FORECASTING THE EUTROPHICATION OF IZVORUL MUNTELUI LAKE

Gabriela Elena DUMITRAN[1], Liana Ioana VUȚĂ[2]

One of the priority directions of European policies in water framework is to assure a good quality of waters, and, as a result, a great interest is showed in diminishing the eutrophication phenomenon which spread more and more and affects lots of aquatic ecosystems. Eutrophication effects on the water quality are very severe, waters can become even inappropriate for certain purposes. This paper presents the study of water quality indicators for the lake Izvorul Muntelui, the characterization from the eutrophication point of view.

The purpose of this paper is to presents a forecast of the phenomenon of eutrophication found in Izvorul Muntelui Lake the largest artificial lake on the interior waters of Romania, based on the current data on water quality. The forecast is done by considering the ecosystem dynamic and the stipulation of the spatial and temporal variation domains for the natural processes to appear and act onto perturbation factors to modify the ecological succession.

Having the evolution of quality indicators from the lake as a starting point, a theoretical study will be carried out, that it will refer to the elaboration of a model, which refers to the way a lake ecosystem works. It will allow numerical simulations of the eutrophication process. The relative error of model estimates was below 20% for all of the water quality parameters (total nitrogen, phytoplankton and herbivores zooplankton).

Keywords: lake, water quality, eutrophication, model.

1. Introduction

Nowadays, since pollution has become a social and economical problem, the urge to use the technical and scientifically developments is crucial. Numerous studies have been undertake in order to identify the right methodology /methods/ models for different aspects of specific pollution. One of the most important scientific areas in pollution is represented by the organic pollution of water bodies [1].

Eutrophication represents the enrichment of water with nutrients, primarily phosphorus and nitrogen which usually leads to enhanced plant growth. These

[1] Lect., Power Engineering Faculty, University "Politehnica" of Bucharest, Romania

may occur as a result of thropogenic changes (cultural eutrophication) or as a result of succession, the natural aging of a lake (natural eutrophication).

An eutrophic lake is subject to algae blooms, and, as a result, the water become more turbid, the anoxic condition (low concentration of oxygen) appear, and the carbon dioxid concentration and the pH value are modified. All those changes determine an alteration of organisms quantities and even of their quality (the valuable species disappear and the ordinary ones are mounting), and the amenity value of the water decrease (e.g. it may become unusable) [2].

Many aquatic ecosystems have become more eutrophic over the past decade as anthropogenic inputs of nutrients increase [3]. So, several models have been already developed, involving hydrodynamics, plankton food web and nutrient cycles, shellfish biomass and growth and macrophyte populations [4]. In this context, the aim of this paper is to quantitatively evaluate changes in lake function resulting from an inappropriately use focus especially to the nutrients. The dynamics of phosphorus are of special interest since; in general, phosphorus is the limiting nutrient during most of the year in most lake ecosystems.

This paper presents an ecological model, which simulates five constituents (total nitrogen, total phosphorus, phytoplankton, zooplankton and detritus) for Lake Izvorul Muntelui, which is the largest artificial lake on the interior waters of Romania. It is primarily used to generate hydroelectricity at the Bicaz-Stejaru hydro-plant. The lake has a length of 40 kilometers, an area of 33 km^2, and a maximum volume of 1,230 million m^3. During the last years, high concentrations of nutrients (phosphorus, nitrogen) and algal biomass have been recorded occasionally, which amplified the deterioration of water quality and generated an eutrophication tendency of the lake.

2. Experimental data

The multiannual study of hydrochemical processes in the lake allow to frame the lake in the oligotrophic category, based on its high oxygenation rate, the low content of organic matter, the low nutrients quantity and the water weakly alkaline reaction [5].

In the Izvorul Muntelui Lake, the chlorophyll (Fig.1) varies between 3.22 and 8.38 mg/m^3 during summer, corresponding to mesotrophe-eutrophe lakes with tendencies toward hypertrophy in hot season. The phytoplanktonic biomass value place the lake into eutrophic category, while the total mineral nitrogen and the total phosphorus, correlated with the phytoplanktonic biomass value, place the lake in the mesotrophic category[6].

