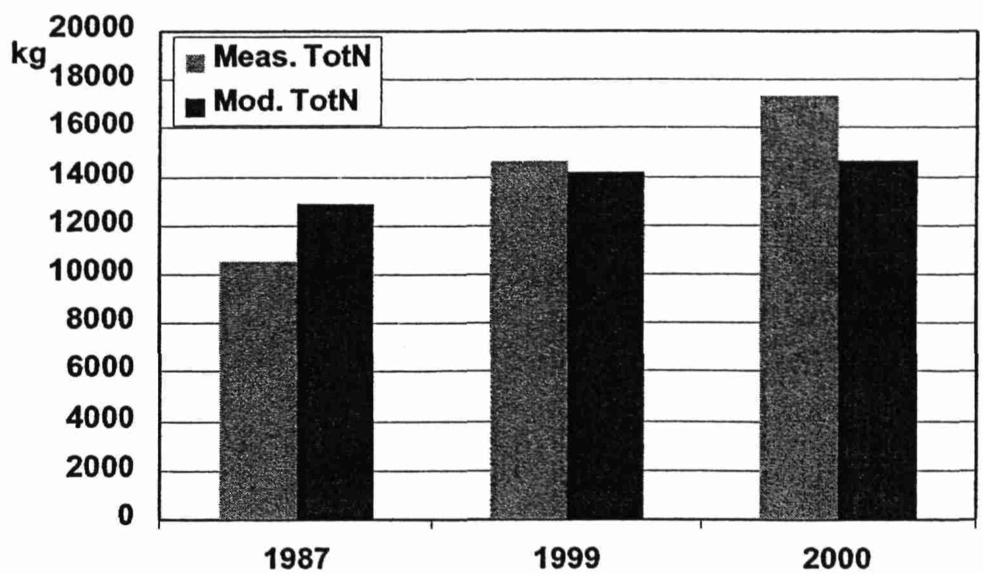
3.1.2. Application of simple loading methods

3.1.2.1. Application of the N export coefficient model in the Savijoki watershed

The first step in applying the N export coefficient model was evaluating the representativity of available measured export coefficients in climatic and land-use conditions similar to those in Savijoki. In Finland, there are only few experimental fields where the effects of agricultural practices on nutrient leaching are studied. Moreover, the study period for testing different practices is usually rather short (only a few years). As a result, it is often difficult to distinguish between the effects of long-term variability in hydrologic conditions and the differences in actual management practices. Due to lack of data on actual measured export coefficients, a data base built for a decision-making system VIHTA (Äijö and Tattari 2000, Puustinen 2001) was utilised for deriving the export coefficients for nitrogen. The VIHTA-model was developed to help selecting the best agri-environmental protective measures to reduce nutrient loads to surface waters. The model utilises estimated values of nutrient loads for a set of field properties, e.g. soil type, slope and vegetation (altogether 96 different categories). In VIHTA-model the vegetation is classified as covering (grass) or not covering (cereals etc.). The load estimates for different field property categories are based on measurements, modelling and experts' assessments.

In Savijoki, interview data on crop distribution and management practices was available only for the years 1987, 1999 and 2000. The dominating soil type on the fields is silty clay and the mean slope of the fields is 0.5 %. The N export value chosen for these conditions was 15 kg/ha/a for covering crops and 18 kg/ha/a for non covering crops. The proportion of the different crop types in the fields have remained rather similar during the study years. The total area of each crop type was calculated for each of the years and the total N load for the agricultural area was calculated by multiplying the export values by the area occupied by the crop. Estimates for N leaching from forests, scattered settlement and the natural background leaching were the same that have been used in the nutrient source assessment system VEPS for Savijoki conditions. VEPS interface was developed at SYKE for assessing nutrient sources and loads at Finnish watersheds.

Figure 11 : Measured and modelled annual total nitrogen load (TotN) in the Savijoki watershed. Model: Nitrogen export coefficient model.



The system provides information on the magnitude of nutrient losses to surface water systems, source apportionment of loads and the variation of loads in time. In VEPS, the estimation of nutrient load from forestry is based on load functions for different forestry practices and statistical information about these practices collected from forestry board districts. The estimates of natural background losses are based on research results from representative basins. For scattered settlement, the estimates of export coefficients for nutrient leaching are based on experimental results for different types of sewage systems and information about population density. Figure 11 shows the calculated totN load for Savijoki watershed. The modelled totN load is of the same order as the measured one. Differences in measured values reflect the variation in annual discharge, which for the test years was lowest in 1987 (344 mm) and highest in 2000 (442 mm). The export coefficient model is not able to take into account the varying hydrological conditions during the study years.

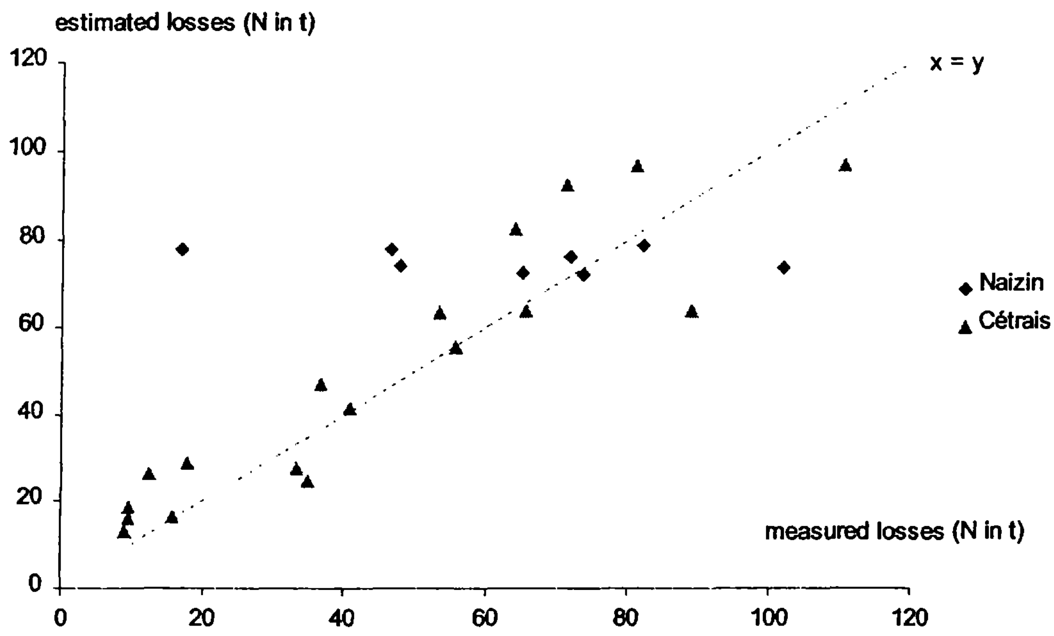
3.1.2.2. Application of export coefficient model on the Cétrais and Naizin watersheds

For Naizin watershed, the crops are quite the same from one year to the other (see point 2.1. for details). So, the estimated N loads are roughly the same from 1993 to 2000. Unfortunately the measured loads are very different from one y can to the other : for dry years, the export coefficient model overestimates the measured loads, and for wet years it underestimates them (see Figure 12).

A mean N load for the 1993-2000 period on Naizin watershed as an estimation from the export coefficient model is 75.4 kg N/ha, with a standard deviation of 2.6. The mean measured N load of 63.2 kg N/ha is different from the estimated value.

For Cétrais watershed, the export coefficient model overestimates the measured N loads every time but for 2000 which is a very wet year (see Figure 12).

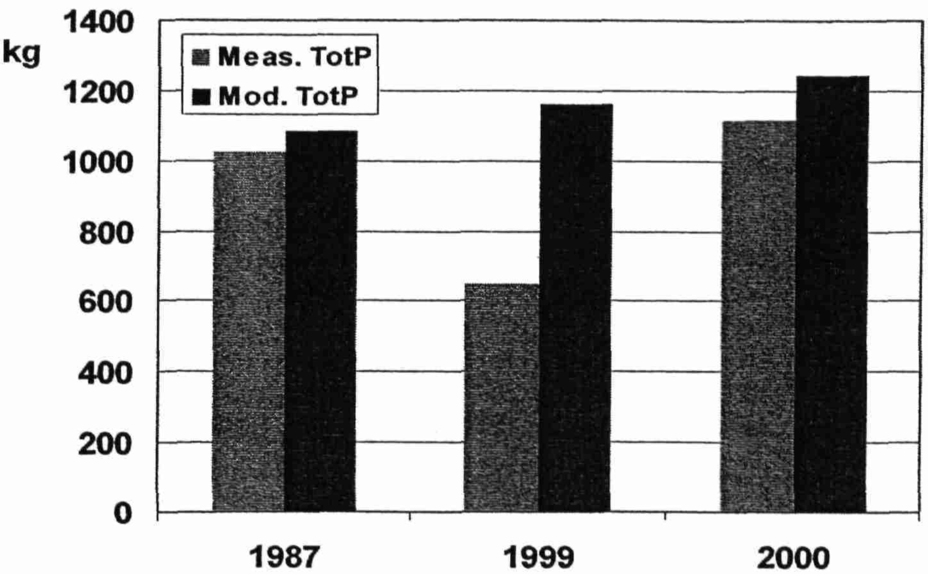
Figure 12 : estimated N loads compared to measured ones – export coefficient model



3.1.2.3. Application of Johnes model on the Savijoki watershed

Input data for Johnes model (Eq. 9) consist of spatial distribution of land-use, fertilizers applied, number of livestock and human population and atmospheric deposition. Phosphorus export coefficients are needed for each identifiable source (e.g combinations of crop and fertilizer). Due to lack of data on actual, measured export coefficients for Savijoki conditions, the same procedure was applied here as when calculating the totN load by the N export coefficient model. The relevant values for P export where chosen from the VIHTA-database, and the overall TotP load from the field area was calculated by multiplying the export values by the area occupied by the crop. The effect of phosphorus deposition is included in the VIHTA values as a default. Estimates for P load from forests and the natural background leaching were the same that have been used in VEPS. The TotP load from scattered settlement was also calculated based on VEPS estimates (kg P/km2 of scattered settlement). The data on crop distribution was available only for the years 1987, 1999 and 2000. Fig. 1 shows the calculated TotP load for the Savijoki watershed. As can be seen, the modelled TotP values fit rather well the measured values in the years 1987 and 2000, but are very much higher than the measured ones in 1999. The measured TotP load for the year 1999 (647 kg) was among the lowest ones for the whole study period 1981-2000. The low measured value can be partly explained by the difficulties related to sampling strategy: some of the peaks in nutrient leaching may not be detected.

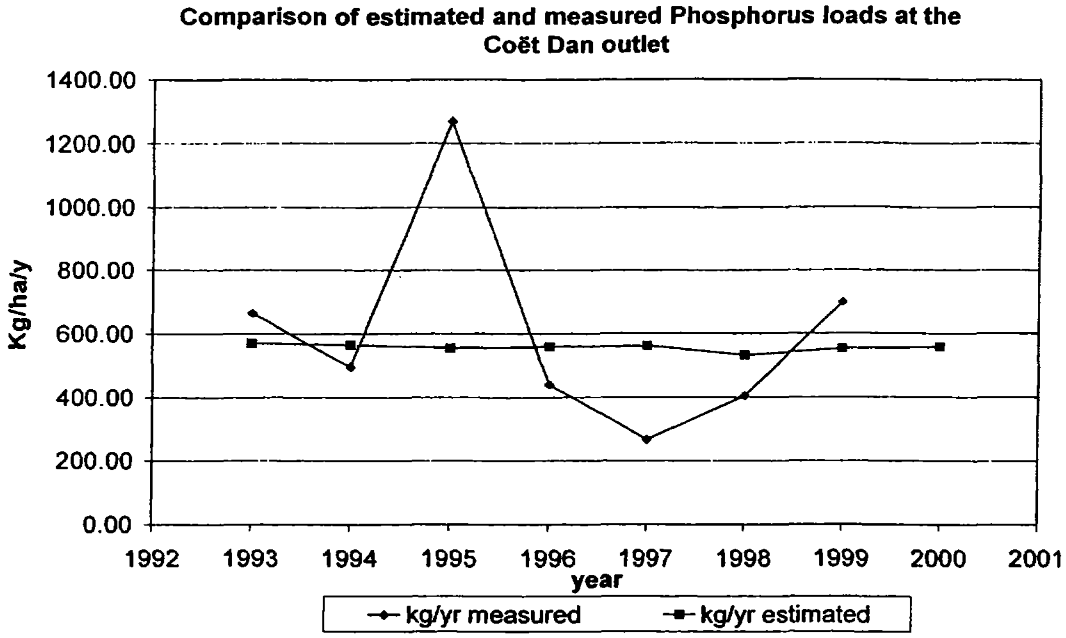
Figure 13 : Measured and modelled annual total phosphorus load (TotP) in the Savijoki watershed. Model: Johnes model.



3.1.2.4. Application of Johnes model on the Cétrais and Naizin watersheds

The Johnes export coefficient model seems to predict the general average of the Phosphorus load at the outlet of the Coët Dan watershed. However, this model is very sensitive to the export coefficient used for corn. Indeed, the value used in this study was 0.65 kg P/ha/yr, which was taken from the "cerals value" reported by Johnes, since no specific corn export values were defined in the article. Other others in the litterature propose much higher values for corn comprised between 1.0 and 5.4 kg P/ha/yr. Applying such values in the model gives much higher exported loads since corn covers an important part of the Coët Dan watershed.

Figure 14 : Measured and modelled annual total phosphorus load (TotP) in the Coët Dan watershed. Model: Johnes model



3.1.3. Goodness and fit

3.1.3.1. Savijoki

For two of the simple methods (N export coefficient model and Johnes model) model estimates were available only for the years 1987, 1999 and 2000 due to lack of date. In order to be able to compare the goodness and fit for all the simple methods for the whole study period 1981-2000, the modelled load for 1987 was used as an estimate for the years 1981-1986 and 1988-1998. All the loads are expressed in kg per km2 of total area.The calculated indexes for goodness and fit are shown in Table 2. In terms of the scaled total error (TE), the results by the original regression model and the regression model modified by precipitation were reasonable. This was also the case for the N export coefficient model. The good fit for the regression models is partly due to the fact, that data from Savijoki was used in deriving the regression equations. The values for the Scaled root mean square error (SRMSE) were somewhat higher than for TE. Here again, the regression models and the N export coefficient model resulted in the lowest values, allthough the variation among different models was low. The values of Model efficiency (ME) were negative for all models except the modified regression model for P and the N export coefficient model. This suggests that in terms of this widely used model performance criteria, all the models were poor.

