MODELLING PHOSPHOROUS LOSS FROM AGRICULTURE CATCHMENTS: A COMPARISON OF THE PERFORMANCE OF SWAT, HSPF AND SHETRAN FOR THE CLARIANNA CATCHMENT

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ABSTRACT
Much research in Europe at present has been directed at generating and assessing modelling tools for use in catchment management, driven by the requirements and schedule of the Water Framework Directive. A logical first step is to assess the suitability of existing models for this task so that any resources used in generating new models can be targeted at actual modelling needs. Crucial questions, relating to the model structure and complexity and spatial and temporal scales required must also be addressed. This paper reports a comparison of the performance and suitability of three "off-the-shelf" distributed catchment models, each with a different level of complexity, applied to modelling phosphorous losses from the Clarianna catchment in Ireland. In this paper, the performance of three such models (SWAT, HSPF and SHETRAN) is compared, both in estimating discharges and phosphorous concentrations in the Clarianna catchment.

Keywords: Total phosphorus; Flow simulation; HSPF; SWAT; SHETRAN; GOPC

INTRODUCTION
Eutrophication has been identified as the major threat to water quality in Ireland due, in most cases, to excess phosphorous inputs (McGarrigle et al., 2002, pp. 28). The phosphorous transported from agriculture land has been found to contribute a significant amount of phosphorous to the river reaches of the Irish catchments. Therefore models of this process are required in order to design and assess management measures as part of the objectives of the European Water Framework Directive (WFD) which represents the deriving force behind the work described in this paper. Accordingly three wide spectrum physically-based distributed catchment models (DPBM) (HSPF, SWAT, and SHETRAN) have been selected for testing their ability to model phosphorous loss from the Clarianna catchment in Ireland. The models vary greatly in (i) the degree of complexity in disaggregating the catchment into smaller units and (ii) the complexity of their representation of the physical processes involved.

In terms of spatial disaggregation, the HSPF model (Donigian et al., 1984) is the simplest, followed by the SWAT model (Neitsch et al., 2001) and the SHETRAN model (Ewen et al., 2000) is the most complex. However in terms of physical representation of the water fluxes, SWAT is the simplest, followed by HSPF and SHETRAN is the most complex. Both the HSPF and the SWAT models can model the phosphorous loss directly as they contain phosphorous-specific components in their structure. On the other hand the SHETRAN model is able to produce the required hydrological variables for a Grid Oriented Phosphorous Component (GOPC) developed by Nasr et al., (2003, this volume) to be used for modelling the phosphorus loss. This paper represents a comparison and assessment of the three models with particular emphasis on their suitability for Irish conditions through applying them on the Clarianna catchment.

CLARIANNA CATCHMENT
The Clarianna catchment is located in county North Tipperary (Ireland) to the north of the Nenagh subbasin in the big Shannon Basin. The catchment is relatively small with an area of 23km^2 approximately. The main stream in the catchment feeds into the lower reaches of the Nenagh River. The principal soil type is a grey brown Podzolic (Fig (1-a)), the parent material consisting of a gravelly limestone till with some shale and sandstone. The soil is well drained, well structured and shows a friable brown to dark brown gravelly loam surface. With good management the soil of the catchment is highly productive for grass and pasture occupies the largest area compared to other crops in the catchment (final report of Lough Derg and Lough Ree, catchment and monitoring system, (2001)).