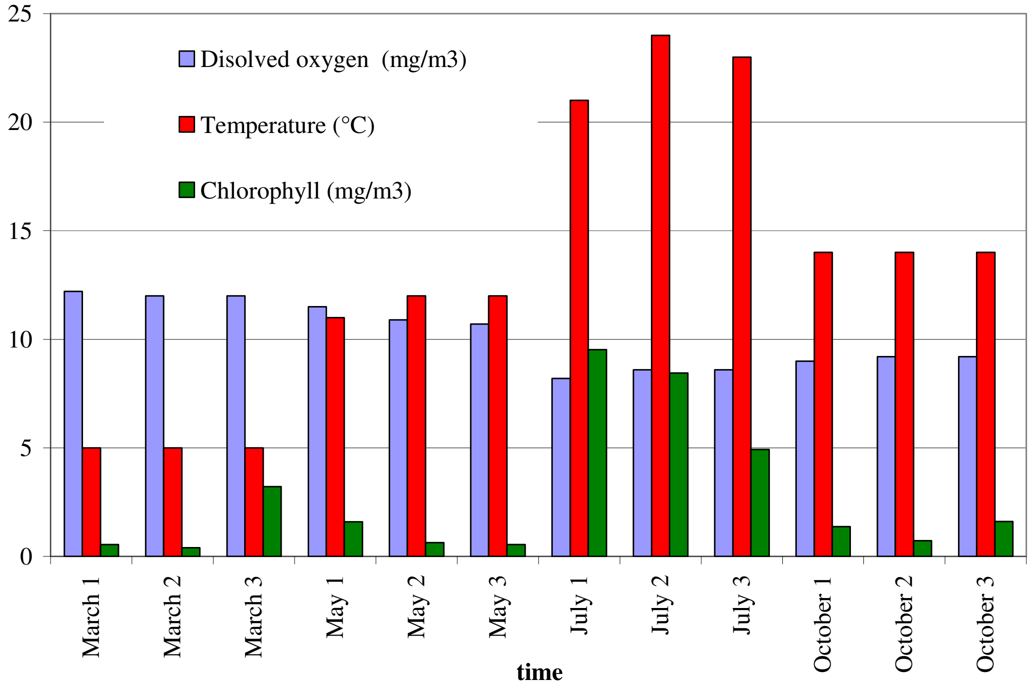

Fig. 1. Experimental values of water temperature, biomass and dissolved oxygen concentration in Izvorul Muntelui Lake

A very significant biological phenomenon, with multiple effects onto water quality is the algae bloom. This is due to the basin eutrophication and to the temporary rise (sometimes of large proportions) of planktonic algae role in the entire ecosystem [7].

Due to the large area of the lake and to the great water volume in the lake, water stagnation is favored. The thermal stratification of water and the penetration of light are the main factors that determine the dynamics of the vertical distribution of phytoplankton. The general tendency of the vertical distribution of the total amount of phytoplankton is a gradual decrease from surface to the bottom of the basin. The temporal variation of the amount of living algae from the phytoplankton has maximum values during the hot period of the year (June-October) [7]. In general, the total algae number decrease from the lake tail towards the bottom, while the living algae are increasing from the lake tail towards the middle and bottom parts of the lake, along with the improvement of the limnological conditions.

Observations have allowed ascertaining that in Izvorul Muntelui Lake the yearly development of the zooplankton does not have a uniform variation. The changes are manifested perhaps most graphically in relation to the succession of the season. Changes occurring during the year affect, on one hand, the water quality and, on the other hand, the quantity of zooplankton. During the year, two peak periods are usually recorded: first one appears at the end of May, as a result of a high increase of phytoplankton due to rising of the period light and intensity of light, water temperature and so on; the second peak appears in the autumn (September) and is related with the next maximum of algae quantity. The zooplankton distribution is presented in Fig. 2.

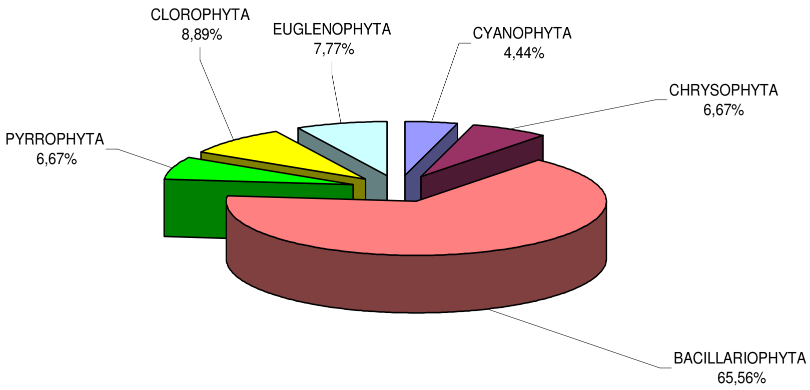

Fig. 2. Dinamic of zooplankton in Lake Izvorul Muntelui.