3.1.3.2. Cétrais and Coët Dan

As noticed before simple methods do not fit very well the nitrogen loads, neither on the Cétrais (see Table 4), nor on the Naizin (see Table 3) watershed :

. for P especially, scaled total error and scaled root mean square errors are extremely high regarding the mean estimated values,

. for N, model efficiency is negative for any tested model (excepted Regression model with rain on Cétrais watershed) on the two watersheds : the tested model are poor even compared with à simple mean of measured values.

On Cétrais watershed, the comparisons have been made with per hectare loads, to be able to compare subwatershed of different size.

Table 2 : Goodness and fit of simple methods on Savijoki catchment. Loads per km2 of total area.

	observed loss		Predicted loss : method 1						
			Regression model		Regression model with rain		Ekholm et al. model	Export coefficient model	Johnes model
year	N	TP	N	TP	N	TP	TP	N	TP
1981,0	744,9	45,1	685,0	64,0	732,3	68,4	99,1	838,6	70,5
1982,0	823,0	48,5	685,0	64,0	626,6	58,5	73,4	838,6	70,5
1983,0	605,3	30,6	685,0	64,0	624,0	58,3	47,6	838,6	70,5
1984,0	1308,3	111,8	685,0	64,0	827,0	77,3	127,6	838,6	70,5
1985,0	683,8	64,0	685,0	64,0	578,1	54,0	48,6	838,6	70,5
1986,0	1075,3	68,6	685,0	64,0	727,4	68,0	98,6	838,6	70,5
1987,0	682,8	66,6	685,0	64,0	690,3	64,5	71,1	838,6	70,5
1988,0	782,3	82,1	685,0	64,0	773,3	72,3	86,4	838,6	70,5
1989,0	744,2	55,3	685,0	64,0	693,5	64,8	74,4	838,6	70,5
1990,0	762,5	51,8	685,0	64,0	708,5	66,2	76,3	838,6	70,5
1991,0	827,3	95,7	685,0	64,0	710,6	66,4	86,4	838,6	70,5
1992,0	648,7	55,9	685,0	64,0	630,4	58,9	75,1	838,6	70,5
1993,0	608,7	53,9	685,0	64,0	614,4	57,4	53,4	838,6	70,5
1994,0	676,3	56,8	685,0	64,0	662,4	61,9	66,0	838,6	70,5
1995,0	1207,5	54,2	685,0	64,0	717,4	67,0	85,2	838,6	70,5
1996,0	743,0	60,8	685,0	64,0	611,7	57,2	59,1	838,6	70,5
1997,0	633,0	36,7	685,0	64,0	653,8	61,1	59,8	838,6	70,5
1998,0	755,0	60,4	685,0	64,0	691,6	64,6	73,2	838,6	70,5
1999,0	951,0	42,0	685,0	64,0	649,6	60,7	75,1	923,2	75,5
2000,0	1126,0	72,5	685,0	64,0	776,0	72,5	91,4	950,5	81,0
mean	819,4	60,7	685,0	64,0	685,0	64,0	76,4	848,5	71,3
number of years : N	20,0	20,0							
Indexes									
Scaled total error	TE		0,2	0,2	0,2	0,2	0,3	0,2	0,3
Scaled root mean square error	SRMSE		0,3	0,3	0,3	0,3	0,4	0,2	0,4
Sutton-Rathcliffe's coefficient	ME		-0,4	0,0	-0,1	0,3	-0,4	0,1	-0,3
Coefficient of Determination	CD		2,2	31,4	1,8	7,8	0,6	23,3	2,9
Coefficient of shape	CS				10,4	10,4	1,0	45,3	56,6
Maximum error	MaxE		623,3	47,8	490,1	34,5	54,0	469,7	41,3
Coefficient or residual mass	CRM		0,2	-0,1	0,2	-0,1	-0,3	0,0	-0,2

Table 3 : Goodness and fit on Naizin –loads per ha of total area

	observed loss		Predicted loss : method 1						
	0	0	Regression model		Regression model with rain		Ekholm model	export coefficient model	Johnes model
year	N	TP	N	TP	N	TP	TP	N	TP
1993	60,7	0,5	11,8	1,3	12,0	1,3	4,6	59,7	0,472
1994	72,0	0,3	12,1	1,3	17,1	1,8	6,0	60,9	0,468
1995	39,6	0,9	12,1	1,3	14,8	1,6	7,9	61,5	0,459
1996	13,9	0,3	12,0	1,3	10,7	1,1	3,8	64,4	0,462
1997	38,5	0,2	12,0	1,3	10,7	1,1	1,7	64,3	0,464
1998	53,8	0,3	11,8	1,2	14,6	1,5	3,3	59,9	0,440
1999	59,4	0,5	21,5	2,4	11,9	1,4	6,0	63,0	0,457
2000	67,9		12,0	1,3			5,5	65,2	0,462
mean	61,32	0,50	15,93	1,71	15,88	1,70	5,90	75,41	0,46
number of ye	8	7							
Indexes									
Scaled total error	TE		0,74	136,08	0,61	113,18	126,53	0,30	138,72
Scaled root mean square er	SRMSE		0,68	2,22	0,59	2,05	9,39	0,36	0,42
Sutton-Rathcliffe's coeffic	**ME**		**-2,98**	**-23,43**	**-2,06**	**-19,80**	**-436,04**	**-0,12**	**0,11**
Coefficient of Determination	CD		0,19	0,12	0,21	0,14	0,14	83,26	0,12
Coefficient of shape	CS		32,59	0,25	72,08	0,78	0,01	78,40	471,18
Maximum error	MaxE		59,83	70,67	54,83	70,14	65,95	50,50	71,49
Coefficient or residual mass	CRM		0,74	-2,91	0,77	-2,40	-12,46	-0,23	-0,27

Table 4 : Goodness and fit on Cétrais – loads per ha of total area

point	observed loss: observed N l	observed loss: TP	Predicted loss : method 1 — Regression model: N	Regression model: TP	Regression model with rain: N	Regression model with rain: TP	Ekholm model: TP	export coefficient model: N	Johnes model: TP
PZ1-97	21,9		10,5	1,1	10,2	1,1	2,2	26,0	0,25
PZ1-98	22,8		10,6	1,1	11,7	1,2	2,2	22,8	0,30
PZ1-99	26,8		10,6	1,1	13,6	1,4	3,0	26,2	0,27
PZ1-2000	36,5	1,1	10,6	1,1	13,3	1,3	4,1	26,2	0,27
PZ3-97	20,3		10,7	no estimation because no measurements	10,4	no estimation because no measurements	no estimation because no measurements	26,4	no estimation because no measurements
PZ3-98	18,2		10,7		11,9			23,5	
PZ3-99	23,1		10,8		13,8			27,6	
PZ3-2000	31,5		10,8		13,4			27,6	
PZ4-97	19,4		12,2		11,9			32,7	
PZ4-98	18,7		12,2		13,6			27,0	
PZ5-97	19,6		10,2		11,4			25,0	
PZ5-98	21,8		10,3		13,2			22,1	
PZ6-97	33,9		11,0		10,7			28,2	
PZ6-98	35,6		11,0		12,1			25,1	
PZ7-97	17,1		11,0		10,8			27,3	
PZ7-98	11,9		11,0		12,2			25,1	
PZN-97	10,8		9,3		9,1			21,0	
PZN-98	17,8		9,4		10,4			18,5	
mean	22,7	0,1	10,7	1,1	11,9	1,2	2,9	25,5	0,3
number of points : N	18	1							
Indexes									
Scaled total error	TE		0,53	91,13	0,48	90,61	84,91	0,28	94,04
Scaled root mean square error	SRMSE		0,61	30,14	0,56	34,08	82,83	0,33	15,64
Sutton-Rathcliffe's coefficient	**ME**		**-2,66**	**-1,97**	**-2,08**	**-2,80**	**-21,42**	**-0,08**	**0,20**
Coefficient of Determination	CD		0,38	0,04	0,27	0,03	0,01	0,04	17,00
Coefficient of shape	CS		109,26	5736,05	28,67	18,67	0,50	5,65	1085,34
Maximum error	MaxE		25,84	35,38	23,47	35,18	32,41	13,34	36,22
Coefficient or residual mass	CRM		0,53	-2,87	0,48	-3,40	-9,09	-0,12	0,03

3.1.4. Time needed to perform simple models

3.1.4.1. Savijoki watershed

Most of the water quality and quantity data (in terms of measured concentrations and water flow at the catchment outlet) are stored in the databases of SYKE. The GIS-data for soils, catchment boundary, field parcels and land-use were also available at SYKE. Precipitation data was bought from the Finnish Meteorological Institute. For the MicroHARP project, the annual loads of TotN and TotP were calculated for the years 1998-2000. The loads for earlier years (1981-1997) were already available (Vuorenmaa et al. 2001). When applying the simple models, the most time-consuming phase was interpretation of the interview data from the years 1987, 1999 and 2000. Only part of the interview data from the year 1987 was stored in a data base, and the crop distribution was not geo-referenced. During the interview for the years 1999 and 2000, detailed information was collected on crops and management practices. The interview was carried out by the Southwest Finland Regional Environment Centre. Applying the regression models was very fast and easy, as only a few parameters were needed. Applying the export coefficient models is also easy, provided that relevant coefficients are available. In the Savijoki case, due to lack of measured export coefficients, estimated values for nutrient export included in two decision-making systems (VIHTA and VEPS) were used in load calculations. This method was also easy and fast to apply, but the discretization scheme for different land-use and management conditions was rather simple. Table 5 summarises the time required to perform simple methods.

3.1.4.2. Cétrais and Coët Dan watersheds

Basic data acquisition is common for all the methods. The watersheds have been delineated on a DEM basis, which is quite simple. But there has been need of more precise

delineation, especially for flat areas (north part of Naizin watershed, most of Cétrais one) : field measurements took one day for Naizin and 2 for Cétrais (because the watershed is larger).
Some data have been bought : DEM, rain. For field percentage, we used one field records, but we could have bought some Corine Land cover maps.

The simple methods are very easy to perform as soon as the required data are introduced in the GIS. It has been a little bit longer on Cétrais watershed because we used the methods on several subwatersheds. Table 5 summarises time required to perform simple methods. Building the reference matrix for export coefficient model was for the longer operation.

Table 5 : time needed for simple methods

Operation	Time (days)			Who can do it
	Cétrais	Naizin	Savijoki	
Basic date acquisition (DEM, rain, Corine Land cover maps) Command, reception and GIS integration	5	5	5	Permanent
Watershed delineation (field measurements and digitalisation)	3	2		Permanent
calculation of nutrient loads for years 1998-2000			1	Permanent
Regression models				
• Data acquisition from GIS	1	0.5		Permanent
• overlay of digital land-use and soil maps and digitised fields parcels by Arc View 3.2			5	Permanent
• Models programmation and run (Excel)	0.5.	0.5	1.5	Permanent
• Goodnessand fit	0.5	0.5	1.5	Permanent
Expert coefficient models :				
• overlay of digital land-use and soil maps and digitised fields parcels by Arc View 3.2			5	Permanent
• soils maps : field measurements and digitalisation	40	25		Student
• field maps : digitalisation				(with
• crop maps : field data acquisition and digitalisation (per year)	10 8	5 5		supervision !)
• interviews at Savijoki catchment			20	Student
• analysing interview data from 3 years			8	Student
• reference matrix for N (some for both watersheds)	45	45		Student
• review of relevant nutrient load from VIHTA			1	Student
• reference matrix for P (some for both watersheds)	?	?		
• data acquisition from GIS	1	1		
• running VEPS for Savijoki conditions			1	Permanent
• models programmation and run (excel)	1	1	1.5	Permanent
• goodness and fit	1	1	1.5	Permanent
Total for regression models	10	8.5		
Total for export coefficient models				
• 1[rst] watershed	114			
• each next watershed		45		(references already acquired)

3.2. Mid-range models

3.2.1. Parameters preparation from GIS

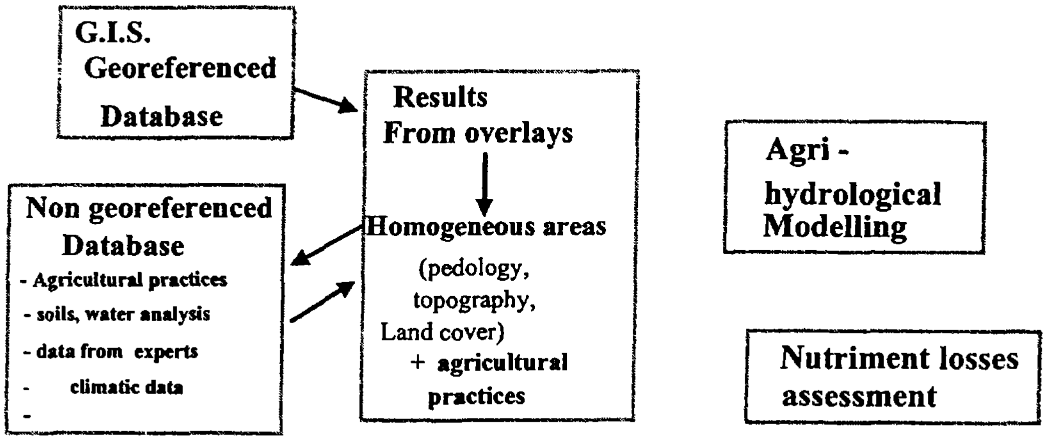


Figure 15 : GIS and databases organisation for NT and PB model and BMP1-GLEAMS

Collecting and organising data in a GIS is the first step before one can model nutriments losses at the watershed scale (see Figure 15).

3.2.1.1. Input and update procedures on GIS include three steps: the structural block, the agricultural field, the elementary unit

First and second entities: the agricultural field and the structural block

The agricultural field is an homogeneous unit where management practices are steady for at least one agricultural cycle. At this scale, fertilisation practices, soil work or crop yields are homogeneous. However, limits of such fields are subject to changes from year to year. Because of this, another unit of larger size must be found, for which the boundaries do not change from year to year.
Such units have been called structural blocks. Practically, it corresponds to the land defined by tree hedges, streams, roads and private property's limits.

The structural block is also farmed by only one farmer, and can be divided into several agricultural fields (which boundaries can vary from year to year).

Thus, watershed boundary, roads, hydrographic network, tree hedges and private property limits have been digitised and serve as the basis for agricultural fields.

Third entity: the elementary unit

This unit is obtained from overlaying agricultural field units with the soil coverage in the GIS. This unit is homogeneous for land use, fertilisation practices, soil type and climate for the whole period of study.

3.2.1.2. Construction of the structural blocks

Watershed boundary

This datum is essential to implement the three methods in the project. Therefore, it is important to explain in details how we managed to define watershed boundaries as precisely as we could.

Watershed boundaries were first delineated from the interpretation of contours from the 1/25000 scale topographic map.

Watershed boundaries were first delineated from the interpretation of contours from the 1/25000 scale topographic map.

Boundary determination using the DEM
The DEM represent landscape's morphology. Actually, land is represented as a series of pixels of defined dimensions and to which is assigned an altitude.

