Available online at www.sciencedirect.com
SCIENCE DIRECT®
Environment International 31 (2005) 1031 – 1039
ENVIRONMENT INTERNATIONAL
www.elsevier.com/locate/envint

The seasonal distribution of dissolved inorganic nitrogen and phosphorous in the lagoon of Venice: A numerical analysis

R. Pastres[a,*], S. Ciavatta[a], G. Cossarini[b], C. Solidoro[b]

[a]Dip. di Chimica Fisica, Univ. of Venice, Dorsoduro 2137, 30123 Venezia, Italy
[b]Istituto Nazionale di Oceanografia e di Geofisica Sperimentale OGS, Borgo Grotta Gigante 42/c 34016, Sgonico (Ts), Italy

Available online 1 July 2005

Abstract

This paper investigates the seasonal evolution of the spatial distributions of dissolved inorganic nitrogen and phosphorus, in relation to the estimation of the N and P loads, which were obtained in the framework of the DRAIN project. Such investigation is carried out by using a 3D reaction-diffusion model which has been calibrated against salinity data and then used for obtaining the most likely scenario of the spatial and seasonal distribution of DIN and DIP. The consequences of different management policies are also discussed, in relation to the current Italian legislation, which sets quality standards for both DIN and DIP in the lagoon of Venice.

Keywords: Seasonal distribution; Lagoon; Nitrogen

1. Introduction

Dissolved nitrogen and phosphorous are widely recognized as potential causes of the eutrophication of coastal water bodies (Cloern, 2002) and, therefore, the estimation of their loads is of paramount importance for a correct management of a coastal ecosystem. As far as the lagoon of Venice is concerned, the DRAIN project provided, for the first time, direct estimates of the loads which were delivered by the main tributaries in the years 1999–2000 (Zonta et al., this issue). These results represent an absolutely necessary baseline for assessing the effectiveness of future management interventions. However, the findings of the DRAIN project, on their own, do not enable one to establish a relation between the loads and their most direct effects on the ecosystem, that is on the nutrient concentration in the lagoon waters, since a systematic monitoring of DIN and DIP concentrations was not included in the project. The relations between N and P inputs and their concentration has important implications in regard to the management of the lagoon, since the current Italian legislation is based on the so-called Maximum-Permissible-Loads (MPLs) policy and, therefore, local authorities are asked to decide on the maximum loads of nitrogen and phosphorus which are compatible with the concentration thresholds of TDN and TDP prescribed by the law. Such relations can be explored by using transport-reaction mathematical models, as it was discussed in Pastres et al. (2003) and Pastres and Ciavatta (2005). In the first paper, local sensitivity analysis in respect to nitrogen sources is proposed as a quick method for obtaining estimations of the effects of management interventions on the average spatial distributions of DIN and related parameters, such as Chlorophyll *a*. In the second one, Monte Carlo techniques are applied to a simplified version of the model, in order to estimate the uncertainty in the average DIN concentration in the lagoon, in relation to the uncertainties in the loads and in the most important parameters of the model.

In this paper we used a 3D reaction-diffusion model in order to describe the seasonal evolution of the spatial distributions of DIN and DIP which were computed on the basis of an updated scenario of nutrient load, and to assess the effectiveness of alternative scenarios of reduction of the current values of the loads, in terms of both the decrease in the average DIN and DIP concentrations in the lagoon and

* Corresponding author. Tel.: +39 041 2348674; fax: +39 041 2348594.
E-mail address: pastres@unive.it (R. Pastres).

0160-4120/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envint.2005.05.013

in the fraction of the lagoon where the quality standards would not be met. Results also include the calibration of the transport part of the model for the grid used in this application, as it will be detailed later on.

2. The mathematical model

Since DIN and DIP can not be treated as conservative tracers because of their interactions with the biota, realistic simulations of the seasonal evolutions of the spatial distributions of DIN and DIP in a coastal ecosystem can be obtained only by means of transport-reaction models, in which both the dispersion processes and the main trophic processes are taken into account. The basic structure of the 3D reaction-diffusion numerical model which has been used in the present analysis is described in a number of papers (Pastres et al., 1995; Solidoro et al., 1996; Pastres et al., 2001; Solidoro et al., 2004). The model covers the entire lagoon and simulates the seasonal evolution of a set of variables which characterize the state of the water column and of the surface sediment. The state of the water column is defined by the vector $\boldsymbol{c}_{\mathrm{w}}$ whose components are: water temperature, concentrations of ammonia, nitrate, reactive phosphorus and dissolved oxygen, concentrations of carbon, nitrogen and phosphorous as dissolved organic matter and the densities of the phytoplanktonic and zooplanktonic pools. The state variables associated with the surface sediment, which are carbon, nitrogen and phosphorous as organic fractions, represent the components of the vector $\boldsymbol{c}_{\mathrm{s}}$. They were introduced in the model in order to describe the remineralisation of the macronutrients, nitrogen and phosphorous, and the oxygen consumption that is related to this process.