3. Eutrophication model

The most common modeling approaches of eutrophication of lake are based mostly on steady-state input-output equations [8]. For the mass-balance, generally, the nutrient concentration is calculated from inputs, and chlorophyll a concentration or another indicator of phytoplankton biomass is predicted by correlation with the limiting nutrient, more often phosphorus. An alternative is the process-oriented water quality models, which include chemical/biological interactions usually not taken into account in mass balance models [9]. Furthermore, the assumption that a lake is a continuously mixed system is very restricted and only applicable at discrete times of the year [10].

The proposed numerical model permits to estimate the evolution of nutrient content and algal biomass in the case of a lake ecosystem. The conceptual model concerns a lake which are considerate a close aquatic system and analyze a simply food web (the nutrients, a primary producers and one secondary consumers). The equations describing those interactions are specific to the prey-predator relations. Thus, the evolution of each food web constituent is conditioned by the presence or absence of the other constituents.

The state variables of the model are total phosphorus (P), algal biomass (A) and herbivore zooplankton (Z). For simplicity, we consider the steady-state and we assume that flow velocity is constant and equal to the mean value. The governing equations are based to the mass conservation law applied for algal biomass, zooplankton and total phosphorus [11]:

$$\frac{\partial A}{\partial t} = \left(k_{\max} \times \frac{P}{P + k_{SP}} - k_{ra} \right) \times A - c_{za} \times A \times Z \,, \tag{1}$$

$$\frac{\partial Z}{\partial t} = \left(a_{ca} \times \varepsilon \times c_{za} \right) \times Z \times A - k_{dz} \times Z \,, \tag{2}$$

$$\begin{aligned} \frac{\partial P}{\partial t} &= a_{pa} \times (1-\varepsilon) \times c_{za} \times Z \times A + a_{pc} \times k_{dz} \times Z - \\ &- a_{pa} \times \left(k_{\max} \times \frac{P}{k_{SP}} - k_{ra} \right) \times A \end{aligned} \,, \tag{3}$$

where t represents temporal coordinate, $k_{\max}$ is the maximum rate of pkytoplankton growth (day^{-1}), k_{SP} are the halfsaturation constants of phosphorus, k_{ra} and k_{dz} are the loss phytoplankton respectively zooplankton rate which include respiration, excretion, natural mortality (day^{-1}), c_{za} is specific zooplankton predation rate, (m^3/mgC day), a_{ca} is phytoplankton carbon – chlorophyll ratio (mgC/mgChl), ε is zooplankton assimilation efficiencies, a_{pa} and a_{pc} represents phosphorus – phytoplankton transformation rate (mgP/mgChl) and a_{pc} is phosphorus – carbon transformation rate (mgP/mgC). The initial conditions of the equations (1) – (3) are $A = A_0$, $N = N_0$ and $P = P_0$, where A_0, N_0 and P_0 represents the experimental values of state variables in lake. The growth algal rate k_c that appears in the equations (1) – (3) depends on the water temperature, solar radiation intensity and also on the concentration of nutrients (in the present case phosphorus). For relatively brief periods (for example, one month) the model can be simplified assuming that the variations of the growth algal rate k_{c} with temperature T and solar radiation intensity I are disregarded [12 - 13]. Moreover, in this model the herbivore zooplankton grazing by the next trophic level organism is neglected.

The ecological model considers phytoplankton production and loss due to respiration, excretion, mortality process and grazing of herbivorous zooplankton. The effects of ingested food quality and quantity on zooplankton gross growth efficiency have been considered using a dynamic parameterization. Zooplankton basal metabolism and ingestion of excess phosphorus during feeding process release phosphate and dissolve and particulate organic phosphorus [14].

4. Results and discussion

Based on the presented model, the computation of nutrients, algal biomass and herbivore zooplankton distributions and is done for a stratified lake and assuming that the water temperature T is constant and equal with 20^{0}C.