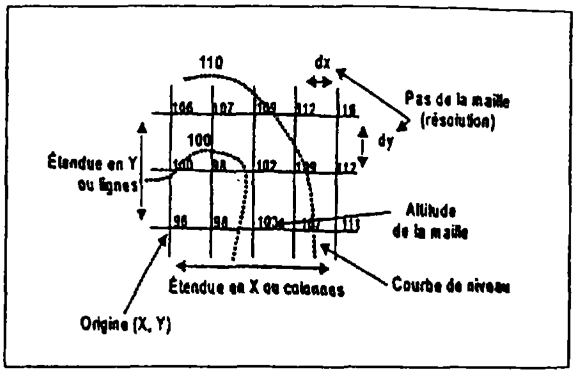


Figure 16 : DEM definition

Both watershed boundaries were verified using the Data Elevation Model. In particular, Cétrais watershed boundary was redefined using the DEM compared to the first assessment from the contour analysis.

The boundaries obtained were then compared with field verification. Some of the boundaries had to be changed especially in the flat areas. Indeed, anthropogenic drain ways like ditches, roads, urban areas can significantly alter natural flow direction.

Roads, hydrographic network, tree hedges
Those data have been digitised using both the 1999 digital aerial photo and the 1/25000 scale topographic map. More details were obtained from field verifications

Private property limits.
Most of the time tree hedges, woods, road or walk ways define property limits. However, only electric enclosures or even no obvious mark sometimes are used as property limits. This information is necessary to deduce the structural block limits. It may also be the most difficult data to collect because farmers may retire or exchange their lands. Those changes have to be accounted for.

3.2.1.3. Construction of the agricultural fields

Structural blocks on both watersheds are used as a basis for the construction of the agricultural fields. The agricultural field is the geographical unit that may be observed when on the field.
The difficulty, as already expressed above, is to be able to satisfactorily represent the crop and practices changes, as well as the possible changes in the field limits from crop cycle to the next. Three main methods are used to obtain this type of information. The first one results from surveys conducted near farmers, the second one involves direct field observations and the third method derives from the use of aerial photographs. This last technique combined photos available from the National Geographic Institute, as well as pictures taken during ultra-light flights at a low altitude of 300 meters. It is a technique which is used more and more frequently nowadays [Scott, 1999 #91].

3.2.1.4. Illustration of the fields and blocks construction

An example of the changes in the crop coverage from Coët Dan watershed is illustrated below. For the purpose of illustration, four obvious land units can be clearly defined. They correspond to structural blocks defined earlier (numbered 288, 322, 324 and 325).

Area	Numéro	
85191.810000	288	C
38966.600000	322	C
46211.060000	322	C
18587.580000	322	C
4123.703000	324	C
12174.560000	324	C
8766.377000	324	C
9509.246000	324	C
12145.510000	325	W

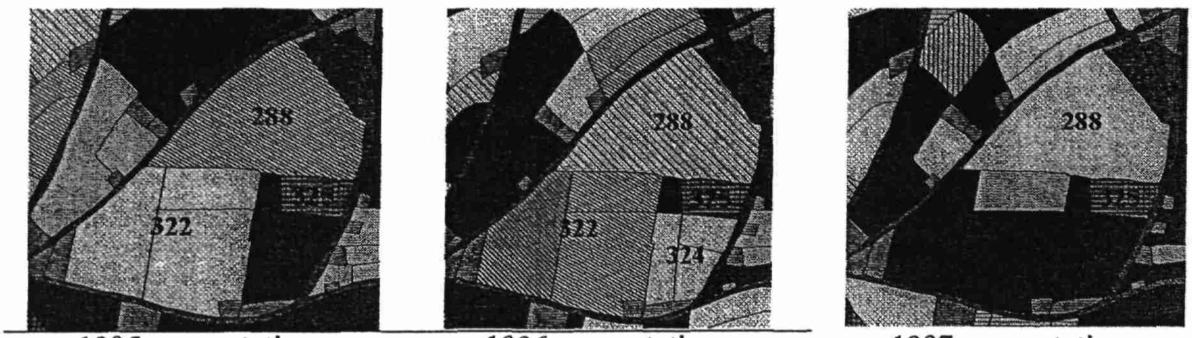
Figure 17 : structural blocks

One can notice on the maps that the geographical limits of the units 288 and 325 do not change from 1995 to 1997 (see figure 26). The same cannot be said for units 322 and 324, which are divided into smaller units with varying boundaries from one year to the next.

After several years a structural block such as 322 could be subdivided into several "cultural units". To take into account effects of previous fertilisation practices, we have to keep these limits one year to the next.

These units form the basis for the agronomic analysis conducted from year to year and are named agricultural fields defined earlier and illustrated below:

This is the polygon attribute table associate to the geographic theme of the agricultural units (see Figure 19 :):



1995 crop rotations (cf Detc95 item)

1996 crop rotations (cf Detc96 item)

1997 crop rotations (cf Detc97 item)

Figure 18 : agricultural fields

Figure 19 : polygon attribute table

Area	Numero	Detc00	Detc99	Detc98	Detc97	Detc96	Detc95	Detc94	Detc93	Expl94	Expl95	Expl96	Expl98	Expl99	Expl00
85191.810000	288	C7	C7	C4	C1	C4	L9	C1	C7	17	17	58	58	58	58
38966.600000	322	C1	C7	C1	C7	A4	C1	C7	A4	21	21	45	45	45	45
46211.060000	322	C1	C7	C1	C7	L9	C1	C7	C1	21	21	45	45	45	45
18587.580000	322	C1	C7	C1	E4	L9	C1	C7	C1	21	21	45	45	45	45
4123.703000	324	C7	C1	L10	J	J	C7	C7	C7	21	21	21	21	21	21
12174.560000	324	C7	C1	L10	C7	C1	C7	C7	C7	21	21	21	21	21	21
8766.377000	324	C7	C1	L10	C7	C1	C7	L9	C7	21	21	21	21	21	21
9509.246000	324	C7	C1	L10	C7	C1	C7	L9	Cu	21	21	21	21	21	21
12145.510000	325	W1	W1	W1	W1	W1	W1	L9	C7	21	21	21	21	21	21

3.2.2. parameters estimation,

Mid-range models need much more parameters than simple models. Climatic data, such as daily rain, temperature and PET come from Météo-France. Soil water capacity is estimated from a soil map and Gleams reference tables.

On Cétrais watershed, only N.Turpin and P.Bordenave model was applied (then was no need of improving export coefficient models as every required reference has been found in literature). For some fields there where soil analysis : for these fields, parameters have been estimated according to the soil analysis values. For any other field, local references have been used for the estimation of soil N supply.

The description of agricultural practices come from 3 enquiries :

- The first enquiry was performed in 1997. It dealt with the description of practices, field per field, from 1992.
- Some farmers have signed a contract : they engaged in 1998 to improve their fertilisation practices and they register what they are doing.
- The farmers who did not signed this contract have been enquired at the beginning of year 2001 : they have been asked what they have changed in their practices for the last 5 years, have and why.

All the reference tables required for estimating the model parameters from these enquired data are described in a previous report (Bioteau, T., et al., 2000). The sub watersheds appear to be quite different PZ4 has a much more intensive use than the others : crops yields and fertilisation are much higher than on the other sub watersheds.

There appear to be a slight extensification from 1998 : the farmers who have signed a contract reduce fertilisations and sometime expected yields. Unfortunately, only 20% of the farmers signed such a contract and among the others many use more fertilisers nowadays.

3.2.3. calibration,

No calibration has been required for mid-range model on Cétrais watershed.

3.2.4. validation

The model has been validated with some field measurements : measured autumn in organic nitrogen is compared with the estimation of the model (see Figure 20). The estimation is accurate for predicting the N content for fields with corn and cereals. There is still a problem for predicting the N content of soil under grassland : the measurement show high contents of ammoniacal N, even in the deep soil layers. These high contents have still no valid explanation yet but they are measured everywhere in the western part of France. For nitrate N content of the soil, the model realises acute predictions.

Figure 20 : estimated and measured inorganic nitrogen in some fields on Cétrais and Coët Dan watersheds

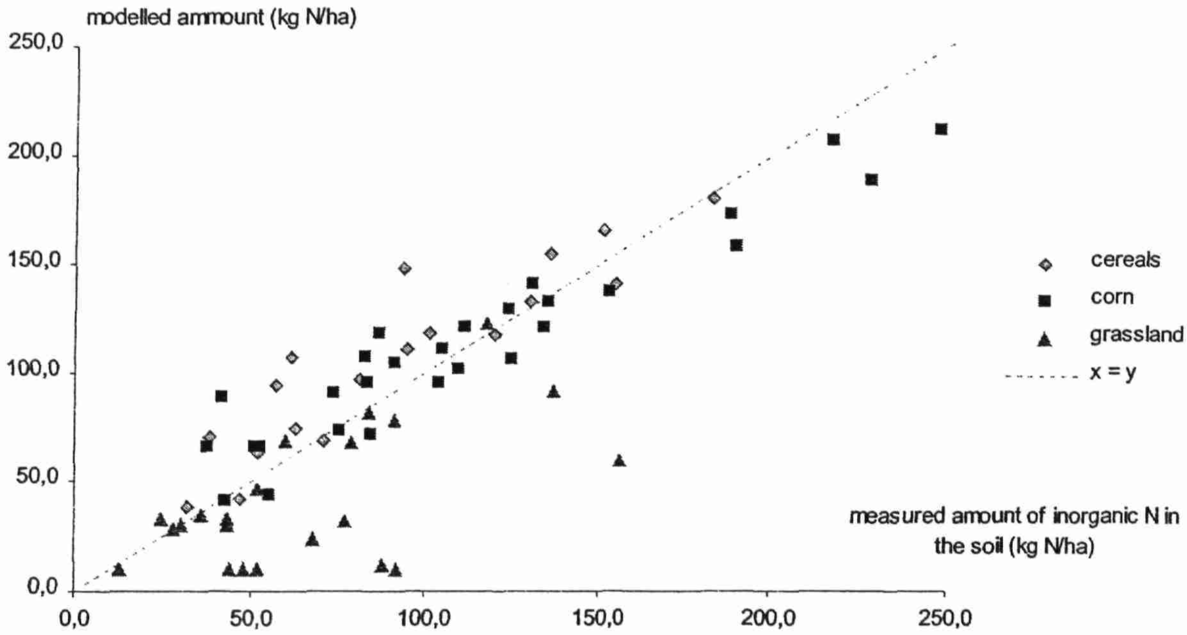
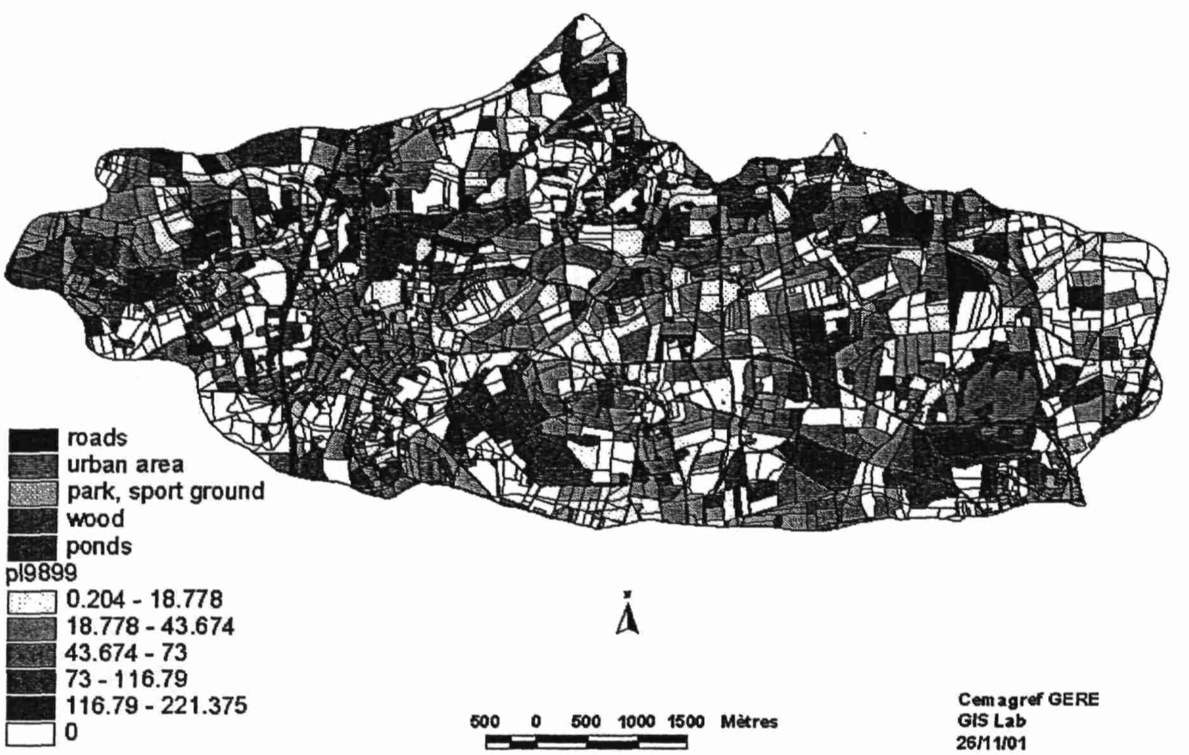


Figure 21 : estimated losses (kg N/ha) on Cétrais watershed (PI98)



3.2.5. goodness and fit

On Cétrais watershed, NT model fits quite well the measurements (see Figure 22), for all subwatersheds and all years (even for wet years such as 2000-2001). One exception is point PZ7 for years 98-99, with estimation twice the measurements. This point is particular in the watershed, because there is an old tin mine : extraction has been performed with sulphuric acid, and the pH in the river are very low (2.5). There is a need of more investigations to be sure one can rely on the measurements performed.

On Coët Dan watershed, the model slightly overestimated the measured loads. The survey of the practices is not as precise as it has been performed on Cétrais watershed. The loads are much higher. Some questions are remaining on the effective rate of volatilisation after slurry spreading (depending on the soil temperature and on the wind speed immediately after spreading operations).

