ESTIMATION OF THE DIFFUSE LOADS OF PHOSPHORUS USING A GIS

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ABSTRACT
This project aims at creating a tool adapted to the desideratas of the managers of small dimension rural catchments. In the long term, this tool will make it possible to simulate the dynamic of phosphorus and to direct the decisions of the managers. The study and the application of existing tools emphasized the advantages and disadvantages of each one of them and defined the future characteristics of our tool. This paper summarizes the bases of reflexion for the creation of our tool and presents the first simulations carried out. Our objective was to use a geographical information system, not as an interface with another model, but directly as a simulation program. The current models which apply this method do not completely take avantage from the potentialities offered by the SIG. Our second objective was to test various structures of modeling and to test various types of representation of the diffuse phosphorus loads. These simulations were applied to the catchment of Haute-Sûre (transborder catchment between Belgium and Luxemburg, of 303km² and characterized by an mainly agricultural landuse) and to one of its subcatchment: Kuebefiels (agricultural micro-catchment of 4km²). It comes out from this study that the SIG can be directly used as a programming tool only limited by a time answer constraint. The spatial positioning of the soil contribution processes takes precedence over the complex representation of these processes.

Keywords diffuse load, GIS, model, phosphorus, catchment management.

INTRODUCTION
CONTEXT
Data-processing modeling is usually used by the managers of catchments to evaluate the quality of surface water. These models make it possible to know the current state of a given situation but also to simulate various scenarios on this catchment. The choice of the model to be used in a specific problem is a significant step that no one should underestimate. The creation of a tool which makes it possible to direct the user in the choice of the model was developed in a previous project (Thunus, 2002). This project also aimed at applying to two small dimension catchments (Kuebefiels 80ha and Teischelt 122ha, Luxemburg) two different approaches of modeling (one deterministic and the other empirical) to a common objective: the simulation of the suspended matter to the outlets of the catchments. This project set the bases of our reflexion as for the use of models bound for the managers of catchments. Various reports were carried out and argued, the following paragraph is a brief summary of them.

Deterministic or empirical
The processes to be simulated present such a complexity that most of the models are based on a deterministic approach. The possibilities of these models are huge as for the significant range of variable which can be estimated. Such models generally make it possible to the users to obtain approximate values of uneasily measurable parameters. This advantage is accompanied by a disadvantage. The calibration of a significant number of factors which spatial variability within the catchment is seldom known. Some managers also complain about the heaviness of the models and the difficulties related to their application. Moreover, many subtleties of the model appear only after many uses. Knowing about these disadvantages, several managers prefer to use empirical models. The models with empirical basis present simpler relations than that developed in the deterministic models. What involves a reduction in the number of factors to be calibrated and often a better knowledge of those ones. This advantage of simplicity is also a disadvantage because it allows only more global simulations of the processes. They are consequently applied to broad step of time and on large areas.

Geographical information system and modeling
The outcoming of the GIS made it possible to take a great step ahead as for the step of encoding the data during the use of models (whatever it is deterministic or empirical). The GIS also present more handy and comprehensive visual interfaces for the managers. But the use of the GIS remains too often confined with the role of interface to models which function at the back like "black boxes" for the user. The present study aims at showing that the GIS have larger potentialities than simple interfaces. In addition to the aspects of database management, the GIS have many programming capacities. The question is to know if these capacities are sufficient to carry out simulations which answer to managers's expectations under specific conditions. This project also presents a distinct approach which gives more importance to spatialization of the processes than to their mathematical representation.

METHODS
Interface
On the basis of several scripts written in Avenue (programming language of the software ArcView 3.x, ESRI), the user applies the various options of the menu " Phos-Bv" (Fig.1).