The model was calibrated with data from 2007 and 2008 in the Izvorul Muntelui Lake. The calibration of the eutrophication model was realized by fine tuning of the model parameters within their observed literature ranges [15 - 16]. The kinetic coefficients and value used in model are presented in the Table 1. The calibration procedure required a balance between phytoplankton growth and disparities of available nutrients from the water column. Particular attention was placed on the dynamics of phosphorus as this nutrient was the main one limiting phytoplankton biomass in Izvorul Muntelui Lake. The validation of model was made for 2 months (60 days) in 2008 summer, from May until July.

Table 1.

Values of used model parameters.

Parameter	Value	Parameter	Value
k_{max} [day^{-1}]	0,3	a_{ca} [mgC/mgChl]	40
k_{ra} [day^{-1}]	0,285	ε [-]	0,6
k_{SP} [mgP/m^3]	2	k_{dz} [day^{-1}]	0,1
c_{za} [m^3/mgC day]	0,0015	a_{pa} [mgP/mgChl]	1

The model reproduces temporal distribution of concentration of water quality constituents such as phosphorus, phytoplankton biomass and herbivore zooplankton. The calculated concentrations for phosphorus, phytoplankton and herbivore zooplankton presented in Fig. 3 agree well with experimental data.

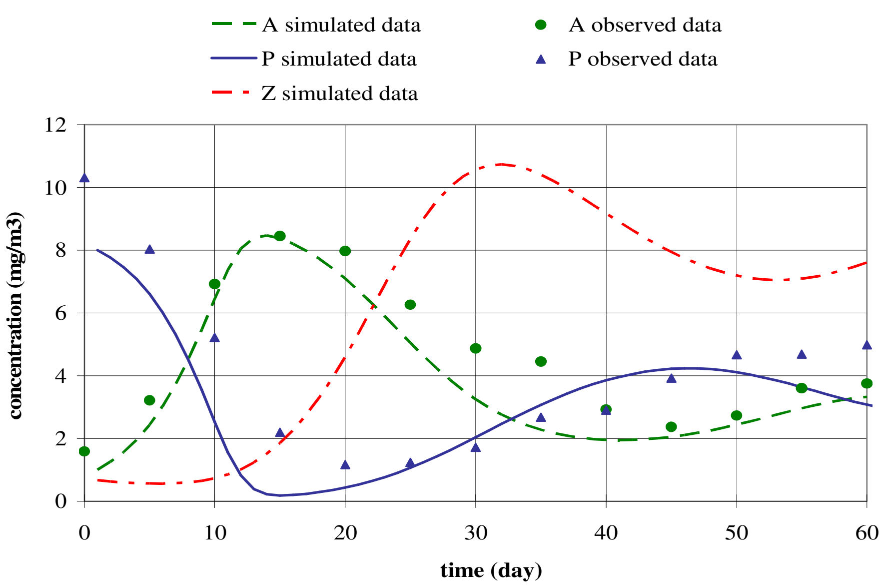

Fig. 3. Comparison between simulated and observated values for Lake Izvorul Muntelui.

Fig. 3 shows that the distribution of phytoplankton is a complex mix of limiting effects induced by availability of nutrients, and density stratification. When the water column was well mixed, phytoplankton concentrations were nearly evenly distributed vertically.

Tracking the evolution of the algae biomass, it can be noticed that once the summer stratification appear, the phytoplanktonic species increase. Therefore in late May the first pick of algae biomass appear, closely related to the main nutrient consumption in the water body. Reduction of primary production takes place mainly due to predation by zooplankton processes and decrease of phosphorus in water. Thus, the concentration of phosphorus in the lake falls below the limit and therefore phosphorus is becoming limiting factor for algal biomass. Zooplankton achieves the maximum concentration several days before the phytoplankton. This is a natural evolution, as long as the amount of food available for this trophic level was higher. Once the primary production slows down, intensive processes of death, sedimentation and main nutrient recirculation appear in water, resulting in rising of the available nutrients in water. This lead to a second phytoplankton bloom, registered at the end of the summer. Assuming the lake like a closed system implies the conservation of mass in the ecosystem. Thus, numerical results obtained were converted into equivalent carbon units which can be compared directly and permit to check the mass conservation in the system at each time step.

The relative error of model estimates was below 20% for all of the water quality parameters (total nitrogen, phytoplankton and herbivores zooplankton).