Figure 22 : estimated N loads compared to measured ones – mid-range model on Cétrais and Coët Dan watersheds

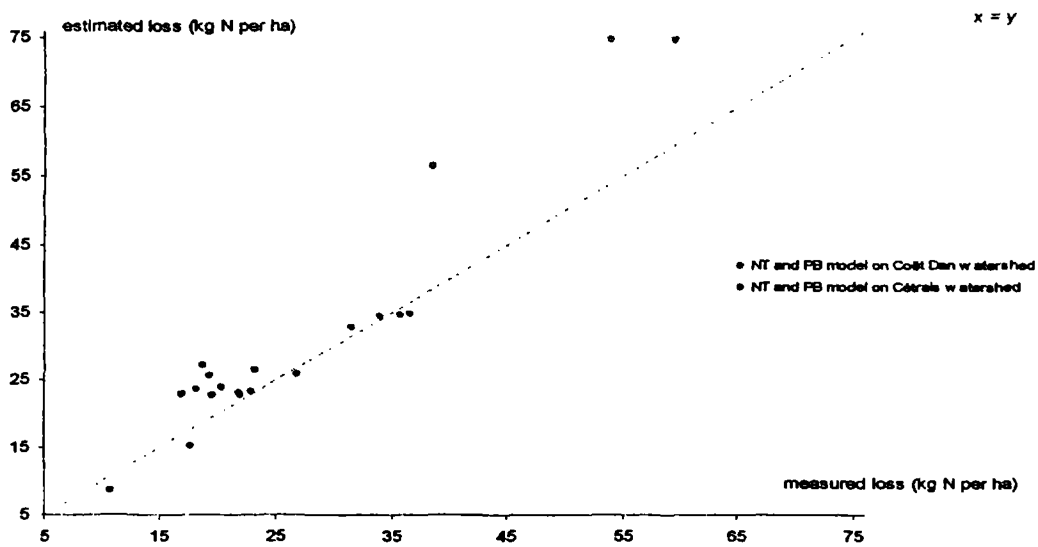


Table 6 : goodness and fit for method 2 on Cétrais watershed

	observed loss		Predicted loss : method 1							Method 2
			Regression model		Regression model with rain		Ekholm model	export coefficient model	Johnes model	NT and PB model
point	observed N l	TP	N	TP	N	TP	TP	N	TP	N
PZ1-97	21,9		10,5	1,1	10,2	1,1	2,2	26,0	0,25	22,6
PZ1-98	22,8		10,6	1,1	11,7	1,2	2,2	22,8	0,30	23,2
PZ1-99	26,8		10,6	1,1	13,6	1,4	3,0	26,2	0,27	25,8
PZ1-2000	36,5	1,1	10,6	1,1	13,3	1,3	4,1	26,2	0,27	34,8
PZ3-97	20,3		10,7	no estimation because no measurements	10,4	no estimation because no measurements	no estimation because no measurements	26,4	no estimation because no measurements	23,8
PZ3-98	18,2		10,7		11,9			23,5		23,6
PZ3-99	23,1		10,8		13,8			27,6		26,4
PZ3-2000	31,5		10,8		13,4			27,6		32,8
PZ4-97	19,4		12,2		11,9			32,7		25,5
PZ4-98	18,7		12,2		13,6			27,0		27,0
PZ5-97	19,6		10,2		11,4			25,0		22,6
PZ5-98	21,8		10,3		13,2			22,1		23,0
PZ6-97	33,9		11,0		10,7			28,2		34,4
PZ6-98	35,6		11,0		12,1			25,1		34,5
PZ7-97	17,1		11,0		10,8			27,3		22,8
PZ7-98	11,9		11,0		12,2			25,1		24,0
PZN-97	10,8		9,3		9,1			21,0		8,6
PZN-98	17,8		9,4		10,4			18,5		15,2
mean	22,7	0,1	10,7	1,1	11,9	1,2	2,9	25,5	0,3	25,0
number of points : N	18	1								
Indexes										
Scaled total error	TE		0,53	91,13	0,48	90,61	84,91	0,28	94,04	0,15
Scaled root mean square error	SRMSE		0,61	30,14	0,56	34,08	82,83	0,33	15,64	0,20
Sutton-Rathcliffe's coefficient	ME		-2,66	-1,97	-2,08	-2,80	-21,42	-0,08	0,20	0,62
Coefficient of Determination	CD		0,38	0,04	0,27	0,03	0,01	0,04	17,00	0,03
Coefficient of shape	CS		109,26	5736,05	28,67	18,67	0,50	5,65	1085,34	1,30
Maximum error	MaxE		25,84	35,38	23,47	35,18	32,41	13,34	36,22	12,04
Coefficient or residual mass	CRM		0,53	-2,87	0,48	-3,40	-9,09	-0,12	0,03	-0,11

 date : 6 December 2001

Table 7 : goodness and fit on Coët Dan watershed (per ha of total area)

	observed loss		Predicted loss : method 1							Method 2
			Regression model		Regression model with rain		Ekholm model	export coefficient model	Johnes model	NT and PB model
	0	0								
year	N	TP	N	TP	N	TP	TP	N	TP	N
1993	60,7	0,5	11,8	1,3	12,0	1,3	4,6	59,7	0,472	
1994	72,0	0,3	12,1	1,3	17,1	1,8	6,0	60,9	0,468	
1995	39,6	0,9	12,1	1,3	14,8	1,6	7,9	61,5	0,459	
1996	13,9	0,3	12,0	1,3	10,7	1,1	3,8	64,4	0,462	
1997	38,5	0,2	12,0	1,3	10,7	1,1	1,7	64,3	0,464	56,2
1998	53,8	0,3	11,8	1,2	14,6	1,5	3,3	59,9	0,440	74,4
1999	59,4	0,5	21,5	2,4	11,9	1,4	6,0	63,0	0,457	74,4
2000	67,9		12,0	1,3			5,5	65,2	0,462	
mean	61,32	0,50	15,93	1,71	15,88	1,70	5,90	75,41	0,46	82,67
number of ye	8	7								
Indexes										
Scaled total error TE			0,74	136,08	0,61	113,18	126,53	0,30	138,72	0,13
Scaled root mean square er SRMSE			0,68	2,22	0,59	2,05	9,39	0,36	0,42	0,18
Sutton-Rathcliffe's coeffic ME			**-2,98**	**-23,43**	**-2,06**	**-19,80**	**-436,04**	**-0,12**	**0,11**	**0,72**
Coefficient of Determination CD			0,19	0,12	0,21	0,14	0,14	83,26	0,12	9,34
Coefficient of shape CS			32,59	0,25	72,08	0,78	0,01	78,40	471,18	11,59
Maximum error MaxE			59,83	70,67	54,83	70,14	65,95	50,50	71,49	20,67
Coefficient or residual mass CRM			0,74	-2,91	0,77	-2,40	-12,46	-0,23	-0,27	0,49

3.2.6. Time needed to perform mid-range models

Table 8 : time needed for mid-range models

Operation	Time (days)		Who can do it
	Cétrais	Coët Dan	
Basic data			
Watershed delineation			
Parameters :			
• soil map	40	25	Student
• fields map	10	5	Student
• crop map (per year – at least 3 years)	8	5	Student
• fertilisation practices (per year – at least 3 years)	40	35	Student
• on Naizin, interpolation between surveys		30	Permanent
• local references for the equation	10	10	Permanent
• coherence verification between all the data	15	15	Permanent
Model understanding	1		
1 simulation	20 minutes	20 minutes	
Validation (usually dead-line for the report)	5	5	permanent

3.3. Physically based models

3.3.1. Parameters estimation

3.3.1.1. Application of ICECREAM

ICECREAM was the first physically based model applied at Savijoki watershed in the MicroHARP project. The model parametrisation and simulations were done before the new farmer interview at Savijoki was carried out (spring 2001). Thus, data on crop distribution was based on the interview from 1987. The new interview revealed only minor changes in crop distribution during 1999-2000, as compared to the situation in 1987 (Figure 23). ICECREAM model was run for the period 1980-2000 (1980 being a warm-up year for the model) for barley, spring wheat and oats, which were the dominating crop types in 1987. The management practices where kept the same through the whole period. Silty clay is the dominant soil type on field parcels, and was chosen as the only soil type for model calculations. The parameters controlling crop growth and water and nutrient flow in soil were selected based on earlier model experiments carried out by ICECREAM in Finland (e.g. Granlund et al. 2000, Rankinen et al 2001, Tattari et al. 2001). The model predicts the surface runoff and nutrient load at the edge of the field and percolation of water and nutrients below the root zone. The VIHTA export coefficients were used to calculate load estimates for grass area and for other crops that were not modelled (VIHTA crop type: not covering) The total potential nutrient load from the field area was then calculated by summing up the modelled loads from different crop type areas for each year. The potential loads from forested area and scattered settlement were estimated following the same method as when applying simple loading models.

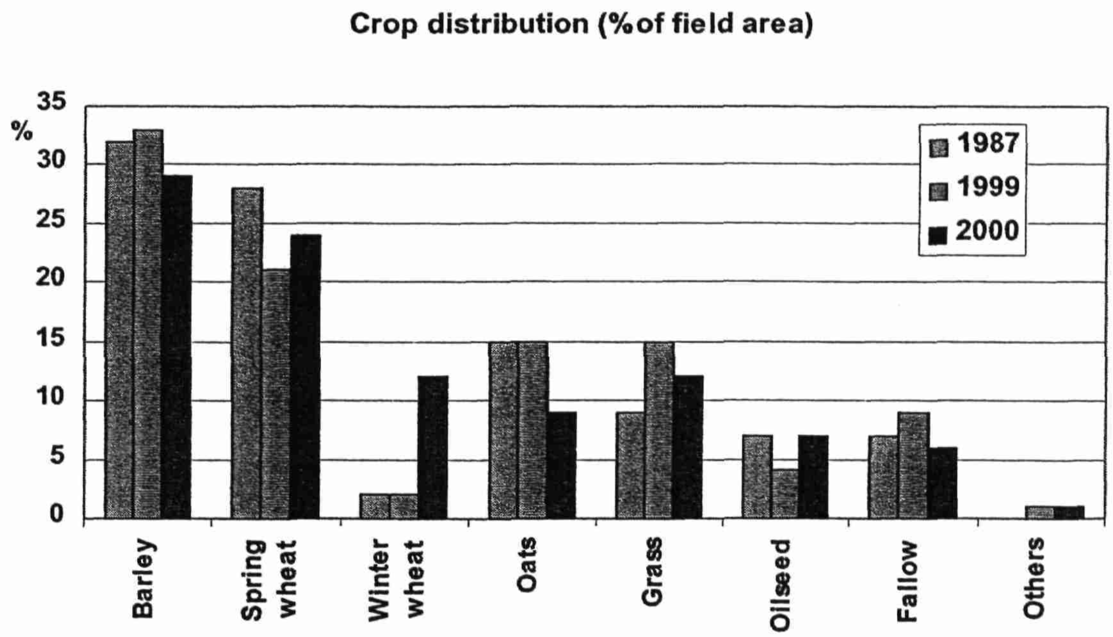


Figure 23 : Agricultural crop distribution (% of field area) in the Savijoki watershed. Data from farmer interviews in 1987, 1999 and 2000.

3.3.1.2. BMP1-GLEAMS

GLEAMS (Knisel, 1993) is "Groundwater Loading Effects of Agricultural Management Systems" model. Principles are described in Appendix 2. GLEAMS (v.2.10) was used and partially calibrated on several fields located on two small watershed in Brittany: Saint Leger watershed (Ille and Vilaine) and Ploudiry watershed (Finistère), and also on Solepur pilot (Finistère). This pilot is a 3000 m2 drained experimental plot (comparable to a macro-lysimetric case) which has received massive pig slurry spreading. Initially, we tested the model without modification using data measured on sites (given climatic, soil physicochemical characteristics and agricultural practices...). Comparisons between predicted values and measured were carried out on PET Penman values, amount of mineral nitrogen present in soil, crop production and on nitrate and ammonia losses under rooting zone.
On each parameter, important deviations were observed between not modified model estimates and real values. This led us to replace calculate PET by values calculated by Meteo France. This first modification involved a clear improvement of percolation value, but not of nitrate losses. The soil mineral nitrogen was very underestimated for several periods due to general mineralisation underevaluation (mostly ammonification process).

Crop production was also very lower than measured values. So we have to modify mineralisation, reorganisation, and denitrification modules to find values close to those measured in the soil.

We slightly corrected the LAI curve for two principal crops (corn forage and winter cereal) simultaneously, in order to get production estimates closer to reality (Mainguy, 1999). Lastly, GLEAMS has been coupled with a simplified hydrological model fixed during the year previous the test. The modified model well reproduced water flows and nitrogen yearly concentration " flows " on each watershed without modifying parameters. Deviations between modelled and measured values are 17 % and 10.6 % for Saint-Léger watershed and Ploudiry watershed respectively (Peltier, 2000).

3.3.1.3. parameter estimation for SWAT on the Cétrais and the Coët Dan watersheds

Four types of data were required to run the SWAT model.

The first type of data is the Digital Elevation Model (DEM). The ones used for both watersheds have been derived from original 50-m resolution sold by the National Geographic Institute (IGN) described in the previous report. The new 5-m resolution was obtained using the Universal 2 Krigging method (Duros, 2001).
Soil map and data make up for the second important type of data in SWAT. Available soil maps have been described in the previous report. Textural properties were associated to each soil unit using textural data obtained from soil pits. Pits were not dug for each soil type initially described. Similar soil unit were put together to finally create a map containing 7 and 9 soil units for the Cétrais and the Naizin Watersheds, respectively.
For land use (third type of data), a detailed database created for each field and block was available (see previous report for construction details). For technical and computation time reasons, exact crop rotations for each and every field could not be input in the model. It would have required constructing more than 400 rotations for each watershed. Instead major types of combined rotations/practices were identified for each catchment (45 and 35 types for the Cétrais and Naizin watersheds, respectively). All other rotations were associated to those major types, depending on how close or similar rotations were from one to another.
The simulations performed with mid-range models have shown the importance of defer-effects of manure spreading operations during the four years before the estimation of the load. So it has been decided to work with crop rotations, and not one year only.
The fertilisation practices and yields on the 45 types of crop rotations on Cétrais watershed has been defined as a mean of all the similar rotations on the watershed. There may be a

bias due to this summary of agricultural practices. To have an idea of this bias, we performed method 2 with the 71 rotations' practices instead of each field surveyed practices. The Figure 24 shows that while doing this, we actually introduce a bias : the loads will be underestimated for all the point (excepted point PZ7). But this bias is smaller that the bias we could obtain when taking into consideration one year only (and thus neglecting defer effect of previous manure spreading).

Climatic data (fourth type of data) were obtained through local official weather stations described in the basin characteristics.

