Ecological Modelling 320 (2016) 393–406

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Evaluation of ecological effects of anthropogenic nutrient loading scenarios in Los Molinos reservoir through a mathematical model

S.B. Rodriguez Reartes[a,*], V. Estrada[a], R. Bazán[b,c], N. Larrosa[c], A. Cossavella[c,d], A. López[c,d], F. Busso[e], M.S. Diaz[a]

[a] Planta Piloto de Ingeniería Química (Universidad Nacional del Sur—CONICET), Camino La Carrindanga km 7, 8000 Bahía Blanca, Argentina
[b] ISEA, Instituto Sup. de Estudios Ambientales, Córdoba, Argentina
[c] Dpto. Qca. Industrial y Aplicada, Fac. Cs. Exactas, Físicas y Naturales—UNC, Av. Vélez Sarsfield 1611, 5000 Córdoba, Argentina
[d] ICTA, Instituto de Ciencia y Tecnología de Alimentos, FCEFyN - UNC - Córdoba, Argentina
[e] Aguas Cordobesas S.A., Córdoba, Argentina

ARTICLE INFO

Article history:
Received 22 April 2015
Received in revised form 12 October 2015
Accepted 13 October 2015

Keywords:
Ecological model
Scenario development
Prospections
Dynamic parameter estimation
Validation
Water planning

ABSTRACT

In this paper we perform a scenario analysis to assess the likely ecosystem structural shifts that might be induced by seven alternative management scenarios relative to current simulated lake dynamics of Los Molinos reservoir, a monomictic lake located in Argentina. To carry out the scenario analysis, first, we formulate, calibrate and validate a mechanistic biogeochemical model to characterize the nutrients and phytoplankton dynamics of the reservoir under study. The model includes a set of partial differential algebraic equations, which results from dynamic mass balances on main phytoplankton groups, nutrients, dissolved oxygen and biochemical demand of oxygen. We consider the main sources of nutrient loading and the dominant phytoplankton groups. The parameter estimation model is a constrained dynamic optimization problem that has been formulated within an equation oriented control vector parameterization environment. We estimated sixteen parameters, previously identified as the most influential ones. Numerical results for calibration and validation phases show good agreement with field data, and then, we use the proposed model as a prospective tool. The obtained results for the designed nutrient loading scenarios indicate the importance of the impacts of current livestock practices and sewage/collective septic tanks discharges on the water quality. Model predictions indicate that the combination of reduction in nutrient loading from the sewage of residential areas in the lake shore, and implementation of measures to mitigate nutrient exports from livestock production will render the most beneficial effects over the studied ecosystem, thus promoting the improvement of the current ecological state of the reservoir. This is the first time such an approach has been applied to the study of Los Molinos catchment. Thus, the proposed ecological model constitutes a management tool to assess the anthropogenic impacts over this freshwater resource.

1. Introduction

Mechanistic biogeochemical models represent the biological, chemical and physical processes taking place in aquatic ecosystems. These models are formulated as a complex set of differential algebraic equations with rate coefficients that must be tuned to the specific conditions of the site under study (Jørgensen and Bendoricchio, 2001). After determining the most influential parameters into the model, dynamic parameter estimation must be performed and the model performance to represent the real ecosystem has to be validated with an independent data set from the site (Bennett et al., 2013; Jørgensen and Bendoricchio, 2001).

In a previous work, we have formulated a first principle based eutrophication model (Estrada et al., 2009), and we have also performed sensitivity analysis (Estrada and Diaz, 2010). The latter model was posed for Paso de las Piedras Reservoir and considered the dominant phytoplankton groups and nutrients present in this water body (Estrada et al., 2009). In the current work we extend Paso de las Piedras model to take into account the particular phytoplankton community, nutrient loading and hydrodynamic regimes and forcing functions existing in Los Molinos Reservoir. Los Molinos Reservoir is a multipurpose freshwater resource providing water for domestic supply, irrigation, energy generation, fishing and recreational activities, located in the Central Region of Argentina (Bazán, 2011). Field data collected between 2002 and

* Corresponding author. Tel.: +54 291 4861700.
E-mail address: brodriguez@plapiqui.edu.ar (S.B.R. Reartes).

http://dx.doi.org/10.1016/j.ecolmodel.2015.10.028
0304-3800/

2005 have allowed classification of the water body as mesotrophic. However, during the last decade, periodic monitoring of the water body allows to detect algal blooms, fish kill events and nutrient enrichment (Bazán, 2011; Cossavella, 2003). These facts evidence the shift of the reservoir state towards eutrophic, unless management measures are undertaken. Moreover, it is a well known fact that phytoplankton blooms in the fresh water source may affect the water treatment process, both physically (e.g. filter clogging) and chemically (e.g. production of harmful cyanotoxins, taste and odour compounds and disinfection by-products). In short, high phytoplankton concentrations in the source water increase the complexity and cost of the raw water treatment process (Ewerts et al., 2013).

Mechanistic biogeochemical models have been widely used for understanding aquatic ecosystems, predicting biotic responses to shifts in the driving forces (nutrient enrichment scenarios, climate change) and assessing restoration strategies for water bodies (Osidele and Beck, 2004; Zhang et al., 2004). Moreover, water quality modelling provides a range of approaches to support water resource management. One approach is to apply physically-based models for assessing water quality in catchments (Matias et al., 2008). These models produce results with limited input requirements allowing catchment assessment and management (Matias and Johnes, 2012). Provided that enough site-specific input data is available, such as to enable model parameter tuning, mechanistic models can also be applied for management purposes. The idea behind using these more complex models as management tools is the possibility of evaluating different nutrient loading scenarios over algae growth, nutrient concentrations and the entire ecological structure. In other words, the use of models in environmental management allows predicting the effect of a given change on the ecosystem under study in a wider extent.