The evolution of the vector $\boldsymbol{c}_{\mathrm{w}}$ is computed by solving the reaction-diffusion Eq. (1.a):

$$\partial \boldsymbol{c}_{\mathrm{w}}(x,y,z,t)/\partial t = \nabla(\boldsymbol{K}(x,y,z)\nabla \boldsymbol{c}_{\mathrm{w}}(x,y,z,t)) + \boldsymbol{f}_{\mathrm{w}}(\boldsymbol{c}(x,y,z),\beta,t). \tag{1.a}$$

In Eq. (1.a), $\boldsymbol{c}$ is the state vector, which is formed by the components of $\boldsymbol{c}_{\mathrm{s}}$ and $\boldsymbol{c}_{\mathrm{w}}$, $\boldsymbol{K}$ is the space-dependent tensor of eddy diffusivities, $\boldsymbol{f}_{\mathrm{w}}$ is the reaction term and β the set of site-specific parameters.

Eq. (1.a) is solved by using a finite-difference scheme. In this application, constant grid sizes equal to $\Delta x=\Delta y=300$ m, $\Delta z=1$ m were used, in order to reduce the computational burden. The components K_{zx} and K_{zy} of the diffusivity tensor are null everywhere, but the component K_{xy}, in general, is not, so that fluxes along x directions depends also on the gradient along the y one, and vice-versa.

No transport is considered in the sediment phase and therefore the state equation for $\boldsymbol{c}_{\mathrm{s}}$ reads as:

$$\mathrm{d}\boldsymbol{c}_{\mathrm{s}}(x,y,z,t)/\mathrm{d}t = \boldsymbol{f}_{\mathrm{s}}(\boldsymbol{c}(x,y,z),\beta,t). \tag{1.b}$$

The reaction terms of Eqs. (1.a) and (1.b) are presented in Table 1. The formulations used and the values of the parameters are reported in the above mentioned papers, and are summarised in Solidoro et al. (2005), in which also the setup of the model and the calibration of the water quality module are described in details.

2.1. Calibration of the eddy diffusivity tensor

As it is explained in Pastres et al. (2001), the model does not include explicitly the advective transport. However, the horizontal components of the diffusivity tensors embody information about the contribution of the tide to the dispersion, as they were estimated at each grid point on the basis of a statistical analysis of the results of a lagrangian particle dispersion model (Pastres et al., 2001). Unfortunately, up to now it was not possible to calibrate this part of the model against experimental data, since accurate estimation of freshwater discharges were not available. Now, thanks to the new database provided by the DRAIN project, it is possible to improve the estimates of the horizontal diffusivities through a quantitative comparison between observed and computed spatial distribution of salinity, taken as a passive tracer. Under this hypothesis, the governing equation is obtained from Eq. (1.a) by setting the reaction term to zero, or, more explicitly:

$$\partial \boldsymbol{S}(x,y,z,t)/\partial t = \nabla \begin{bmatrix} \Phi_x \\ \Phi_y \\ \Phi_z \end{bmatrix} = \nabla \begin{bmatrix} K_{xx} & K_{xy} & 0 \\ K_{yx} & K_{yy} & 0 \\ 0 & 0 & K_{zz} \end{bmatrix} \begin{bmatrix} \nabla S_x \\ \nabla S_y \\ \nabla S_z \end{bmatrix}. \tag{2}$$

The calibration was carried out on the assumption that the previous estimates of the components of the eddy-diffusion tensor were "correct" up to a scaling factor, α, since they were obtained from a statistical analysis of an average velocity field. Accordingly, the horizontal components were expressed as:

$$K_{xx}(x,y) = \alpha K'_{xx}(x,y) \quad K_{yy}(x,y) = \alpha K'_{xx}(x,y) K_{xy}(x,y) = \alpha K'_{xy}(x,y) \tag{3}$$

where the prime indicates the diffusivities estimated in Pastres et al. (2001).

Since salinity data concerning the year 1999 were not available, the calibration of the horizontal diffusion coefficients was carried by comparing the model output with a set of data which was collected in 2001, within the framework of a comprehensive 3-year-long monitoring program (Solidoro et al., 2004). The program, named "MELa1", began in September 2001 and was carried out by the Consorzio Venezia Nuova on behalf of the Venice Water Authority. The monitoring network was made up of 30 stations, evenly distributed in the whole lagoon. The concentrations of 24 water quality and trophic parameters and of eight trace metals in the water column were determined. Samples were taken approximately every 4 weeks, in neap tide conditions.