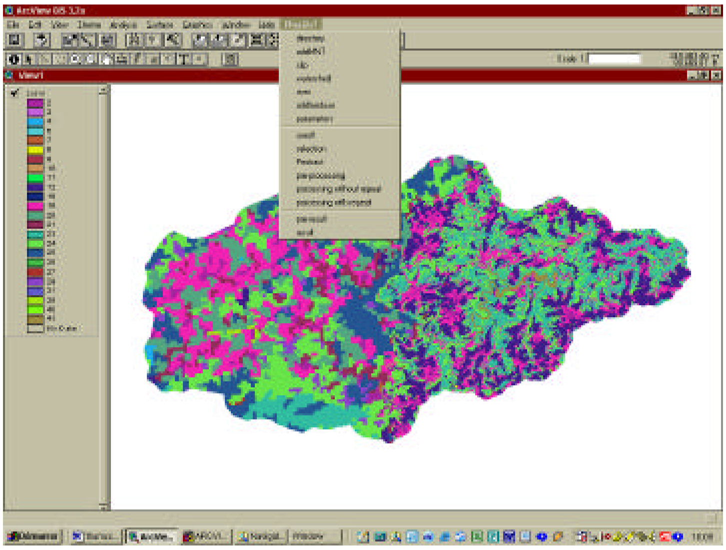
Figure 1: Interface of the Phos-Bv model

These options make it possible to the user to post the maps of altitude and landuse for the studied catchment, as well as entering the useful parameters (coefficient of transmission, ground cover percentage, parameters of extraction and soil phosphorus concentrations). A ".txt" file is also required with the flows (surface and subsurface runoff) at one point of the catchment. The calculations of the surface and subsurface runoff are obtained by application of the statistical relation of Arnold for splitting the flood hydrograms (Arnold et al., 1995). This relation was selected on the basis of a comparative study of the splitting methods (manual and automatic) usually used by the hydrologists (Fig.2).

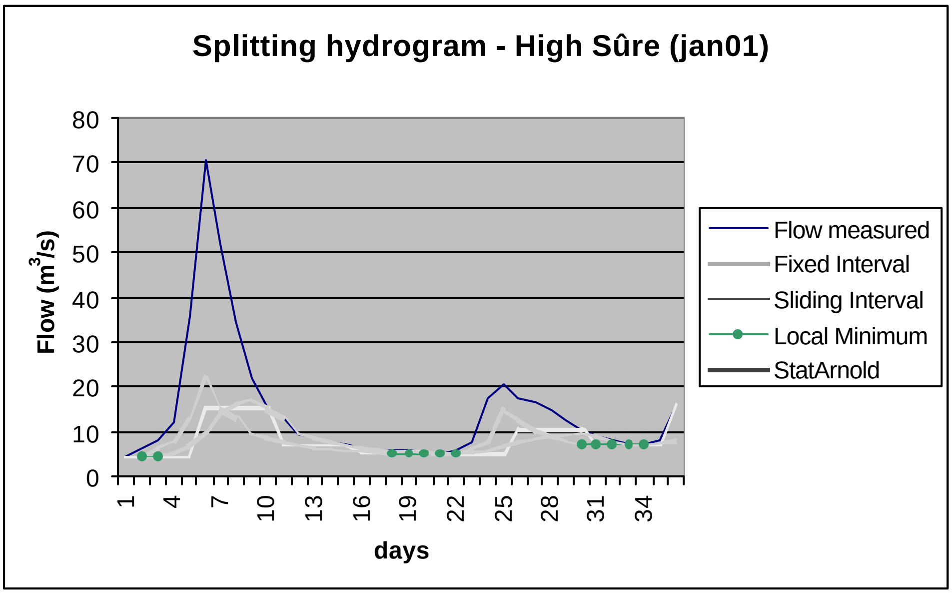

Figure 2: Comparison of various splitting methods of flood hydrogram

Study Catchment
To test this tool, two different size catchments were selected:

- Catchment of the Haute-Sûre : 303 km², mainly agricultural landuse
- Catchment of Kuebefiels: 4 km², agricultural landuse