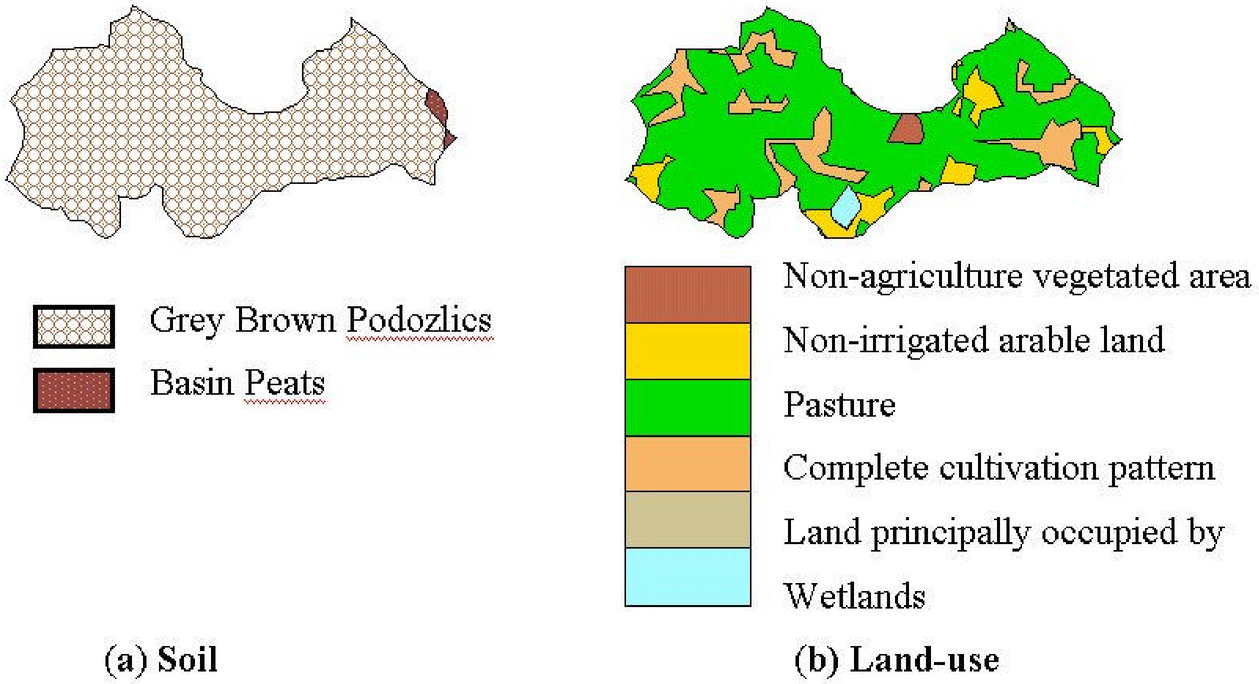

Figure 1 Soil and land use maps - Clarianna catchment (county North Tipperary, Ireland)