In this context, the aim of this work is to assess the likely impact of a range of alternative management scenarios on nutrient loading in the short and middle term over Los Molinos reservoir ecosystem. The effects of each considered scenario over the trophic state and phytoplankton dynamics is analyzed. To achieve this goal, we formulate a water quality model that fits site-specific conditions of Los Molinos Reservoir. Then, we evaluate the model performance through qualitative and quantitative diagnostic measures (Bennett et al., 2013). Based on field data, we also determine the reservoir current trophic state.

2. Materials and methods

2.1. Case study

Los Molinos Reservoir is an artificial water body located at 65 km SW of Córdoba city in Argentina (31°43′30″S y 64°32′20″W). It was constructed between 1948 and 1953 for drinking water supply, hydro electrical energy generation, irrigation and flood attenuation. The reservoir has a mean depth of 14 m, a maximum depth of 52 m, an area of 21.1 km^2 at spillway level and a maximum volume of 400 hm^3. Its retention time has been estimated in 451 days. Its main tributaries are: San Pedro River, Los Espinillos River, del Medio River and Los Reartes River. Its effluent is Los Molinos River (see Fig. 1). Los Molinos is a monomictic lake, thermally stratified during summer (Bazán, 2011).

The power plant Los Molinos I generates 148 MW for the Central Region of Argentina. The reservoir supplies drinking water to half a million people of Córdoba city (one third of the population of that city). Currently, this water body represents a major tourist attraction for the region and is also used for recreational activities like fishing and water sports. The main activities performed in the basin are related to agriculture and livestock.

The watershed of Los Molinos Reservoir extends over an area of 978 km^2. In the last decade there has been an important urban development in the lakeshore area, as well as tourism increase. According to a census made in 2008 (Censo Provincial de Población, 2008—Provincia de Córdoba), there are 3500 people that permanently inhabite in the four main lakeshore villages: Potrero de Garay, Villa Ciudad de América, Los Reartes and Ciudad Parque Los Reartes. Census data also reveal that the treatment of domestic wastewater in the region is made through septic tanks and cesspools, which result inefficient due to soil characteristics of the area, and to the proximity of the dwellings to the reservoir (less than 50 m from the coast for some buildings) (Nadal et al., 2012). Moreover, in some cases, the direct discharge of the domestic effluents, i.e. without previous treatment, is performed. Additionally, a great number of tourists visit the area every year; and during summertime the population doubles in the area (Molinero Rodríguez, 2008). Around 300 animals (cows and horses) graze in the west coast of the reservoir and use it as drinking trough (Nadal et al., 2012) providing a direct discharge of their manure into the water body.

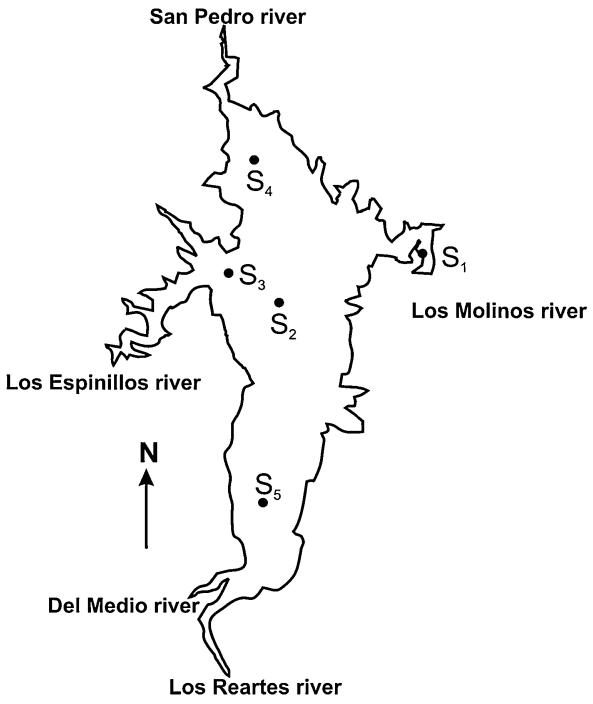

Fig. 1. Los Molinos Reservoir location. S1, S2, S3, S4 and S5: sampling stations.

The lack of land-use policies related to urbanistic development in the area, together with the inappropriate household wastewater treatment, promote nutrient enrichment of the water body (Nadal et al., 2012), especially phosphorus, which constitutes one of the essential factors for phytoplankton growth. Therefore, having a tool to assess the impact of human activities over this ecosystem is critical to the management of the water resource.

2.2. Sampling and experimental procedures

Physico-chemical and biological data have been monthly collected from January to December of 2007 and 2008 at different depths in five sampling stations (Bazán, 2011): S_1 (in the dam of the reservoir), S_2 (in the center of the water body), S_3 (in the mouth of Los Espinillos River), S_4 and S_5 in coastal zones (in the mouth of San Pedro and Los Reartes River, respectively), see Fig. 1. Sampling was performed at different depths considering the mixing and stratified periods. During the mixing regime, samples were taken at 0.2 m, at the limit o photic zone (considered as twice the Secchi disk depth), and 1 m from the lake bottom. When a thermocline was detected,