The phosphorus data in the river for the calibration of the Haute-Sûre catchment come from water sampling campaigns realized at the Bridge of Bigonville during the year 2001 and 2002 using an automatic sampler with a step of 6 hours time. The soil phosphorus data come from soil sampling campaigns realized semi-annually on twenty fields distributed on the catchment. Measurements of flow come from the Martelange limnimetric station managed by the Region Wallonne.
The equivalent data for the catchment of Kuebefiels were taken within the framework of previous studies (Mösig, 1994) and (Salvia, pers. comm.). The water samples were collected daily during the years 1994 to 1996. The flow data were considered starting from a curve of taring carried out during this period on the level of water. The soil phosphorus concentration data date from 2001.

Representation of the processes
The empirical relations used in this model to represent the processes are:

- The flows of the point of measurement to each cell of the catchment are computed on the basis of comparison of the catchment areas and a coefficient of distribution of the rains (presumely homogeneous and thus constant on all the catchment for the simulations presented in this paper).
- The calculation of the concentrations exported in each cell is based, for particulate phosphorus, on the ground cover percentage, the soil phosphorus concentration (organic and inorganic), of a factor of extraction and a factor of erosion. For soluble phosphorus, the relation takes account of the soil total phosphorus concentration and of a factor of extraction.
- The relation of transmission of each cell of the catchment with the cell of the river. Two methods are tested:
  1. the first carries out a simple addition of the phosphorus concentrations extracted on each cell to which have to apply the coefficient of transmission of the cell and conveys it by preferential flow with the cell of river.
  2. the second applicate by consecutive routine the addition of transported phosphorus with the extracted phosphorus to which one applies the coefficient of transmission of the cell. The evaluation of these two methods are presented in this paper.

RESULTS AND DISCUSSION

The first simulations

The tool created within the framework of this project is currently tested under various conditions for, on the one hand, validating the programming and, on the other hand, to know the sensitivity of the parameters of the model. The first simulations were carried out on the Haute-Sûre catchment. A first rough calibration is carried out on the parameters of the model using the first method of transmission. The first reports are carried out:

- The relations chosen to describe particulate phosphorus and the suspended matter implies a similarity between these two simulated curves. This similarity had been observed on the results of water sampling to the outlet of the catchment.
- The simplicity of the selected relations allows an easy calibration of the model. A variation of 10% of the values of the coefficients of extraction and erosion causes a direct variation of the phosphorus concentrations and the sediment concentration of 10 %.
- Knowing that the soil total phosphorus concentration and the coefficient of dissolved phosphorus extraction are maintained constant in time, the curve of dissolved phosphorus (in µg/l) is represented by a line. This line does not move away enormously from the curve of dissolved phosphorus concentrations measured in the river.

These reports are also carried out on the first simulations using the second method of transmission.

For the Kuebefiels catchment, the calculation of the extraction and erosion coefficients has been relalized from measured datas. The coefficient of dissolved phosphorus extraction was estimated by a simple relation between the soil phosphorus concentration and the orthophosphate concentration in the river (XC=0.03). The coefficient of particulate phosphorus extraction was estimated with the relation of Sharpley (Sharpley, 1995) based on the neperian logarythm of the sediment quantity (ER=3.8 with a_0=2.2 and a_1=-0.24). The coefficient of soil erosion was estimated like the K coefficient of the Wischmeier Equation (Moeremans, 1995) with a relation depending of the soil composition, the content of organic matter, the soil structure and the soil permeability (K=0.18). The same reports are observed (Fig.3 and 4).