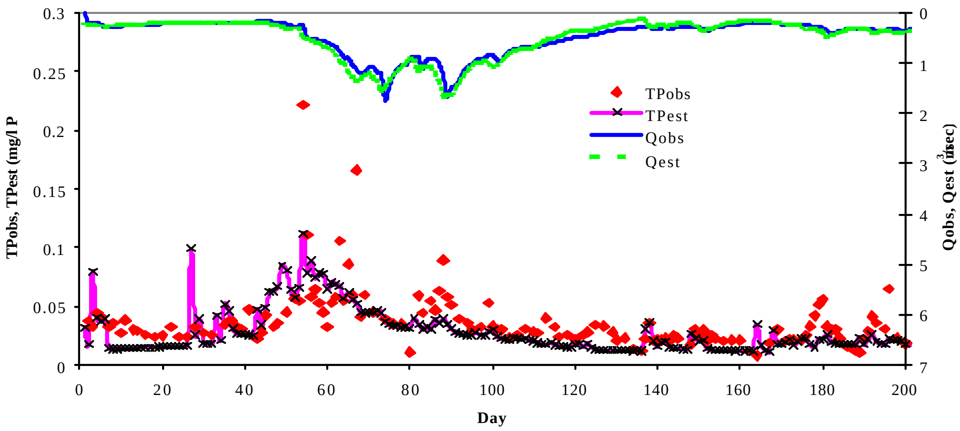

Figure 2 Simulation of the flow and the TP with HSPF model

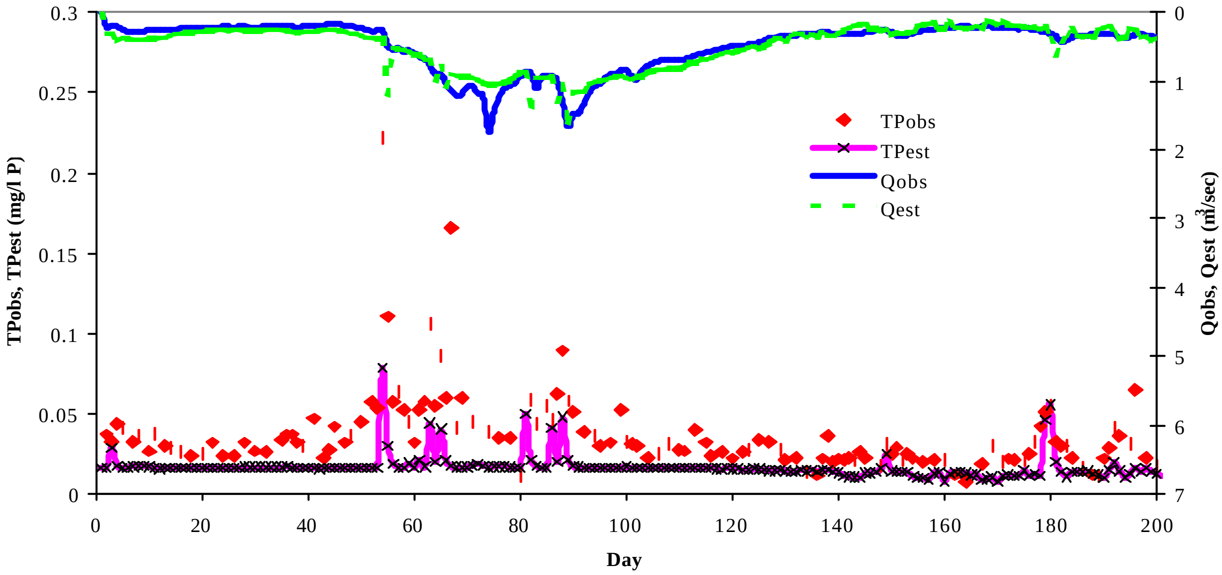

Figure 3 Simulation of the Flow and the TP with SWAT model

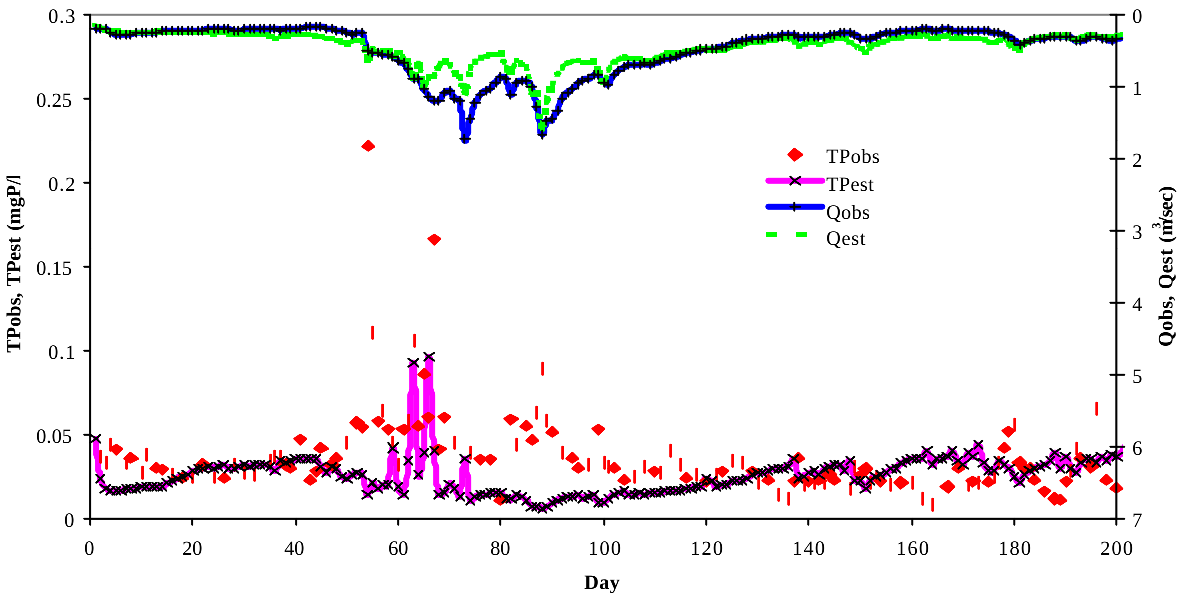

Figure 4 Simulation of the Flow with SHETRAN model and the TP with GOPC

RESULTS

For each of the three models the flow discharge simulation at the catchment outlet has been calibrated for the period from 1/12/2000 to 18/6/2001. This was obtained by changing values of the model parameters which have most effect on the flow estimation for each model. After achieving a satisfying flow calibration the parameters of the best flow calibration were used in all the phosphorus calibration cases. The flow outputs from the models were assessed by comparing them to the observed values at the Ballyanny station located at the catchment outlet. There is no available sediment record to evaluate the sediment results from the models. Instead, the models have been calibrated to produce estimates of the phosphorus concentrations which can be compared to the available data. The phosphorus simulation was obtained directly from the HSPF and SWAT models while the flow and the sediment outputs of the SHETRAN model were inserted into the GOPC to estimate the phosphorus concentrations.

To enable an easy comparison among the performance of the three models in estimating the phosphorus concentration only the best results for the flow and the phosphorus concentrations from the three models are presented in this paper.

DISCUSSION

In all figures, the observed flow (Qobs) and the estimated flow (Qest) hydrographs are displayed at the top while the observed TP (TPobs) and the estimated TP (TPest) graphs are at the bottom. This arrangement could help in determining the effect of the flow simulation on the phosphorus one. The simulation time covers the period between 1/12/2001 and 29/7/2002. Each figure will be discussed individually.

