STUDY ON STANCA-COSTESTI LAKE EUTROPHICATION PROCESS – CAUSES, EFFECTS AND MANAGEMENT SOLUTIONS

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

The purpose of this paper is to presents a forecast of the phenomenon of eutrophication found in Stanca-Costesti Lake, based on the current data on water quality. The model reproduces spatial and temporal concentration distribution of water quality constituents such as differed forms of nutrients and plankton biomass. 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 nutrients.

Keywords: lake, water quality, eutrophication, model.

1. Introduction

In the present the most important aspects of surface water pollution are increasing global primary production of bodies of water due to large amount of nutrients, called eutrophication. These 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 [1]. 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). The effects induced by the occurrence of this phenomenon on water quality are severe, so that they may become unsuitable for some uses.

Many aquatic ecosystems have become more eutrophic over the past decade as anthropogenic inputs of nutrients increase. So, several models have

[1] Lecturer, Power Engineering Faculty, University POLITEHNICA of Bucharest, Romania,e-mail: l_vuta@yahoo.com
[2] Lecturer, Power Engineering Faculty, University POLITEHNICA of Bucharest, Romania, e-mail: dumitran@hydrop.pub.ro

been already developed, involving hydrodynamics, plankton food web and nutrient cycles, shellfish biomass and growth and macrophytes population.

Global existence of a large percentage of lakes with eutrophication problems, demands a predictive tool for the quality of these ecosystems [2 This paper presents an ecological model, which simulates four constituents (total nitrogen, total phosphorus, phytoplankton and zooplankton) for Lake Stanca-Costesti.

In this context, the aim of this paper is to quantitatively evaluate changes in lake function resulting from an inappropriately use and focus especially on 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.

2. Case study

Lake Stanca-Costesti is the largest artificial lake of Romania and it was created after the completion of a dam built on the Prut River during 1972-1975 and now it's a border crossing point between Romania and Moldova. This lake has a complex use and serve for regularization of Prut river flows for irrigation, domestic and industrial water supply, fishing, allowing the flood attenuation, generation of hydroelectricity at the Stanca-Costesti hydro-plant and ensure the navigation water levels on the Prut river, downstream the hydraulic node, in the path length limits agreed by both parties. The lake has a length of 90 km, a large area of 590 km^2 which leads to maximum volume of 1400 million m^3 and a maximum depth of 43m. Under the agreement between the two countries, the total flow needed for drinking and industrial water supply should be 10 m^3/s (314 million m^3) - 5 m^3/s (157 million m^3) for uses on the right side and 5 m^3/s (157 million m^3) for uses on the left side.

The reservoir physical characteristics have been substantially changed [3], so it is a heavily modified water body. The measurement frequency of physicochemical and biological data is in agreement with European norms.

Therefore the experimental data represents the integrated samples from the dam section, middle and tail of the lake.

Figure 1 presents the observed values for the mean temperature of water, the dissolved oxygen concentration and the phytoplankton density in lake. Thus, the temperature was between 2 °C and 28 °C and the saturation on the dissolved oxygen varied between 48%, in summer 2009, and 108.2 %, in summer 2010.

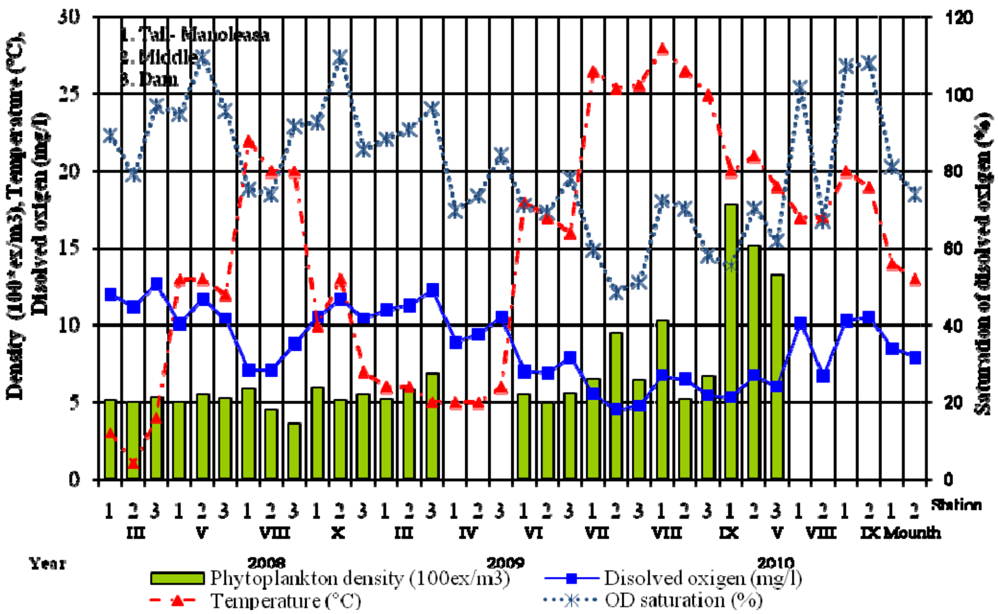

Fig. 1. Experimental values of water temperature, dissolved oxygen and biomass concentrations.

Concerning the evolution of nutrients content, the total mineral nitrogen concentration varies between 0.56 and 2.18 mg/l, while the total phosphorus concentration changes from 0.013 to 0.08 mg/l. Also, in the Stanca-Costesti Lake, the phytoplankton which is dominated by diatom, chlorophyta and cyanophyta, varies between 1.5 and 18.83 mg/l per total during summer (Fig. 2).