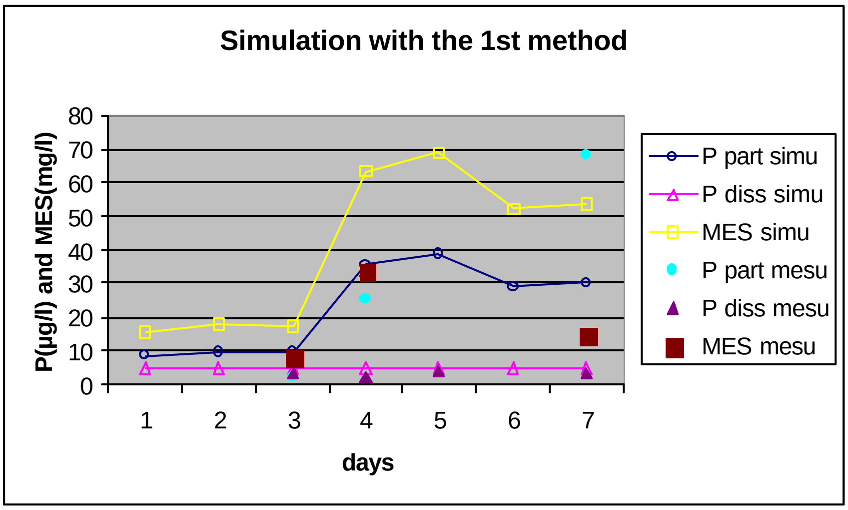

Figure 3: Simulation on the Kuebefiels– 19 to 25 Jan95 (1st method)

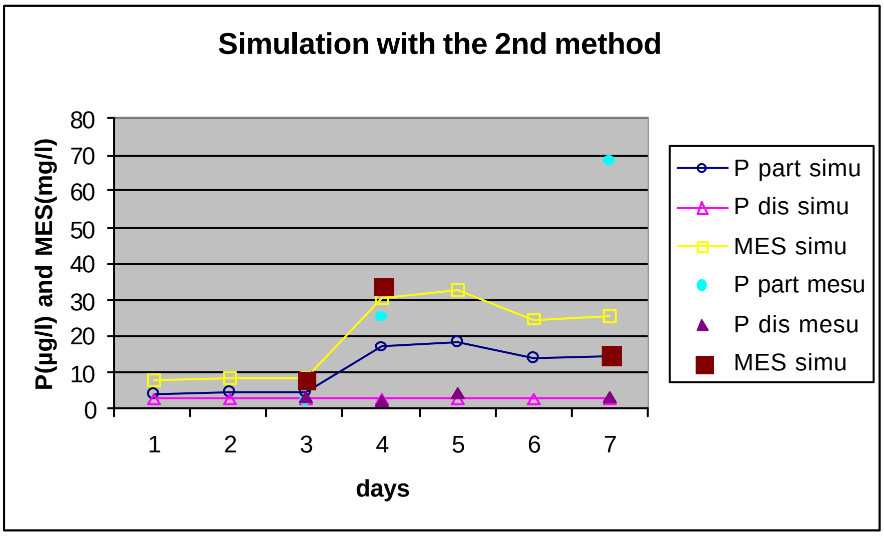

Figure 4: Simulation on the Kuebefiels– 19 to 25 jan95 (2nd method)

Results compared of the two methods

On basis of constant values for the coefficients of extraction, cover and transmission, the results simulated by the two methods of extraction can be compared. Logically, in connection with the constitution of the methods, the second method has weaker results than the first one. This decrease in the results (expressed in µg/l for phosphorus and mg/l for the sediments) is not negligible: average differences of 53% for particulate phosphorus, of 51% for dissolved phosphorus and from 52% for the sediments for the Kuebefiels catchment.

Moreover if one modification of the coefficients intervenes, the results obtained will be different according to the method used. A modification of the ground cover percentage of the agricultural field of 40% produces a variation of the results for the first method of 47% for particulate Phosphorus and 48% for the sediments (results of dissolved phosphorus not varying). For the same variation applied to the second method, one observes a variation of 28% for particulate phosphorus and 29% for the sediments. This difference in variation between the two methods is not negligible for the manager who simulate this kind of scenario.