Figure 24 : use of mid-range model with management practices introduced in SWAT

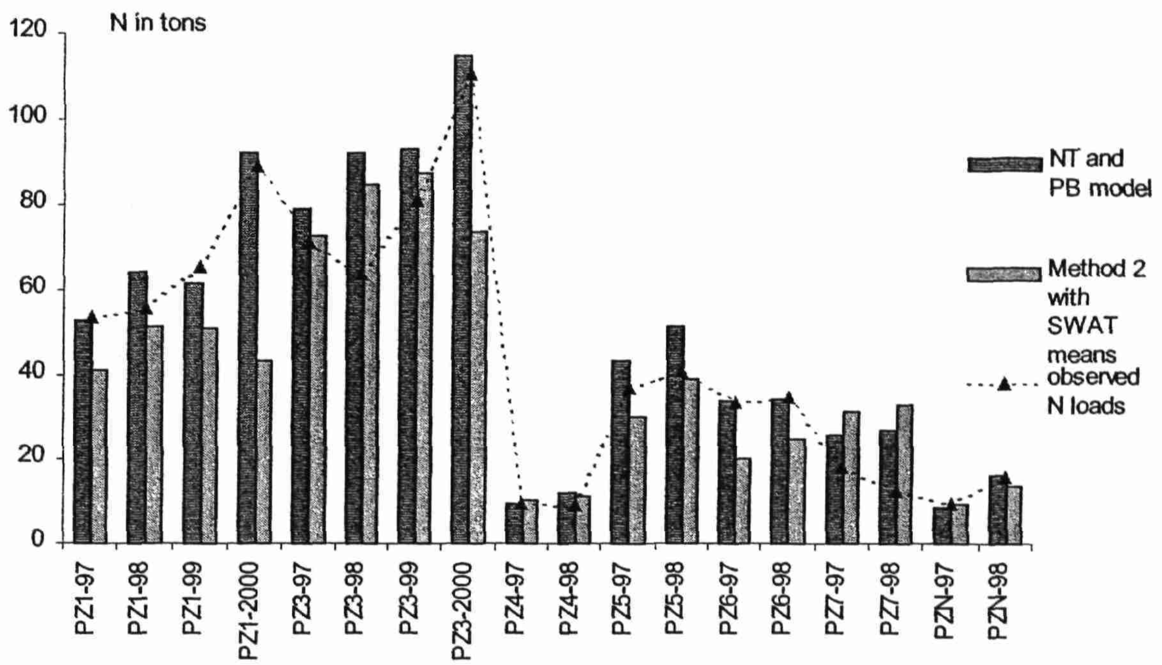
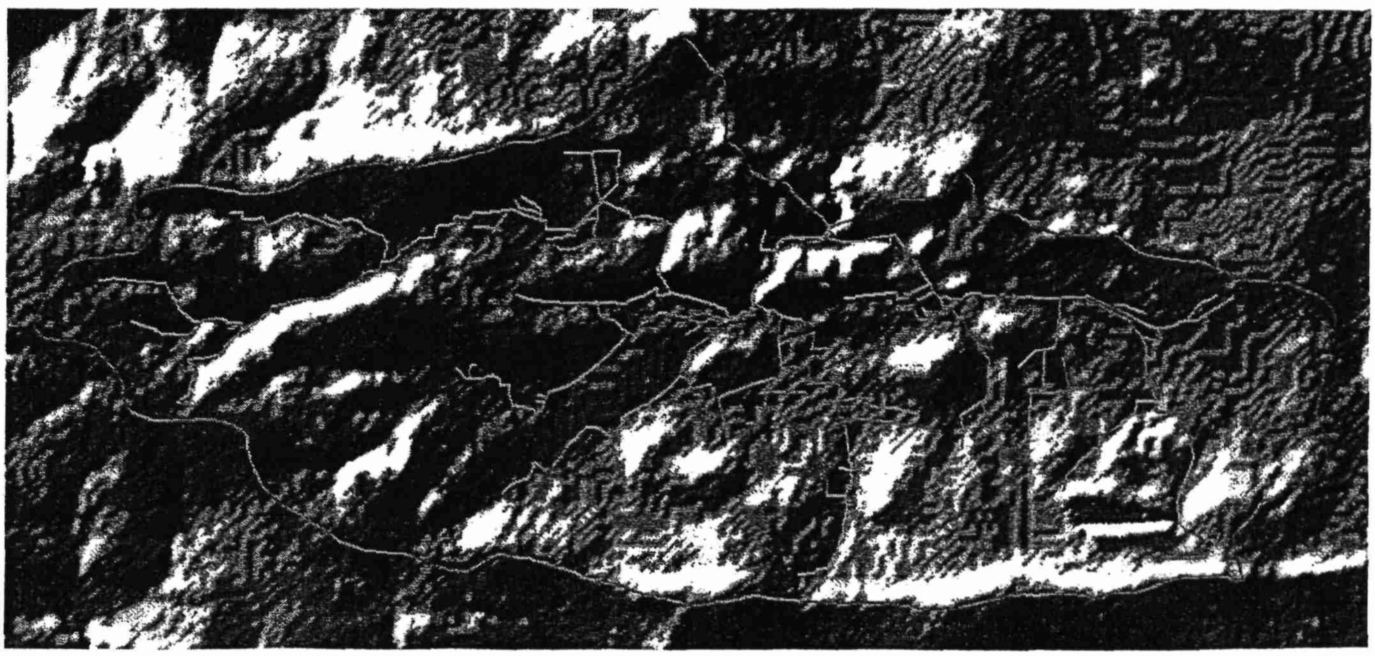
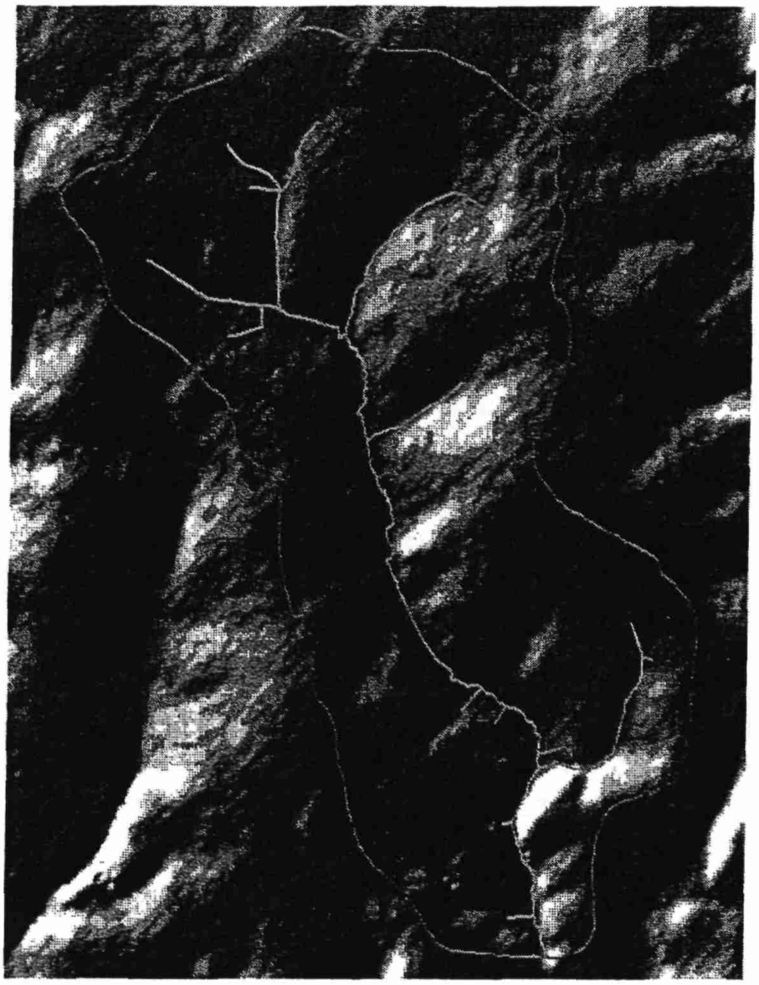


Figure 25 : use of Krigging Universal 2 method on a reference file (Duros, 2001)





3.3.2. calibration,

3.3.2.1. ICECREAM

ICECREAM was not calibrated or validated in the present study as no measurements on nutrient leaching or nutrient contents in field soils were available from Savijoki fields. The parametrisation was based on earlier applications of the model in similar conditions.

3.3.2.2. BMP1-GLEAMS

Results obtained on Solepur pilot are related to calibration of denitrification and of volatilization because measured values were available (Martinez, Peu, 1999; Martinez, 1997). Denitrification was predicted correctly but volatilization is underestimated. After four years spreading (1992 to 1995) corresponding to 23,250 nitrogen kg.ha-1 on the whole period, the model simulates a faster nitrogen concentration decrease in draining water than that measured. Evolution of amount of total soil nitrogen is well predicted, but not quality: The model predicts an accumulation of mineral nitrogen whereas it is an accumulation under organic form actually.

This preliminary step of calibration enabled us to identify modules, which must be improved for a use on numerous fields of a watershed. The animal waste module must be improved concerning solid manure because it is mineralized too fast. In fact, there are not sufficient back effects and nitrogen losses by leaching are over-estimated during the year of spreading. The nitrogen flow between two soil nitrogen pool requires also improvement. Neither flow nor nitrogen dynamic seems correct. Lastly, the case of grazing meadows requires specific module, which will be written. In spite these reserves, GLEAMS modified use coupled to a hydrological module BMP1-Gleams model appears relevant to us a priori, to carry out simulations of management practices impact on nitrogen flow in water.

Two years of monitoring (1992-1994) were used to calibrate flows for the BMP1-Gleams model. Results obtained for six non-calibrated years show a good correlation between the simulated and measured cumulated nitrogen fluxes at the outlet of the Coët Dan (Naizin) watershed. Overall, 301 tonnes of nitrogen were simulated to leave the watershed after six years, while 334 tonnes were measured. A 10% underestimation was thus made using this model for this criteria.

3.3.2.3. *SWAT on Cétrais and Coët Dan*

It was decided that there should not be any deep aquifers considered in the SWAT simulations for the French watersheds because of the rocky and impermeable substrate below the 1-m thick soils.

Three parameters were used as calibration factors:

- The curve number, which by default was too high for the French watersheds
- The Alpha base flow was calibrated for adjusting shallow aquifer after-evetn discharge
- The groundwater delay parameter as also tested although it had little effect on the model results.

Three methods were used for calibration. 1) Comparison between measured daily flows to estimated ones at both watershed outlets; 2) Comparison between cumulated flows; 3) Visual comparison was essential for calibrating the Alpha base flow.

Results for flow calibration:

All default curve numbers were eventually reduced by 20 points for all crops to better fit local French conditions. Curve numbers were not changed for roads and impermeable surfaces.

Calibration procedure is summarised in the table below.

	measured	simulation 1	simulation 6	simulation 13	simulation 24	simulation 27
Curve Number		default values	10 points dropped	20 points dropped	20 points dropped	20 points dropped
Alpha baseflow		0.03	0.03	0.1	0.18	0.038
GroundWater delay		1	1	0.05	0.05	1
R^2 97		0.65	0.73	0.74	0.8	0.65
R^2 98		0.36	0.45	0.67	0.67	0.49
R^2 99		0.63	0.63	0.63	0.7	0.72
average R^2		0.44	0.56	0.65	0.67	0.54
cumulative flow	54902 m^3	99407	87601	78272	72040	67695

Table 9 : Swat calibration for the Cétrais watershed.

Results and observations for modelled nitrogen exports

The 1999 version of the SWAT model was first used. In this version, leached nitrogen computed at the bottom of the soil profile is not routed to the shallow aquifer. As a consequence, N in the surface water leaving the watershed did not include computed leached N but only N included in surface runoff and lateral flow.

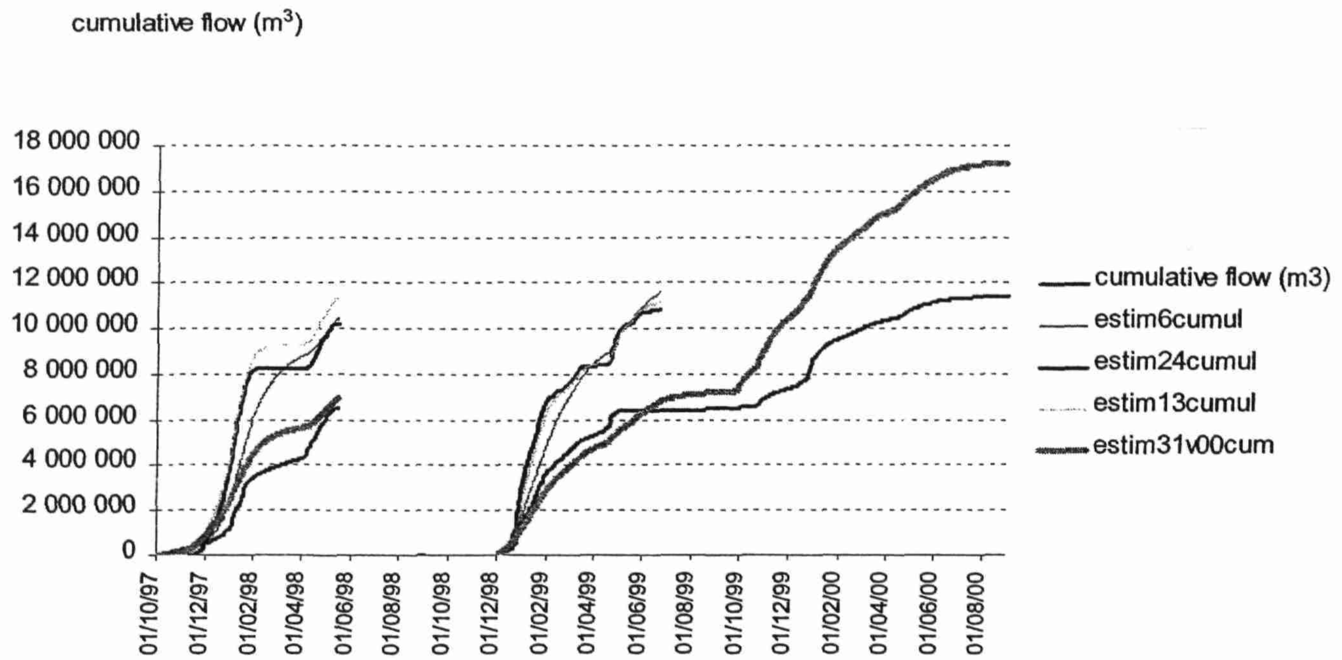
The 2000 version of SWAT was thus further used since it was reputed having corrected that problem. Yet, using the version directly downloadable through the SWAT Internet site, it is our understanding that leached nitrate computed at the bottom of the soil profile is still not tracked through the shallow aquifer to be further delivered at the outlet. Instead, an optional value of initial nitrate concentration per HRU in the shallow aquifer has been added in the latest version. The nitrate concentration in the shallow aquifer is therefore unrelated to the nitrate loads computed at the bottom of the soil profile. It is our understanding that using the available versions of SWAT, there is little hope of linking the N cycle computed in the soil and nitrogen leaving at the outlet of the watershed.

It is our opinion that nitrates computed at the bottom of the soil profile should eventually be tracked and routed through the shallow aquifer. However, time required to make this modification in the source code was not taken for this study. Instead, a simpler modification in the source code was made. "Nitrate leached from the soil profile" (referred to as NO3L among the variable names) was added to "nitrate transported into the main channel in the groundwater loading form the HRU" (referred to as NO3GW). This modification is imperfect because there is not buffering that should occur in the shallow aquifer.

