Nutrient loads from developing urban areas, a simulation approach and identification of information requirements

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Abstract

A model designed to simulate daily runoff and nutrient loads from developing urban areas is described and applied to 2 townships, one in the Orange Free State near Bloemfontein and one in the E. Cape Province near East London. The model is used in conjunction with a previously developed socio-economic survey approach to determine the annual amount of phosphorus that is discharged onto the catchment surface. The authors recognise that the amount of information on the processes involved is currently insufficient to fully conceptualise all components of the model. However, the management requirement for some method of providing immediate estimates dictated that an initial approach should be made to simulate the system involved.

The paper illustrates the sensitivity of the simulation results to the input data and some of the parameter values. In the absence of adequate guidelines on the quantification of at least some of the parameter values, the sensitivity analyses can be useful to indicate the range over which certain statistics of the time series of runoff, nutrient storage and wash-off load are likely to vary in reality.

The paper concludes with some observations on the possible model deficiencies in relation to what is currently uncertain about the operation of the processes involved in linking runoff, nutrient build-up and nutrient wash-off from catchment surfaces.

Introduction

Two of the problems associated with developing urban areas are the determination of the impact of nutrient loads generated in runoff and the development of ameliorative management approaches. Part of the problem is quantifying the time distribution of the non-point source load relative to that of point-source loads derived from sewage treatment works. The CSIR (Grobler et al., 1987) has developed techniques for translating socio-economic data into information on the source and quantities of phosphorus that are likely to form the input to the phosphorus budget in developing urban areas. Depending upon the methods of waste disposal that operate in a specific case, some of this input phosphorus will be removed to sewage works, some will enter the catchment below the surface or enter the soil profile, while the remainder will lie on the surface. It is the fate of the latter two components and how their fate relates to natural hydrological runoff events that is the topic of this paper.

One of the observations that was made in a previous study (Grobler et al., 1987) on a developing urban area in the Orange Free State was that the non-point load is mainly derived from wash-off of surface phosphorus storage during large storm events. As this coincides with relatively high volumes of runoff, which tend not to be retained in downstream impoundments, their impact is relatively minor compared to the continuous point-source loads from sewage works. The critical issue is therefore the relative time distribution of the two loads. The logical method for approaching this problem would therefore seem to be to apply a suitable time-series simulation model which links the hydrology of the urban catchment with the generation of nutrient loads.

The question arises as to what constitutes a suitable time-series model? To develop a stochastic model would require a great deal of time and effort to enable a representative sample of loads to be collected. It is doubtful whether this could be achieved given the non-linearity of the processes involved.

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The alternative of developing a deterministic approach is also problematic in that our quantitative knowledge of the processes involved is meagre. Nevertheless, the authors believe that this is the best approach to adopt for the following reasons :

- There are existing deterministic rainfall-runoff models that could form the basis of the nutrient export model.
- As more information becomes available on the processes involved, the model can be adapted and extended to incorporate the improved conceptual understanding.
- Because such a model is causal rather than stochastic, comparison with observed time series of nutrient load and runoff data can be used to examine the simulation results and suggest conceptual improvements.

Having decided on a conceptual/deterministic approach it is also important to decide on the type of model that is to be adopted. Several points have to be considered :

- The spatial distribution system to be used. Are there likely to be sufficient spatial variations to warrant adopting a distributed rather than a lumped approach? At least a semi-distributed, or subcatchment approach is probably necessary and sufficient, while a fully distributed type of approach is unlikely to be justified, at least until the processes are better understood.
- The time interval over which model iterations are to be carried out is of equal importance. In South Africa, the main national rainfall data base is at a resolution of one day and this seems to be a logical time step to use. A monthly time step is unlikely to be adequate as much of the runoff and nutrient wash-off is storm event driven.
- The choice of which type of approach to use to simulate the rainfall-runoff processes is difficult. There are many such approaches available, ranging from simple empirical to complex physically based. The final model is expected to be used in a management framework, where long time series need to be simulated to enable mean, median and extreme representative conditions to be evaluated. It seems sensible to the authors to adopt an approach that is not so complex that the amount of