A NEW TOOL

The design of this new tool was created to meet the requirements of the managers of catchment. The use of a SIG makes it possible to work in form vector or form raster. Each one of these forms were already used within the framework of modeling project by various teams. If these projects draw advantages from the spatial encoding of the data, they seem to forget the possibility of also spatializing the processes of transmission of each cell of catchment towards the river. To present the possibility that this spatialization offers and to answer the desideratas of managers who wish to obtain an easy tool for application with little heaviness of parameterization, the number of input data to apply the model to voluntarily limited. This choice directed the representation of the processes towards an empirical approach. The maps of input data (MNT and landuse) are largely available for the majority of the catchments. The entering parameters are gathered in a table which is easily modifiable. The number of parameter which varies according to the landuse limits to three: ground cover percentage, soil phosphorus concentration and the coefficient of transmission. The number of parameters which are constant on the catchment (single encoding) limits to three: the coefficient of soil erosion, the coefficient of extraction of dissolved phosphorus and the coefficient of extraction of particulate phosphorus.

The application of the model is divided into several steps and with each step a output map is produced. The user can thus easily check each step of simulation and thus detect quickly the errors or parameters to be corrected. These output maps can also be used as source of information for the managers. Let us take the example of the option ' Pextract' which produces a map of the phosphorus extracted for each cell from catchment, this map is connected with a map of risk of phosphorus export as can produce by ' Phosphorus Index '.

Spatialization of the processes

The choice of one or the other of the methods to represent the transmission processes to the river conditions the calibration of the model. The coefficients of phosphorus extraction will be able to vary for the same catchment according to the selected method. It can be appear paradoxical knowing that these coefficients can be directly estimated starting from soil data (cfr the coefficient's estimations in the paragraphe The first simulation). The choice of the method of transmission will also condition the results of the various scenarios applied to the catchment. A variation of the ground cover percentage will modify the quantities of phosphorus and sediment exported by its eigenvalue but also by the position of the field compared to the river one. This last factor intervenes only in the calculation of the transmission of the phosphorus exported by the second method.

Computing time

Conceptually, the spatial positioning of the phosphorus and sediment contributions processes seems an essential element for which it is necessary to hold account for any simulation on a catchment. This method is accompanied unfortunately by an increase of the model computing time. In the case of the first method, the function of transmission is applied only one time and takes about 10 seconds on desktop PC (PIII 550Mhz). In the case of the second method the function of transmission is applied to each row of cell. A row of cell is a growth series of distance from the cell to the river by preferential flow. A relatively large catchment with a low density of river represented will have a consequent on computing time. It will be thus significant to define well the representation of the network of river.

A reduction of the computing time however possible if a principle is accepted: more the field is far from a river and least it will transmit its quantity of extracted phosphorus. A script was created to define the number of row of cell considered and to select the corresponding cells. The choice of the row of cell is carried out starting from a value threshold of the potential average transmission of the extracted phosphorus from the cell to the river. For each cell the corresponding average transmission coefficient is calculated by doing the average of all cells which the phsophorus extrated will have to forwards to arrive to the river. This average of coefficient of transmission is balanced by the distance from the cell to the river. This script makes it possible to select the cells which part of extracted phosphorus will arrive at the river. This script could become, with some modifications, an intermediate method between the two methods presented herebefore.

CONCLUSIONS

The tool which was created within the framework of this project seems to be a promising tool. In addition to its facility of implementation and the directly interpretable results produced for the managers of catchment, it makes it possible to take account the spatial position of the simulated processes and to answer as well as possible the various scenarios of the managers. This tool requires to be supplemented by a module of phosphorus ponctual load and by a module of transport within the river. It is currently operational because it provides in a ".dbf" output file, for each step of time, an estimate of particulate and dissolved phosphorus load for each cell of river (referred in coordinates X and Y). This file is thus directly usable as an input file for other models like PEGASE, WASP... This tool will be also tested as for the sensitivity of each one of these parameters by statistical analysis.

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