In summary, the available version allows the user to set an initial nitrate concentration into the aquifer. It is likely that good results on the nitrogen fluxes could be obtained if indeed, actual nitrate concentrations in a particular HRU were to be pretty much constant, and, if good flows were computed. However, computations done for the nitrogen cycle within the soil profile and at its bottom are unlinked or unrelated to nitrogen fluxes computed at the watershed outlets.

For HRU delineation, we chose a multiple hydrologic response unit calculation with 1% land use over subbasin area, and 1% soil class over land use area. Duros (2001) built a script to affect each HRU to its spatial localisation, so that maps can be drawn (see Figure 27).

Figure 26 : estimated and measures flows on Cétrais watershed



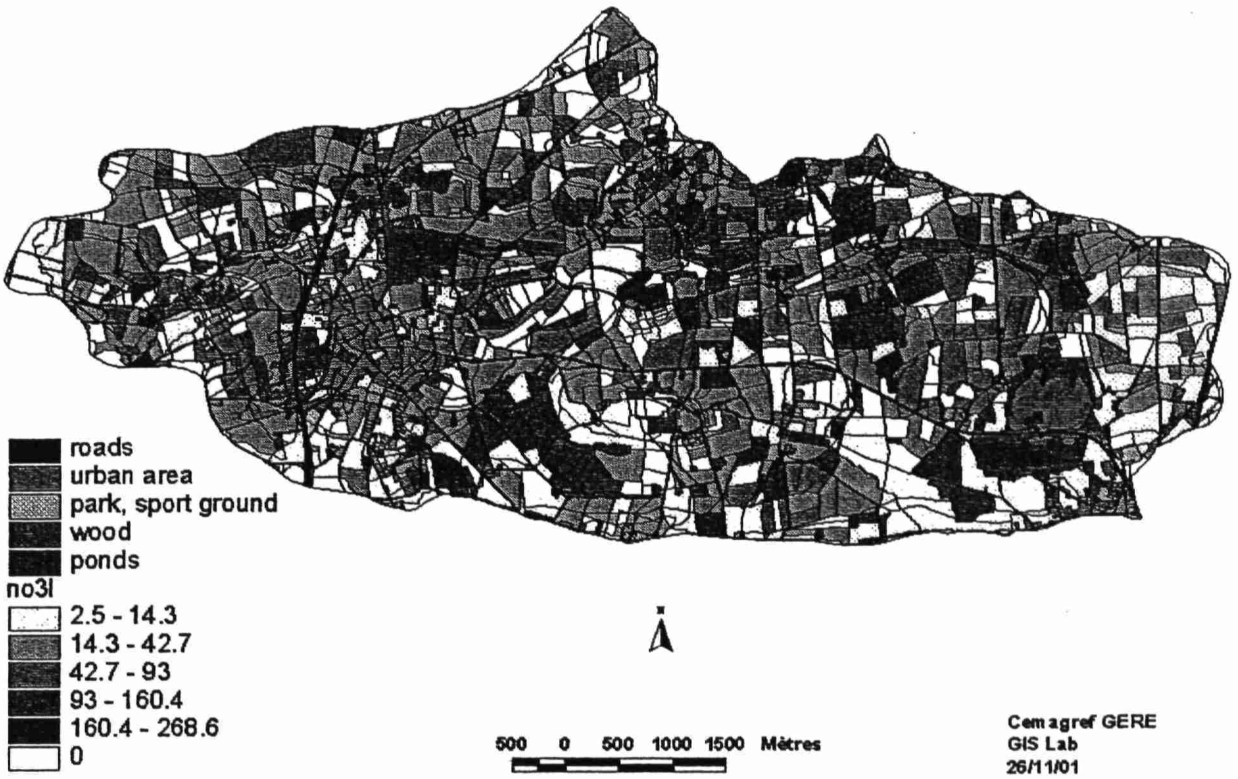


Figure 27 : estimation of leaching with SWAT

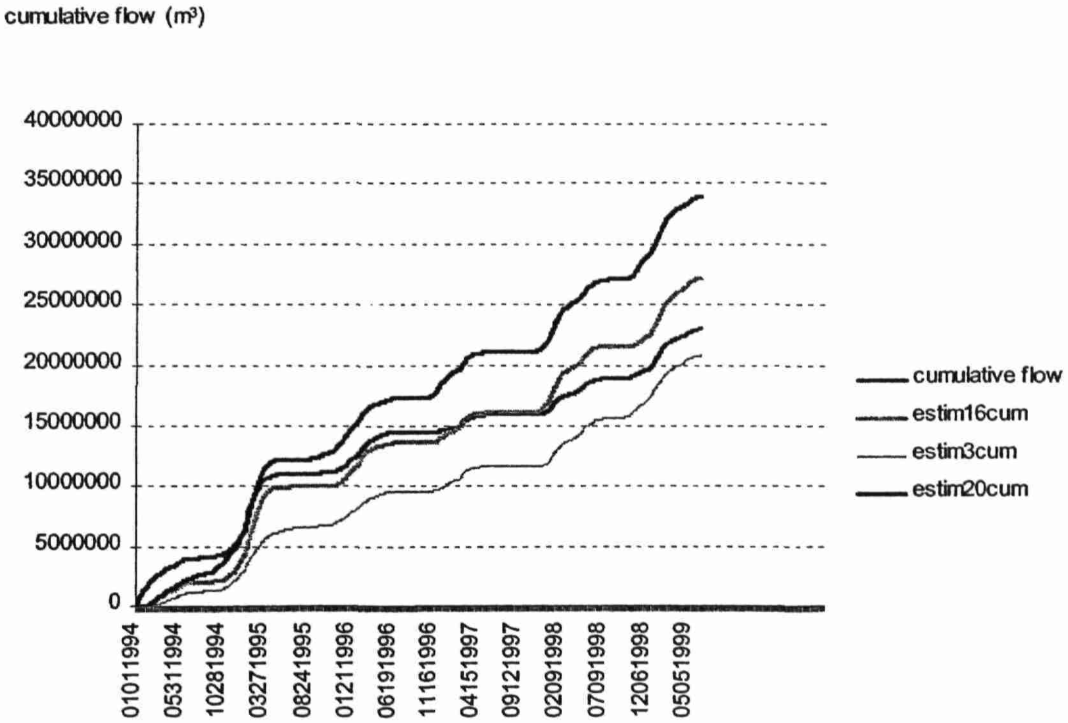


Figure 28 : estimated and measures flows on Cétrais watershed

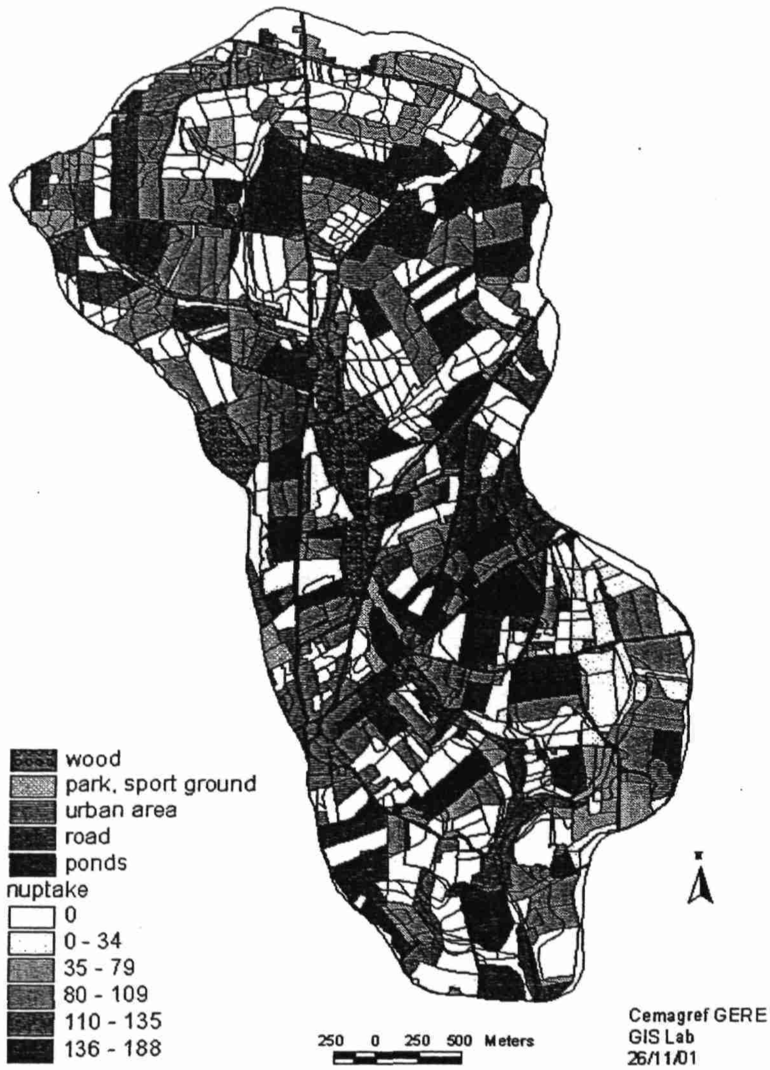


Figure 29 : exports by crops (SWAT)

3.3.3. validation

3.3.3.1. ICECREAM

The modelled total load from the catchment area represents the potential total load to the river and it does not take into account any retention. Figure 30 : Modelled and measured TotP (a) and TotN (b) loads in the Savijoki watershed. Model: ICECREAM for cereals, other land-uses as described in text. shows the modelled and measured nutrient losses in Savijoki for the period 1981-2000. In most cases the modelled values are lower than measured ones for both TotN and TotP. The result reflects the fact that the mean load estimates for spring cereals calculated by ICECREAM were rather low (12.4 $kgha^{-1}a^{-1}$ for TotN and 0.7 $kgha^{-1}a^{-1}$ for TotP). The low values are probably due to discrepancies found in the model: the present version of the model doesn't allow mineralisation from the new harvest residue during autumn. In reality, mineralisation of organic nitrogen continues in autumn after harvest and in spring depending on the temperature. The mineralized nitrogen is susceptible to leaching due to autumn and winter rains, and snow melt induced peak flow. The process description in the model will be re-written in the near future by the model developer group at SYKE.

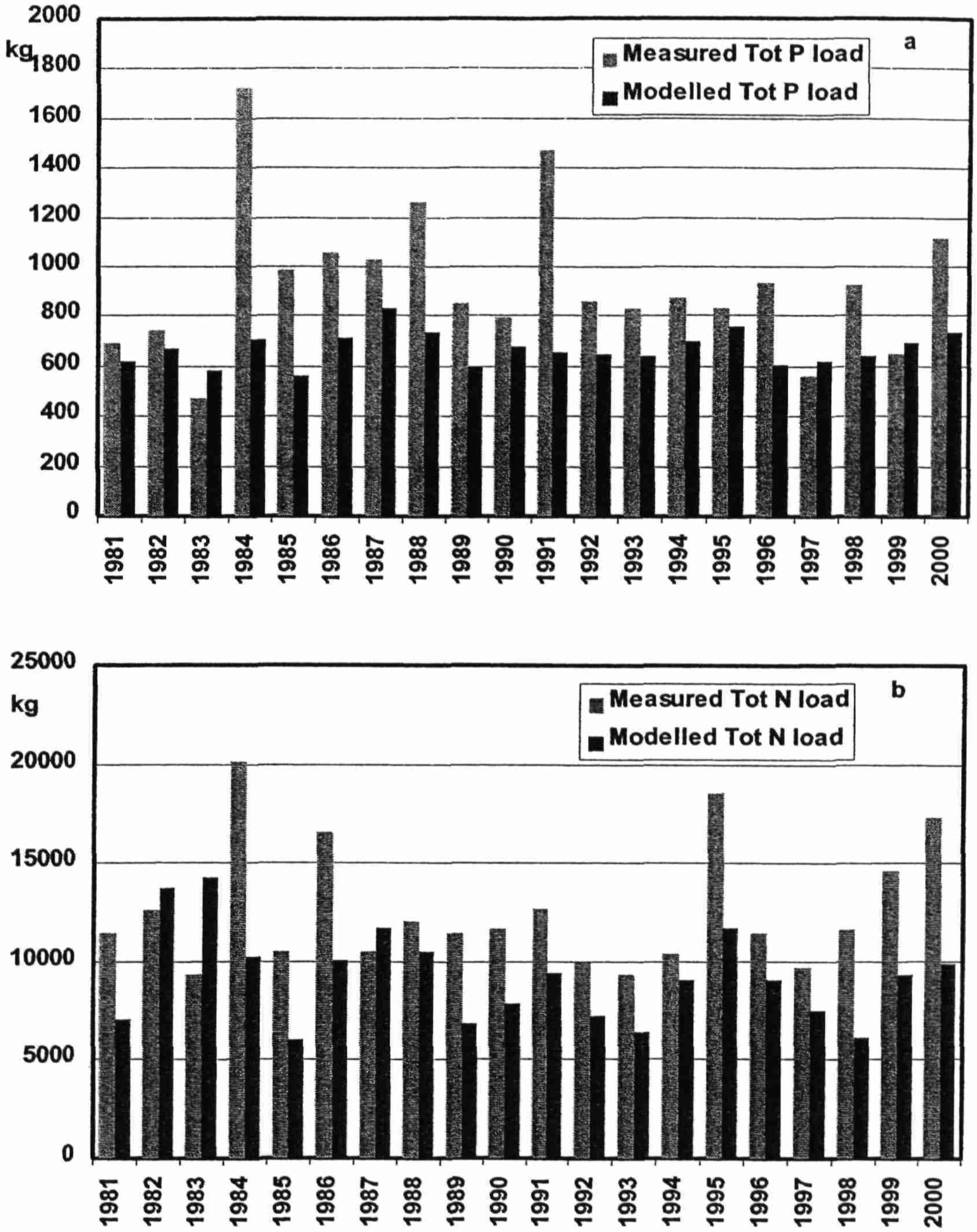


Figure 30 : Modelled and measured TotP (a) and TotN (b) loads in the Savijoki watershed. Model: ICECREAM for cereals, other land-uses as described in text.

3.3.3.2. BMP1-GLEAMS and SWAT on French watersheds

Two years of monitoring (1992-1994) were used to calibrate flows for the BMP1-Gleams model. Results obtained for six non-calibrated years show a good correlation between the simulated and measured cumulated nitrogen fluxes at the outlet of the Coët Dan (Naizin) watershed. Overall, 301 tonnes of Nitrogen were simulated to leave the watershed after six years, while 334 tonnes were measured in the mean time. A 10% underestimation was thus made using this model for this criteria.

