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Comparison of physically based catchment models for estimating phosphorous losses

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Abstract
As part of a large EPA-funded research project, coordinated by TEAGASC, the Centre for Water Resources Research at UCD reviewed the available distributed physically based catchment models with a potential for use in estimating phosphorous losses for use in implementing the Water Framework Directive. Three models, representative of different levels of approach and complexity, were chosen and were implemented for a number of Irish catchments. This paper reports on (i) the lessons and experience gained in implementing these models, (ii) compares the performances of the individual models and (iii) assesses their sensitivities to the main parameters and to spatial scales.

Keywords:

Introduction
Water bodies receive pollutants either from point source discharges or from nonpoint sources. The concern has been focused towards modelling the nonpoint source pollution as it represents a major source of pollution to the receiving water and also because point source pollution can be easily quantified and many efforts have been exerted to reduce their significance as source of pollution. The amount of certain pollutant in the receiving water body is highly correlated with the conditions in the catchment which rely on its characteristics. Therefore it is quite plausible to have nonpoint source pollution models with structure composing of several components describing the processes that occur in pollution transport through land surface and water. Since the nonpoint source pollution modelling is linked to various processes in the catchment, it is always required to supply large data and parameters as input to the models. The simulated output by the models is usually very sensitive to the spatial resolution of the input data (Mackay and Fitzhugh, 2000). Furthermore, the inputs have a time variation that should be considered in the models. Such type of modelling approach is referred to as distributed physically based approach (DPBA) and the models of this type called distributed physically based models (DPBM).

The DPBA can be looked at as a descriptive modelling approach which in other words means modelling with the objective of achieving a better understanding of the physical and chemical processes involved in the nonpoint source pollution. The equations used in the DPBM are generally theoretically based micro-level non-linear relations representing the physical and chemical laws which control the nonpoint source pollution. However, empirical equations obtained from experimental studies are also used to describe some of the processes that are difficult to be modelled with theoretical relations. It is possible to point out two types of DPBM according to the time scale of the resulted outputs, namely continuous and event oriented models (Novotny, 1986). The later type simulates the response of a catchment to a major rainfall or snowfall event. On the other hand the continuous type of modelling sequentially simulates all processes incorporated in the model. The operation time interval of the continuous model ranges from a day to a fraction of an hour. The system water balance and pollutant mass balance are always preserved in the continuous model.

Either the model is event or continuous the parameters required by each of them can be used as an additional feature to differentiate between the DPBM. Thus the model can be either based on the lumped or distributed parameter and this in turn controls the spatial discretisation of the catchment.
In the case of the lumped parameters model type, whole or large portion of the catchment can be treated as one homogenous unit which produce uniform response to the external inputs. On the other hand the application of the distributed parameters models requires establishing a grid network over the catchment. The inputs (rainfall, evaporation, etc.) and controlling flow and pollutant parameters (Slope, crop, Manning coefficient, hydraulic conductivity, etc.) are specified for each grid, thereby accounting for their spatial distributions. The grid network representation would also allow the estimation of the variables of interest at each point in the catchment whereas these variables can be obtained at certain locations in the lumped models.

It is obvious that there is variety of models rendering themselves to be possible alternatives for the nonpoint source pollution studies and also it is worth mentioning that there is no absolute good model that can be used for all cases. Therefore it is always necessary to review some of the potential models that can be used for certain problem before deciding on the models which are to be used. The work in this paper is part of a project funded by the Environmental Protection Agency (EPA) in Ireland and coordinate by the TEGASC (Institute of Agriculture) in Ireland to quantify the amount of phosphorus which removed from the agriculture catchment to the main water bodies using the DPBA. Three well known DPBM, HSPF, SWAT, and SHETRAN, were chosen to be applied in a number of Irish catchment where the agriculture practices are the dominant in order to examine their capabilities to quantify the phosphorus loss from these catchment. This paper highlights some of the experiences which have been acquired in applying the models in the Irish conditions especially for two of the models, HSPF and SWAT, which have been widely used in different conditions than the Irish one. The third model, SHETRAN, is somehow internationally and it was implemented on places where the privilege conditions are similar to the one in the region the Irish catchments. In this paper the role that the GIS technology plays in performing some of the models tasks will be explained. Another aspect which will be discussed in this paper is the sensitivity of the models to their main parameters in predicting the flow and the phosphorous concentrations with the aid of example of implementing the models to an Irish catchment.

The GIS role in applying the HSPF, SWAT, and SHETRAN models to the Irish catchments

Due to the spatial nature of the basic input data required by the three models (HSPF, SWAT, and SHETRAN) there is significant role that the GIS technology can play. Two of the models, HSPF and SWAT, have been integrated in the Better Assessment Science Integrating Point & Nonpoint Sources (BASINS) system which has been built using the ArcView macro language (Avenue). All the spatial input data required by the two models can be pooled in the BASINS environment where they can be processed to create the necessary files to run the model on certain catchment. The third model, SHETRAN, can use the same spatial input data to generate the grid network and the required parameters of the grid for the catchment. Therefore it is quite plausible to say that the GIS BASINS system can be used solely to produce all the required files to run the three models on the catchment.

Digital Elevation model (DEM) of the catchment is required by the three models to define the catchment outer boundary and also to delineate the stream networks within the catchment. The disaggregation of the catchment into smaller units is direct in SHETRAN model where the catchment is divided into number of cells to form the orthogonal grid overlaying the catchment area. The size of the cell is a user’s discretion and it always depends on the accuracy required by the model. The stream networks of the catchment should be superimposed over the catchment in the way that each stream link is locating at the edge of the grid cell and this might need some manually editing to the resulted stream networks from the GIS. The land use and the soil maps of the catchment should be in a raster format with a grid size similar to the one of the catchment in order to define the land use and the soil associated with each element in the grid.
Using the resulted stream networks from the DEM delineation the subcatchments in HSPF and SWAT models can be defined such that each subcatchment is draining the area upstream of certain location in the stream networks. However the case is different for HSPF and SWAT model than SHETRAN model in defining the smallest modelling unit where the land use and the soil maps are needed to accomplish this task. In SWAT the smallest spatial unit is the Hydrologic Response Unit (HRU) which is characterised by a uniform response to all the external inputs. The HRU within each subcatchment is obtained by overlaying the land use map first and then the soil map over the subcatchment and the user should define threshold area value under which any land use types with area equal or below this threshold are excluded. Likewise a threshold area value is defined for the area of the soil types to be excluded from the overlain over certain land use type in the subcatchment. The land use map of the catchment should be classified into the recognised types by the HSPF model so that the subcatchments can be divided into subunits. Moreover the subunits can be disintegrated further into two types of different hydrological characteristics either into pervious or impervious lands. For each of subunits in the HSPF, the soil map is used to identify the soil types on them.

References