HSPF (Figure 1)

: Most of the peak values in the flow hydrograph were well captured by the HSPF model while a small number were not well estimated. Generally the shape of the simulated flow hydrograph resembles the actual one except for some discrepancy during the falling limb. Although the simulated flow values were significantly comparable to the observed the model estimation for the TP was not as good as the flow. The model produced high TP value during the initial period which does not match any observed value. This high TP value from the model was followed by values lower than observed until an unexpected rise in the simulated values occurred. This may be a model "spin-up" problem relating to initial conditions. After that point, the model seems to work fine as the resulting TP values are in good agreement with the observed. High TP values were first observed coinciding with the rising points of the flow hydrograph and continued throughout the high flow period during which the model had poor TP prediction. Apart from one point all the other point with high TP values were under-estimated by the model. During the falling limb and the low flow periods the observed TP values were commonly low. The trend of the simulated TP during those periods follows the observed trend but with values lower than the observed. The good simulation of the hydrology as it has been observed in the flow prediction by the model was not sufficient to accurately model all the TP values. Many other factors might influence the TP prediction. The most important would be the amount of phosphorous transported from the soil especially when knowing that the land use type in the catchment is grassland which contains different sources of phosphorus inputs. (e.g. fertilisers, animal manure, etc..) which are difficult to quantify.

SWAT (Figure 2)

The simulated flow hydrograph from SWAT is not in good agreement with the measured one and is much worse than HSPF. The peak values are either under or over predicted except for one of the two highest which is estimated accurately by the model. An unusual feature in the flow prediction is the relatively high simulated value at the rising point of the hydrograph. This could be caused by a high rainfall event associated with high prediction of soil moisture which assists in producing more overland flow. The model exhibits oscillation for the low flow values which might be attributed to one of the parameters controlling the base flow prediction. The general trend in the TP prediction is that there was nearly constant low TP base values associated with the base flow while there was high TP values taking place during the runoff storms. The constant low TP base values could be the result of inadequate low flow estimates from the model and also due to the assumption of a constant phosphorus concentration in the base flow. Because of this the model does not accurately estimate the phosphorus load contributed by the base flow. Essentially, this means the model ignores soil phosphorus movement in the lateral dimension and considers it in the vertical direction only. All of the high TP values fall below the observed values which could reflect the general tendency of the model to underpredict at high flows. The hydrology effect on the TP simulation by SWAT model seem to be obvious especially for the high flow values which the model failed to simulate and, as a result, the associated TP values were also not simulated properly.

SHETRAN (Figure 3):

During the initial period, the SHETRAN model generated flows comparable with the actual ones. After the initial period the predicted flows generally followed the measured values except for a single very large estimated peak, which was not reflected in the data. The model performed well in simulating the flows in the rising limb followed by under estimation of most of the values. The model again worked well during the falling limb, but failed again to match the measured flows during the early part of the low flow period. Subsequent low flows were well simulated by the model. The hydrological variables simulated by SHETRAN constituted an input to the GOPC which has been used to estimate the TP concentrations. The TP simulation experienced a marked drop during the initial period which does not correspond to a deficiency in the flow simulation. The only reason for this could be the effect of the initial soil phosphorous concentrations which diminished quickly and the model started to behave quite well producing values similar to the observed. There is an underestimation of the high values of TP associating with the high flows. Since the high flows were generally under predicted by SHETRAN it can be expected that the runoff volume, contributing to this flow, was also not precisely estimated and likewise the associated sediment load. Therefore the effect of the improper hydrological simulation in producing the flow peaks had a shadow on the GOPC performance resulting in TP values lower than the real ones. The low TP values from the GOPC generally matched the observed values.

CONCLUSION

Three DPBM (HSPF, SWAT, and SHETRAN) were applied to the Clarianna catchment in Ireland to estimate the phosphorus loss from the agriculture land to the channel reach. The models vary in their complexity of representing the spatial scale of the catchment and hydrological detail. HSPF and SWAT simulate the flow and the phosphorus directly whereas the SHETRAN feeds the GOPC with the required hydrological values for phosphorus modelling as a post-process.

In terms of the flow simulation, the HSPF model proved itself to be superior to the other two models for all cases (low and high flows). The second best in the overall flow simulation is the SHETRAN model while SWAT is the second to HSPF for high flow simulations.

The comparable shape to the observed TP graph was obtained from the HSPF model case except for the significant under estimation of the high values. The shape of the TP graph from the GOPC demonstrates the effect of the soil phosphorus dynamics and it shows remarkable changes to the phosphorus concentrations during the low flow period which is believed to result mainly from changes to the soil soluble phosphorus. The performance of SWAT model in predicting the TP values did not show any significant changes to the low concentration values but instead constant value was observed. The constant low TP value is an outcome to ignoring the soil phosphorous movement in the lateral direction. Furthermore SWAT also fails to predict any of the high TP values and hence this model is at the third position comparing to the other two (HSPF and GOPC). The effect of the quality of the flow simulation on the estimated TP values seems to be strong in all the three cases.

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