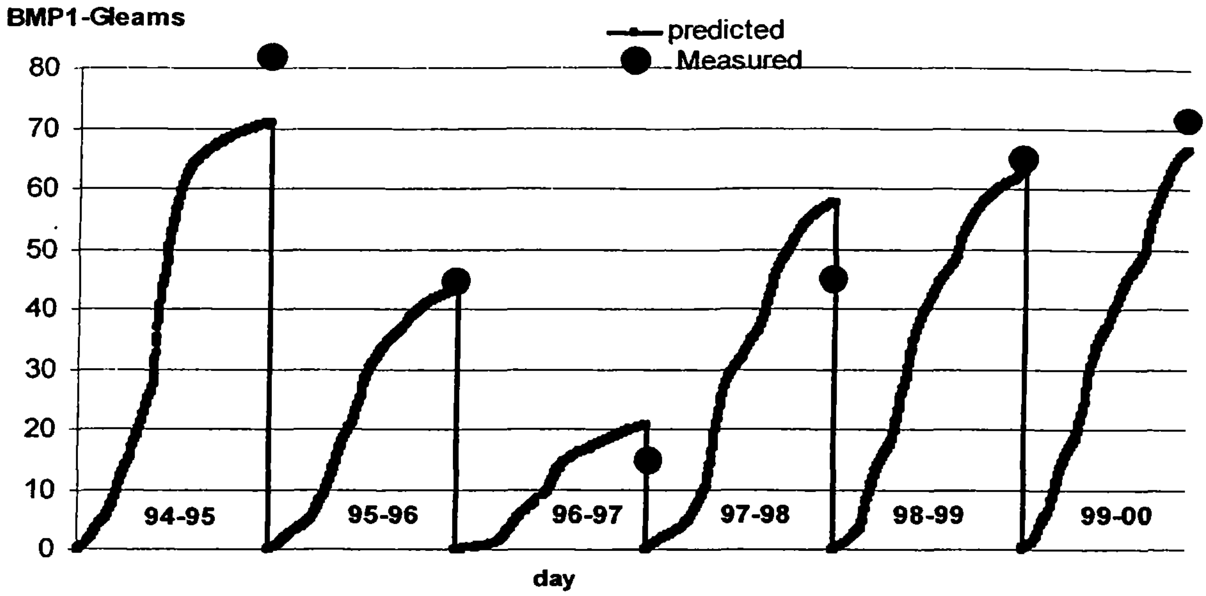


Figure 31 : Comparison between daily simulated and measured cumulated Nitrogen fluxes (Mg)

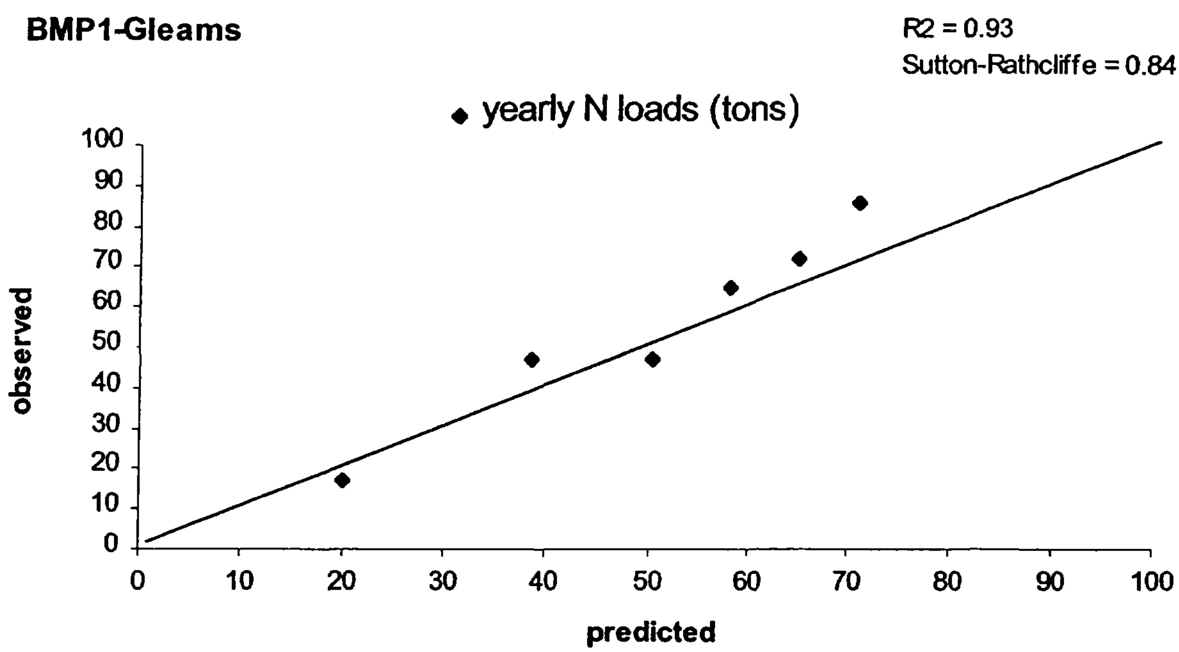


Figure 32 : nitrate leached under fields – model BMP1-GLEAMS

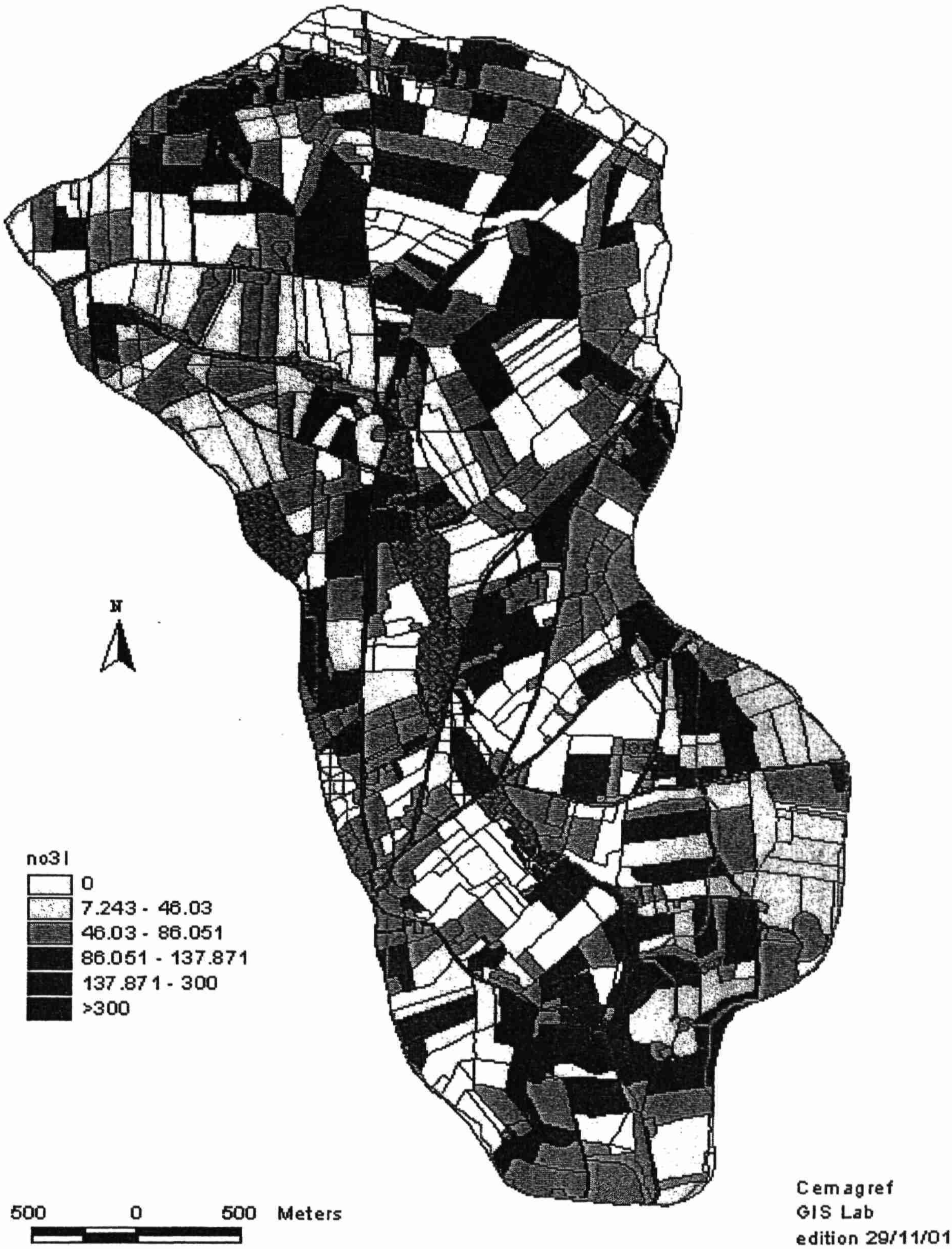
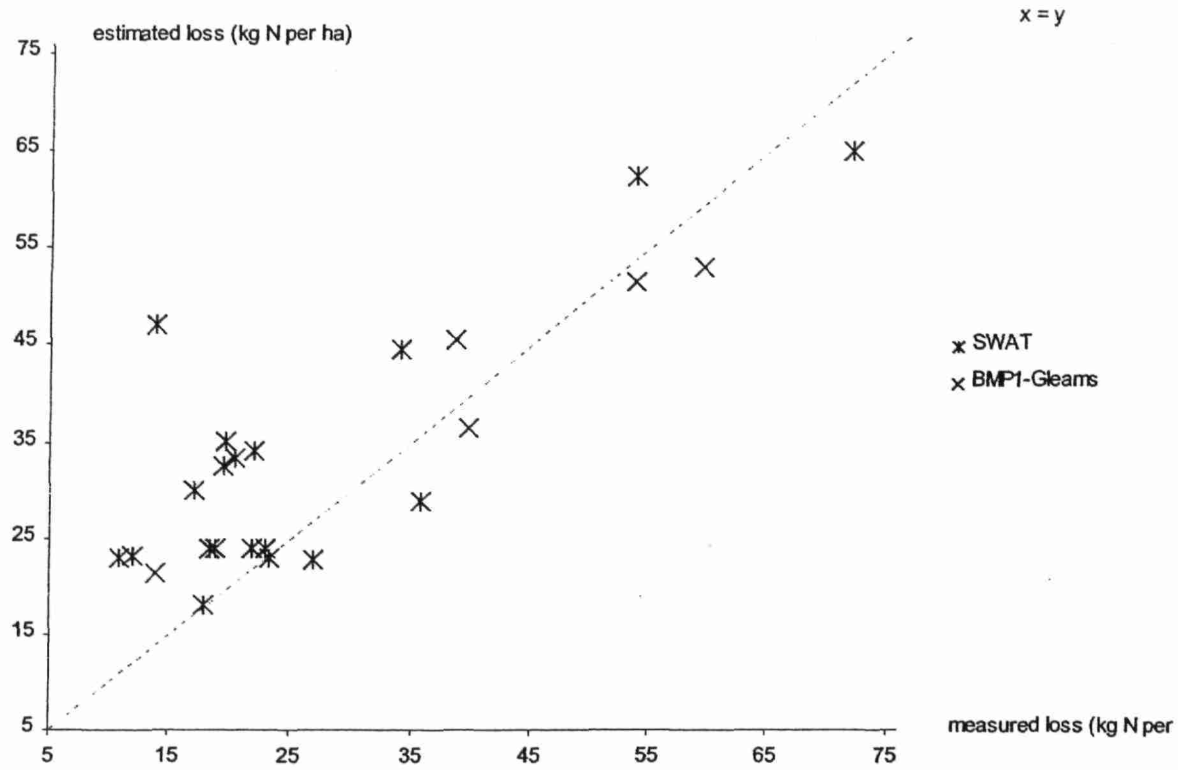


Figure 33 : yearly N loads from 1994-95 to 1999-2000 on Coët Dan watershed – model : BMP1-GLEAMS



3.3.3.3. All methods on French watersheds

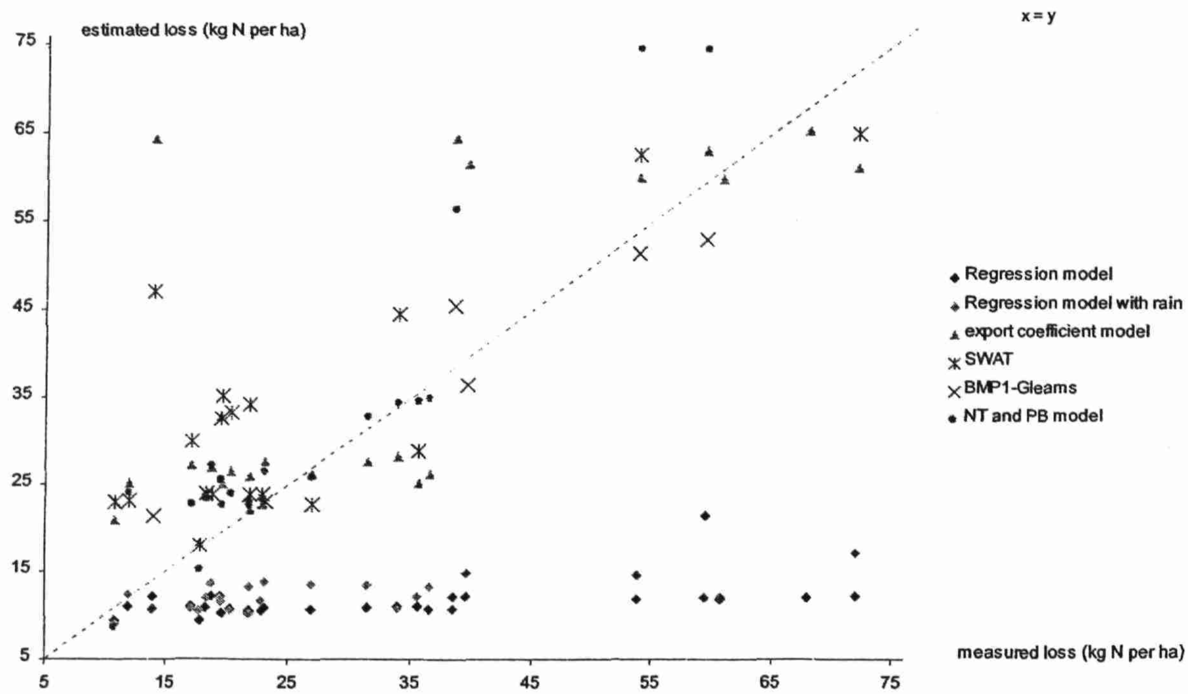


Figure 34 : measured and estimated N loads all models on Cétrais and Coët Dan watershed

