Available online at www.sciencedirect.com
SCIENCE DIRECT®
Ecological Modelling 184 (2005) 37–53
ECOLOGICAL MODELLING
www.elsevier.com/locate/ecolmodel

Modelling nutrient emissions from river systems and loads to the coastal zone: Po River case study, Italy

L. Palmeri*, G. Bendoricchio, Y. Artioli

Dipartimento di Processi Chimici dell'Ingegneria, Universita di Padova, Via Marzolo 9, Padova 351131, Italy

Abstract

The nutrient emission model MONERIS (MOdelling Nutrient Emissions into River Systems) is applied to the Po catchment, a large (>70,000 km^2), densely populated, highly agriculturally exploited and industrialized landscape. The catchment is located in northern Italy. The Po River discharges into the northwestern Adriatic Sea. Model runs cover the period 1991–2000. The purpose is to model the catchment in 2001, estimating nutrient emissions and natural background in the basin and loads to the coastal area. The model was calibrated with data for the period 1990–1995. After validation with data for the period 1995–2000, the model is used to evaluate future catchment management scenarios.

MONERIS is a spatially distributed parameters steady state model with a time scale of 5 years. The emissions considered are originated from diffuse and point sources and delivered trough various pathways (groundwater, erosion, overland flow, atmospheric deposition, urban systems and WWTPs). In order to estimate nutrient loads to the river system, MONERIS includes a retention model.

An overview of model input requirements, data needs and related problems and solutions adopted is presented in the paper. Simulated and measured data of several sections along the river are compared for calibration and validation. The relative importance of different nutrient generation pathways are evaluated. Finally, forecasted yearly nutrient loads at the outlet of PO basin for the years 2001, 2008 and 2016, consequence of different basin management scenarios, are presented. The results are ready to be supplied to a water quality Coastal Zone Model, allowing us to evaluate significant switches in trophic state conditions of the coastal ecosystem [see Artioli, Y., Bendoricchio, G., Palmeri, L., this issue. Defining and modelling the coastal zone affected by the Po River (Italy). Ecol. Model.].

Keywords: Nutrient loads; Non-point source pollution; Catchments modelling; Water quality management

1. Introduction

The challenging problem of estimating nutrient loads from non-point sources (NPS) is of increasing interest, particularly since the endorsement of the European directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources (EEC, 1991).

Beforehand Zingales et al. (1984) proposed to apply conceptual mathematical models for screening and planning. This kind of models are based on mass

* Corresponding author. Fax: +39 049 827 5528.
E-mail address: lpalmeri@unipd.it (L. Palmeri).

0304-3800/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolmodel.2004.11.007

balance via an extension of Nash' conceptual scheme of rainfall–runoff transformations. The proposed model structure consists of a lumped parameter formulation that may serve as an alternative to empirical routing procedures. This approach was proven to be satisfactory when the estimation of loads is carried over long time scales, i.e. at least annual. In order to estimate solute loads (e.g. nitrate), the screening modelling technique was generalized by inclusion of production/removal processes of solute (Rinaldo et al., 1989).

An important source of uncertainty in mass balance models comes from discharge estimation. Complete and detailed experimental data on discharges in several gauging stations along the river, is highly recommended in order to allow better estimations of the water balance Abrahamsson and Håkanson (1998) proposed a stochastic approach for modelling seasonal flow variability in rivers, that may be helpful in case of lack of detailed data. However such approximations always generate significant uncertainties, especially in areas where artificial drainage and water abstraction is very relevant such as in the Po catchment.

GIS are useful tools for implementing screening models (Reiche, 1994). The detail of a GIS based model can be very high. Grizzetti et al. (2003) propose an implementation of the US-EPA model SWAT, taking into account with great detail all the processes involved in nutrient loads generation and transport in a river catchment. The short time scale and high spatial resolution of this model require great detail in experimental and spatial data, causing the model to become quickly unmanageable as the dimensions of the studied watershed increase.

The model proposed in this paper attempts on one side to reduce the uncertainties associated with water balance calculation, by including the existing knowledge on discharge in the model. Hence water balance is calibrated according to measured discharge values.

On the other side, in order to remain manageable on a large watershed, the application proposed is made over long time scales (yearly, i.e. much larger than the characteristic times of the hydrologic response) and with low spatial resolution (spatial data are aggregated into units that are sub-catchments with dimensions on the order of hundreds of km^2).

This approach, producing estimations of nutrient loads generated by considerably large river basins which are satisfactorily accurate (at least in the order of magnitude), at the same time permits to include in the model several socio-economical aspects. This last option, in connection with the use of an appropriate GIS base, is very useful in order to develop future watershed management scenarios (Grossman, 1994).

2. Materials and methods

MONERIS (MOdelling Nutrient Emissions into River Systems) is the model applied in the Po catchment area (POCAT). The model estimates nutrient loads originated from natural and anthropogenic sources in the basin. MONERIS has been developed by Behrendt (IGB, Berlin, Germany). A description of the general methodology can be found in Behrendt and Opitz (1999); for a detailed analysis of MONERIS, see Behrendt et al. (2000).

MONERIS is a steady state distributed parameters model with a yearly time step. The spatial scale is about a 100 km^2. As depicted in Fig. 1 the model calculates the loads generated by different sources: diffuse (concentration in topsoil and paved areas) and point sources (WWTP). The basis for emissions estimation from different pathways is the hydrologic balance. The model is organized through a set of interconnected spreadsheet files. There are three types of files: the input file BASICINFO in which all the data describing the simulated basins are collected. The calculation files (PATHWAYS) in which nutrient emissions from diffuse and point sources are estimated using mass balance and that contain the equations and parameters of the sub-models. Finally the results of the model are summarized in the file MONERIS.

Model application requires analytical, geographical and statistical data. The analytical data concern environmental monitoring programs of surface waters (nutrient loads and surface discharge) and meteorological gauges (rainfall, ET). The geographical data are obtained from digital maps (land use, soil type, location of WWTP, etc.), using GIS. Statistical data of population distribution in the catchment and agricultural surplus of nutrients are used. The input database is assembled into 11 sheets of the file BASICINFO. Each record in the sheets contains data concerning a single