6. Conclusions

An ecological model was configured for the Izvorul Muntelui Lake from Romania. The model was calibrated and validated with data from 2007 and 2008 in the Izvorul Muntelui Lake. The food web structure of the model makes it possible to relate alternative managerial scenarios and associated nutrient loadings with compositional shifts in the plankton community.

The model reproduces spatial and temporal concentration distribution of water quality constituents such as phosphorus, phytoplankton biomass and herbivore zooplankton. The comparison between calculated results and field data are reasonably consistent. The values of the kinetic coefficients obtained from model calibration and validation analyses are consistent with the values reported in the literature.

Analyzing the recorded data and the numerical results allow to appreciate that the eutrophication phenomenon is related to large amount of phosphorus. The restoration of Izvorul Muntelui Lake can be based on phosphorus inactivation or artificial circulation.

This approach can be improved by considering the variations in temperature and solar radiations intensity in water and also taking into account the hydrodynamic water flow.

R E F E R E N C E S

[1]. *Gabriela E. Dumitran,* Elemente de ecologie pentru ingineri (Ecological notion for enginering), Editura Politehnica Press 2008.

[2]. *Gabriela E. Dumitran,* "Modelarea hidrodinamica, termica si biochimica a calității apei in lacuri de talie mica". Rev. Chim, **vol. 47**, nr.10, 2004, pp. 20-27.

[3]. *D .Magnus, I.W. David, L. Hakanson*, "A combined suspended particle and phosphorus water quality model: Application to Lake Vanern", Ecol. Model., **vol. 190**, 2006, pp. 55–71.

[4]. *G. B. Arhonditsis, M. T. Brett*, "Eutrophication model for Lake Washington (USA), Part I. Model description and sensitivity analysis", Ecol. Model., **vol. 187**, 2005, pp. 140–178.

[5]. *Malmaeus, J. Hakanson, L.*, "Development of a lake eutrophication model", Ecol. Model., **vol. 171**, 2004, pp.35–63.

[6]. *Gabriela E. Dumitran, Liana Vuță*, "Study on Lake Izvorul Muntelui rehabilitation", Proceedings of the 3rd International Conference on Sustainable Energy&Environmental Protection – Part I, Glasnevin Publishing, Dublin, Ireland, 2009, pp.374 – 379.

[7]. *S.C. Chapra*, *R.P.Canale*, "Long-term phenomenological model of phosphorus and oxygen for stratified lakes", Water Res. **vol. 25**, no.6, 1991, pp. 707–715.

[8]. *R. Popa*, Modelarea calității apei din râuri (Water quality modeling for river systems), Editura H*G*A* Bucureşti, 1998.

[9]. *S.E. Jørgensen*, "State-of-art of ecological modeling with emphasis on development of structural dynamic models", Ecol. Model. **vol. 120**, 1999, pp.75–96.

[10]. *G. B. Arhonditsis, M. T. Brett*, "Eutrophication model for Lake Washington (USA), Part II. Model calibration and system dynamic analysis", Ecol. Model., **vol. 187**, 2005, pp. 179–200.

[11]. *Gabriela E. Dumitran,* "Brădişor Lake restoration affect to eutrophication process", U. P. B. Sci. Bull., series D, **vol. 70**, no.4, 2008, pp. 241 – 250.*S.C. Chapra*, Surface Water – Quality Modeling, McGraw-Hill, New York, 1997.

[12]. *S.E. Jorgensen, L. Kamp-Nielsen., L.A. Jorgensen*, "Examination of the generality of eutrophication models", Ecol. Model., **vol. 32**, 1986, pp. 251-266,

[13]. *J-T. Kou, W-S. Lung, C-P. Yang and al*, "Eutrophication modelling of reservoirs in Taiwan", Environmental Moddeling&Software, **vol. 21**, 2006, pp. 829-844.

[14]. *G. Schladow S. G., D.P. Hamilton*, "Prediction of water quality in lakes and reservoirs: Part I- Model description", Ecol. Model., **vol. 96**, 1997, pp. 91–110.

[15]. *G. Schladow S. G., D.P. Hamilton*, "Prediction of water quality in lakes and reservoirs: Part II- Model calibration, sensitivity analysis and application", Ecol. Model., **vol. 96**, 1997, pp. 111–123.