3.3.4. goodness and fit

point	observed loss		Predicted loss : method 1							Method 2		
			Regression model		Regression model with rain		Ekholm model	export coefficient model	Johnes model	NT and PB model	Method 2 with SWAT means	SWAT
	observed N I	TP	N	TP	N	TP	TP	N	TP	N		
PZ1-97	21,9		10,5	1,1	10,2	1,1	2,2	26,0	0,25	22,6	16,9	34,2
PZ1-98	22,8		10,6	1,1	11,7	1,2	2,2	22,8	0,30	23,2	21,0	23,9
PZ1-99	26,8		10,6	1,1	13,6	1,4	3,0	26,2	0,27	25,8	21,0	22,8
PZ1-2000	36,5	1,1	10,6	1,1	13,3	1,3	4,1	26,2	0,27	34,8	17,7	
PZ3-97	20,3		10,7		10,4			26,4		23,8	20,8	33,3
PZ3-98	18,2		10,7		11,9			23,5		23,6	24,2	24,0
PZ3-99	23,1		10,8		13,8			27,6		26,4	25,0	23,1
PZ3-2000	31,5		10,8		13,4			27,6		32,8	21,0	
PZ4-97	19,4		12,2		11,9			32,7		25,5	21,4	32,5
PZ4-98	18,7		12,2	no estimation because no measurements	13,6	no estimation because no measurements	no estimation because no measurements	27,0	no estimation because no measurements	27,0	22,7	23,9
PZ5-97	19,6		10,2		11,4			25,0		22,6	15,9	35,2
PZ5-98	21,8		10,3		13,2			22,1		23,0	20,7	23,9
PZ6-97	33,9		11,0		10,7			28,2		34,4	20,6	44,5
PZ6-98	35,6		11,0		12,1			25,1		34,5	25,4	28,9
PZ7-97	17,1		11,0		10,8			27,3		22,8	29,7	30,0
PZ7-98	11,9		11,0		12,2			25,1		24,0	31,6	23,2
PZN-97	10,8		9,3		9,1			21,0		8,6	10,5	23,0
PZN-98	17,8		9,4		10,4			18,5		15,2	15,3	18,1
mean	22,7	0,1	10,7	1,1	11,9	1,2	2,9	25,5	0,3	25,0		27,8
number of points : N	18	1										
Indexes												
Scaled total error	TE		0,53	91,13	0,48	90,61	84,91	0,28	94,04	0,15	0,29	0,31
Scaled root mean square error	SRMSE		0,61	30,14	0,56	34,08	82,83	0,33	15,64	0,20	0,39	0,39
Sutton-Rathcliffe's coefficient	**ME**		**-2,66**	**-1,97**	**-2,08**	**-2,80**	**-21,42**	**-0,08**	**0,20**	**0,62**	**-0,50**	**-0,49**
Coefficient of Determination	CD		0,38	0,04	0,27	0,03	0,01	0,04	17,00	0,03	0,06	0,04
Coefficient of shape	CS		109,26	5736,05	28,67	18,67	0,50	5,65	1085,34	1,30	2,21	1,41
Maximum error	MaxE		25,84	35,38	23,47	35,18	32,41	13,34	36,22	12,04	19,62	15,60
Coefficient or residual mass	CRM		0,53	-2,87	0,48	-3,40	-9,09	-0,12	0,03	-0,11	0,06	-0,09

year	observed loss		Predicted loss : method 1							Method 2	Method 3	
			Regression model		Regression model with rain		Ekholm model	export coefficient model	Johnes model	NT and PB model	BMP1-Gleams	SWAT
	0 N	0 TP	N	TP	N	TP	TP	N	TP	N	N	N
1993	60,7	0,5	11,8	1,3	12,0	1,3	4,6	59,7	0,472			
1994	72,0	0,3	12,1	1,3	17,1	1,8	6,0	60,9	0,468			64,85
1995	39,6	0,9	12,1	1,3	14,8	1,6	7,9	61,5	0,459		36,39	88,75
1996	13,9	0,3	12,0	1,3	10,7	1,1	3,8	64,4	0,462		21,51	47,15
1997	38,5	0,2	12,0	1,3	10,7	1,1	1,7	64,3	0,464	56,2	45,49	81,31
1998	53,8	0,3	11,8	1,2	14,6	1,5	3,3	59,9	0,440	74,4	51,28	62,37
1999	59,4	0,5	21,5	2,4	11,9	1,4	6,0	63,0	0,457	74,4	52,94	
2000	67,9		12,0	1,3			5,5	65,2	0,462			
mean	61,32	0,50	15,93	1,71	15,88	1,70	5,90	75,41	0,46	82,67	53,67	83,28
number of ye	8	7										
Indexes												
Scaled total error	TE		0,74	136,08	0,61	113,18	126,53	0,30	138,72	0,13	0,07	0,35
Scaled root mean square er	SRMSE		0,68	2,22	0,59	2,05	9,39	0,36	0,42	0,18	0,07	0,43
Sutton-Rathcliffe's coeffic	**ME**		**-2,98**	**-23,43**	**-2,06**	**-19,80**	**-436,04**	**-0,12**	**0,11**	**0,72**	**0,95**	**-0,59**
Coefficient of Determination	CD		0,19	0,12	0,21	0,14	0,14	83,26	0,12	9,34	1,32	2,53
Coefficient of shape	CS		32,59	0,25	72,08	0,78	0,01	78,40	471,18	11,59	3,83	2,37
Maximum error	MaxE		59,83	70,67	54,83	70,14	65,95	50,50	71,49	20,67	7,59	49,16
Coefficient or residual mass	CRM		0,74	-2,91	0,77	-2,40	-12,46	-0,23	-0,27	0,49	0,49	0,15

3.3.5. time needed to perform physically based models

time needed for physically based models

Operation	Time (days) GLEAMS	Time (days) SWAT	Who can do it
Basic data			
Watershed delineation			
Parameters :			
• soil map	40	40	Student
• fields map	10	10	Student
• crop map (per year – at least 3 years)	8	8	Student
• fertilisation practices (per year – at least 3 years)	40	40	Student
• on Naizin, interpolation between surveys	15	15	Permanent
• coherence verification between all the data	5	5	Permanent
• building a database for all the data		15	
• building SWAT input files			
Model understanding	10	30	
Calibration :			
• soil data measurements	2 years	2 years	
• water measurements	3 years	3 years	
• calibration for water fit	10	10	
1 simulation	10 hours	2 hours	
Validation (usually dead-line for the report) goodness and fit	5	10	permanent

4. Retention

4.1. Testing of the HARP Guideline #9

One of the targets of the MicroHARP project was, whenever appropriate, to quantify the retention processes of nutrients within the study catchments for testing the HARP Guideline #9. Ackording to the Guideline #9 (Reference number: 2000-12), retention of nitrogen and phosphorus is defined as permanent removal of phosphorus and nitrogen in the surface waters of the river systems. Parameters influencing nitrogen and phosphorus retention are, inter alia, renewal time in lakes, input of nitrogen and phosphorus to freshwater systems, trophic level, oxygen condition, volumes of lakes, temperature, nitrogen fixation, general water chemistry, water vegetation and human activity in the catchment. The Guideline #9 classifies the different methods for estimating retention into three categories:

· Models of nitrogen and phosphorus retention based on the mass balances of river systems (including both rivers and lakes), c.f. example in Annex 1 of the Guideline #9

- Models of nitrogen and phosphorus retention based on mass balances of lakes and transformation of these findings related to the whole river system, c.f. example in Annex 2 in the Guideline #9
- In-situ measurements or other types of measurements that provide retention coefficients for nitrogen removal in streams and rivers.

In the MicroHARP catchments, only the first method for estimating retention has been tested, since there are no lakes in the catchments, and no In- situ measurements on retention coefficients were available. The method described in Annex 1 of the Guidelines (Nitrogen and phosphorus mass balance models for river systems, a German approach) is based on an analysis that has been carried out with data on the discharges/losses and riverine loads of nitrogen and phosphorus in 100 different rivers, located in different parts of Europe. River catchments smaller than 100 km^2 were not considered. The original reference given in the Guideline (Behrend & Opitz 1999. The fate of point and diffuse nutrient emissions into river systems – results of an input-output analysis. Hydrobiologia (in print)) is probably a draft title, as it was not found in a literature review. Instead, a paper by Behrend & Opitz (2000) describes the method proposed by Guideline #9 in details. The problem is that the notation in the Guidelines and the original paper (Behrend & Opitz 2000) are somewhat different. After some comparison of the method descriptions it was found out that the retention of nutrients can be calculated ackording to the equations given by Guidelines #9 after some assumptions made on the units in the equations. The method used in the Guidelines is described below.

Calculation method

In the following, it is assumed that retention processes are the main reasons for the difference between the observed load (L) and total discarge/losses (D):

$$R_{abs} = D - L \qquad (1)$$

where

R abs = retention expressed in absolute units (e.g. kg a-1)
D N,P = sum of all losses/discharges within a river basin upstream from the river mouth monitoring station, and
LN,P = N or P load at the river mouth monitoring station.

In order to eliminate the influence of catchment area when comparing river basins, it is essential to use normalized values for retention. Behrend and Opitz (2000) define load weighed nutrient retention RL as Rabs divided by LN,P.

The model presented by the Guidelines for quantification retention requires the following parameters:

a. The catchment area (A in km^2);
b. The water-flow (Q in m^3s -1); and
c. The area of surface waters within the river catchment (As in km^2).

The area of the surface waters in the catchment (AS) can be calculated from detailed statistics on land use or by using the surface area of the lakes and reservoirs (ALake), on the basis of land use maps (e.g. CORINE Land-cover) and the river surface according to the following equation:

$$A_S = A_{LAKE} + 0{,}001 \cdot A^{1.185} \quad [\text{km}^2] \qquad (2)$$

Where;
As = area of surface waters;
ALAKE = area of lakes in the catchment; and
A = catchment area.

The second part of the sum is derived from the analysis of different river systems according to stream order (e.g. Billen et al., 1995) and measurements in rivers of different size (c.f. also Behrendt & Opitz 2000). The parameters in this equation should be developed specifically for the region/catchment under consideration.

Behrendt & Opitz (2000) found that the specific nitrogen and phosphorus retention (load weighed retention RL) of river systems can be described by the following statistical model

RL = a ·xb, (3)

where x is the driving force and a and b are the coefficients of the model. The analysis was carried out based on data from 100 European catchments, the size of the catchments varying from 121 to 194 000 km2. The most important driving forces were the hydraulic load and/or specific runoff. Hydraulic load (HL) is defined as the annual runoff (Q) divided by the water surface area (As) of the river basin. Specific runoff (q, in ls-1 km-2) is defined as the runoff divided by the area of the river basin. The unit for HL is not mentioned in the Guideline, but in Savijoki Q in m3a-1 and As in m2 were tested. The coefficients a and b are given in the Guidelines for both q and HL (HL3 in the Guidelines).

4.2. Results from Savijoki

First, the area of surface waters (As) was calculated for Savijoki. The total catchment area is 15.4 km2 and equation (2) then gives As = 0.026 km2 (ALAKE = 0). For Savijoki, HL was 218.68 ma-1 and q 11.7 ls-1 km-2 (mean for the period 1981-2000). The coefficients a and b were given in the Table 1 (Guideline #9) for totN and totP and for both HL and q. Thus, two estimates were calculated for RL:

For nitrogen: RL,N(HL) = 0.10 and RL,N(q) = 0.46

For phosphorus: RL,P(HL) = 0.09 and RL,P(q) = 0.40

Rabs for totN and totP can then be calculated by multiplying the measured load by RL,N and by RL,P, respectively. The estimates for RL,N and RL,P based on HL seem reasonable, suggesting that approximately ten per cent of the measured load is retained. The method based on q gives much higher values for specific retention. The reason for this is possibly that the specific runoff q does not directly take into account water residence time in the catchments. The hydraulic load HL takes into account the surface area of the channels and better describes the time-lag in runoff. However, since no comprehensive analysis on the variation of q and HL in Finnish catchment is available so far, no further conclusions on these properties can be drawn from the Savijoki results. Moreover, as there are no lakes in Savijoki and artificial drainage is widely used in the fields, the residence time in the catchment is short. As aresult, Savijoki is not a representative area for testing the proposed method.

5. Conclusion

Physically based models have been applied on schist soils having very shallow groundwater table. Those pedoclimatic conditions therefore seemed quite ideal to apply the models used.
Physically based models are rather appealing because they simulate water fluxes as well as nutrient cycles and fluxes. In addition, available interfaces make their use easier than ever before. However, at one point or another in the models, routines are eventually based on empirical equations. In addition, many parameters are introduced as a result of modelling a large number of processes. Many not to say most of those parameters are nearly impossible to measure individually. For instance, the percentage of the root zone, which mineralises is practically impossible to measure on a field by field basis. Similarly, denitrification coefficients, curve numbers or initial groundwater levels on a field by field basis are very difficult to quantify. Daily variations of parameters such as groundwater levels cannot be verified on all fields either.

Parameters used in physically based models are therefore calibrated by comparing measured crop exports, inorganic nitrogen pool in the soil or nutrient loads at the outlets of the watersheds. Those measured parameters are not input parameters in the models but are results of the models themselves. An important calibration effort is therefore necessary as shown earlier in this report.

Calibration time can be very long (at least one month for hydrology with the model used). Among that time, one should take into account the time necessary to familiarise oneself with the model and its subtleties. For instance, it was necessary to modify the source code for BMP1-Gleams. Even while testing the model on small watersheds, it was necessary to make some modifications to account for environmental context different from the conditions for which the model was originally written.

It is our opinion that for physically based models, and more so for this type of model, the couple model/modeller is crucial. In other words, for this type of models, only very experienced personnel can effectively use the models.

In addition, knowing the difficulties encountered while using and calibrating those models in relatively small watersheds (less than 3500 ha), we are doubtful on their applicability on large watersheds. Similarly, we have shown that those models do not manage to properly represent and simulate existing agricultural practices (see results on SWAT simulations). We are thus doubting the ability of these models, with the same expertise acquired in the course of this study, to satisfactorily predict water quality changes after improvements in agricultural practices.

In fact the choice of a particular model is derived from the objectives: for diagnostic purposes, models used in method 2 seem quite satisfactory. However, these models cannot be used to simulate nutrient fluxes at the outlet of the watersheds. It seems that this method works rather well because in the studied basins, there is a more or less constant correlation between water and nutrient fluxes. This implies that nutrient sources are nearly unlimiting. There is no evidence that the nutrient sources would still be unlimiting and the current relation between water and nutrient fluxes would still hold after changes in fertilisation practices for instance.

Problems unresolved for method 2 can be summarised as such: nitrogen budget is open. Fate of the organic nitrogen pool, nor the amount of nitrogen volatilised are not accounted for in the current version.

In conclusion, it is our opinion that the choice of a model must be made according to the objectives, the means available to attain those objectives and the expertise available to do the job.

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