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Modelling of point and non-point nutrient loadings from a watershed

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Abstract

An integrated model was developed to estimate the loadings of nutrients and organic matter from point and non-point sources in a watershed by use of the software Pamolare. The model accounted for the loadings from industrial and municipal wastewaters, atmospheric deposition and runoff from the drainage area. We tested the model using data from Lake Glumsø, Denmark, with a drainage area of about 1054.9 ha and with known annual loadings into the lake in 1978, 1982 and 2000. The model was first calibrated against one year's record, followed by one year's validation, and finally a prognosis scenario was performed. The predictions by the model were consistent with the observations. Thus, the model may be applicable for estimating nutrient loadings from drainage areas, when observations in general are not available. It can also be used to examine the current conditions and test the effects of management and planning scenarios within a watershed.

Keywords: Loading; Nutrient; Drainage area; Non-point sources; Wastewater; Nitrogen; Phosphorus

Software availability

Program title: PAMOLARE
Developer: Jørgensen, S.E., Tsuno, Hidaka, T., Mahler, H., and Santiago, V.
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E-mail: vicente.santiago@unep.or.jp
Year first available: 2003
Software requirements: Windows 98 or higher, IBM compatible PC with 64 M RAM and minimum 25 M disk space.

1. Introduction

Growth in population, urbanization and intensified agriculture, has progressively opened the biogenic nutrient cycles. One of the most obvious consequences of this is a mobilization of nitrogen and phosphorus and an increased exchange between land and surface water, and hence its impact on the functioning of aquatic systems (Turner et al., 1999). Problems with eutrophication from excess nutrient loadings from watersheds are significant in water quality management. Lakes are particularly vulnerable to nutrient enrichment because of their relatively lower retentions. The nutrient loading comes traditionally from two sources. The point sources of nutrients are mainly from municipal and industrial wastewater, whereas non-point sources are related to atmospheric deposition and drainage water and are mainly from adjacent agricultural areas. The loadings from point sources are little influenced by such stochastic forcing functions as precipitation and temperature and can usually be determined with a reasonable accuracy. By contrast, those from non-point sources are difficult to determine accurately due to the stochastic hydro-chemical processes and the heterogeneous soil properties and vegetation (Nikolaidis et al., 1998; Zhang and Wang, 2002).

Estimation of nutrient loadings is crucial to environmental management and planning. Measurements are

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obviously better than model simulations, which become necessary, however, for predictions of future loadings. For example, no observations are available for a reservoir under construction. Development of models to estimate its loadings is therefore important. Loading models may have both mechanistic and empirical components. The higher resolution of mechanistic models may often result in larger errors (Reckhow and Chapra, 1999), whereas, the accuracy of empirical models relies mainly on data. Several mathematical models have been developed to estimate nutrient loadings in watersheds, such as ANSWERS (Beasley et al., 1980), EPIC (Williams et al., 1983), GLEAMS (Leonard et al., 1987), ADAPT (Ward et al., 1988), AGNPS (Young et al., 1989), SWRRBWQ (Arnold et al., 1990), LEACHM (Hutson et al., 1997), SWAT (Arnold et al., 1995), MIKE SHE (DHI, 1998), ANN-approach (Let et al., 1999) and the new version BASINS (USEPA, 2001). Parson et al. (2001) overviewed and estimated more than 14 currently widely used models, in terms of its general characteristics, validation and interfaces, simulated processes and contact information. Each model has its own limitations, however. While some models require large amounts of data, others incorporate numerous parameters. Large sets of good data are often unavailable and parameter calibration is always a great task and the weakest point in modelling (Jørgensen, 1999). Nikolaidis et al. (1998) summarized early the current models as lumped parameter models, whose parameters are difficult to estimate, as hydrologic conceptual models that overlook physical processes, as the models which ignore the groundwater flow or transport processes, and as event-based models that are useless for multiple rainfall-runoff events or continual base flow simulations.

Thus, an alternative and simple, integrated model such as the one examined in this paper, which has few parameters but describes most of the important processes, may prove useful for many sets of data. It is attractive to researches and planners for estimating the loadings from watersheds in environmental management. The model to be presented accounts for all the sources, is easy to use and understand (for instance, requires less knowledge of hydrology), requires few data and is easy to calibrate (very few parameters). However, the model probably yields in some cases, a less accurate estimation of non-point sources than most of the models mentioned above. Therefore, this model is mainly useful for prognoses, where the data have a large uncertainty, for instance for estimating future loadings.

Therefore, this paper introduces Jørgensen et al.'s (2003) integrated nutrient loading model and tests it against datasets from Glumsø Lake, Denmark, where annually measured loadings of nutrients and water from point and non-point sources were available from 1978, 1982 and 2000. The loadings from different sub-watersheds of the drainage area, i.e., from agriculture, forest and resident areas will be simulated by the model. A comparison of these results from different parts of the drainage area will also be made.

2. Materials and methods

2.1. The model

The Nutrient Loading Model (NLM) is one of the five models in the PAMOLARE (Planning And Management Of Lakes And Reservoirs) program package. The structurally dynamic model is the most sophisticated and has been tested by Zhang et al. (2003). NLM supplies the eutrophication models with assessment of daily loadings of organic matter and nutrients from point and non-point sources. It covers point nutrients from municipal and industrial wastewaters and from septic tanks, and non-point nutrients including those from watershed runoff and atmospheric deposition. An important feature of the model is that users can define parameters and state variables with measured results or use default values provided. In practice, some measurements are often available. In these cases, the measurements should be used as far as possible. Moreover, the model has very few parameters that need to be calibrated, and the processes in the model are simplified and easy for users to comprehend, as mentioned previously. The assumptions and equations in NLM are given below. A summary of the symbols and their definitions and some of their values used in the model are shown in Appendix A.

2.1.1. Nutrient loadings from wastewater

2.1.1.1. Municipal wastewater. The following default values are used in the model, if the observations are not applicable. The values are based on the water consumption among various countries.

1. 200-l water per capita is assumed for industrialized countries or recently industrialized countries with a low cost of water supply.
2. 180-l water per capita is assumed for industrialized countries with a medium-high cost of water supply (in some countries, there is a green tax on water consumption).
3. 150-l water per capita is used for industrialized countries with a very high cost of water supply (and wastewater treatment).
4. 100-l water per capita is applied for developing countries.

The different levels of water consumption per capita and the corresponding concentration of nutrients are given in Table 1.