Due to the large area and the great water volume of the lake, stagnation phenomenon is favored. Based on the experimental variation of the phytoplankton biomass (Fig. 5), it results that temperature of lake water and light penetration are the main factors that determine the dynamics of the vertical phytoplankton distribution (Ryabov, 2010). 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 algae from the phytoplankton has maximum values during the hot period of the year (June-October). Generally, the algal biomass decreases from the lake tail towards the bottom, while the living algae increases from the lake tail towards the middle and bottom parts of the lake, along with the improvement of the limnological conditions (Fig. 2).

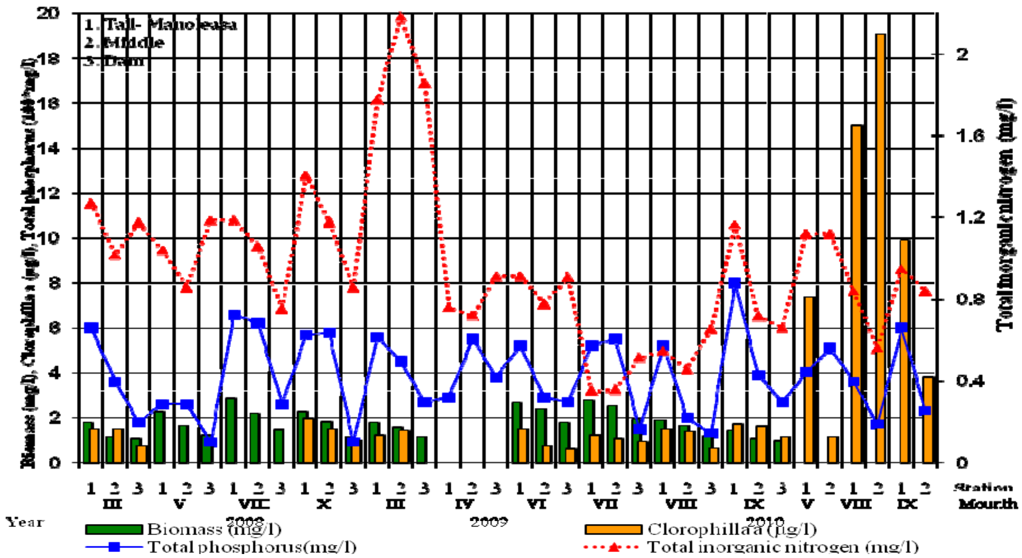

Fig. 2. Experimental time variations of concentration values of phosphorus, nitrogen, chlorophyll a and phytoplankton biomass.

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. The multiannual study of hydro chemical processes in the lake allows framing the lake in the eutrophic category, based on the current data on water quality and using the Nurnberg and Carlson criteria (Table 1.) [5].

Table 1

Trophic State Boundary Values

Indicator	O-M	M-E	E-H
TP (mgP/m^3)	10	25	100
Chl. A (mgChl/m^3)	3.5	9	25
Secchi (m)	4	2	1
Min DO (mg/L)	7.2	6.2	
TN (mgN/m^3)	350	650	1200
TSI	< 40	40 - 50	50 - 70

The quality and trophic state of the lakes are described by concentration and loading rate of nutrients, which are the cause, and by physical and biological indices, which are the effect. The trophic state indices (TSI) values obtained for Stanca-Costesti Lake indicate that the lake is in large proportion in eutrophic status. The resulting TSI values for the nutrients concentrations (TN>0.65 mgN/L and TP>0.025 mgP/L) show that the lake is placed in the eutrophic category throughout the period 2008-2010. However, regarding at the chlorophyll a content variation, the lake is in oligotrophic stage during 2008 and 2009, but since 2010 it became a mesotrophic lake, even eutrophic in July.

3. Methods

The most important problem in developing high quality models is to identify the adequate mathematical formulae to describe the transformation processes for the considered level of trophic chain [6].

The two layer models for studying eutrophication phenomenon in lakes consider the interactions nutrients – trophic chain and are capable to illustrate very accurate the functioning of aquatic ecosystems. The model presented in this paper is dealing only with the biochemical part of the process and permits to estimate the evolution of nutrient content and algal and zooplankton biomass in the Stanca Costesti lake ecosystem. The conceptual model consider 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 others constituents.

The state variables of the model are total phosphorus (*P*), total inorganic nitrogen (N), algal biomass (*A*) and herbivore zooplankton (*Z*). The governing equations are based to the mass conservation law applied for the state variable [7]:

$$\frac{\partial A}{\partial t} = \left(k_C(T,I,N,P) - k_{ra}\right) \times A - c_{za}(T) \times A \times Z \,, \tag{1}$$

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

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

$$\begin{aligned}\frac{\partial N}{\partial t} = {} & a_{na} \times (1-\varepsilon) \times c_{za}(T) \times Z \times A + a_{nc} \times k_{dz}(T) \times Z - \\ & - a_{na} \times \left(k_C(T,I,N,P) - k_{ra}\right) \times A\end{aligned} \tag{4}$$

where *t* represents temporal coordinate, k_{ra} and k_{dz} represents the loss of phytoplankton and 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} represents phosphorus – phytoplankton transformation rate (mgP/mgChl) and a_{pc} is phosphorus – carbon transformation rate (mgP/mgC). 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).

The model was calibrated with data from 2008 in the Stanca-Costesti Lake. The calibration of the eutrophication model was realized by fine tuning of the model parameters within their observed literature ranges. 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 Stanca-Costesti Lake. The validation of model was made for 2010.

4. Results

In the study period the reactive soluble phosphorus is strongly assimilated by plants in the epilimnion layer and the primary production is the result of decreasing the amount of nutrients available. High value of ratio of total nitrogen and total phosphorus suggest that the phytoplankton is limited by phosphorous (fig. 3). Even if the phosphate is not entirely depleted, its low concentration shows this limiting tendency. Thus, the phosphorous pass into the particulate form and the insoluble fraction is increasing.

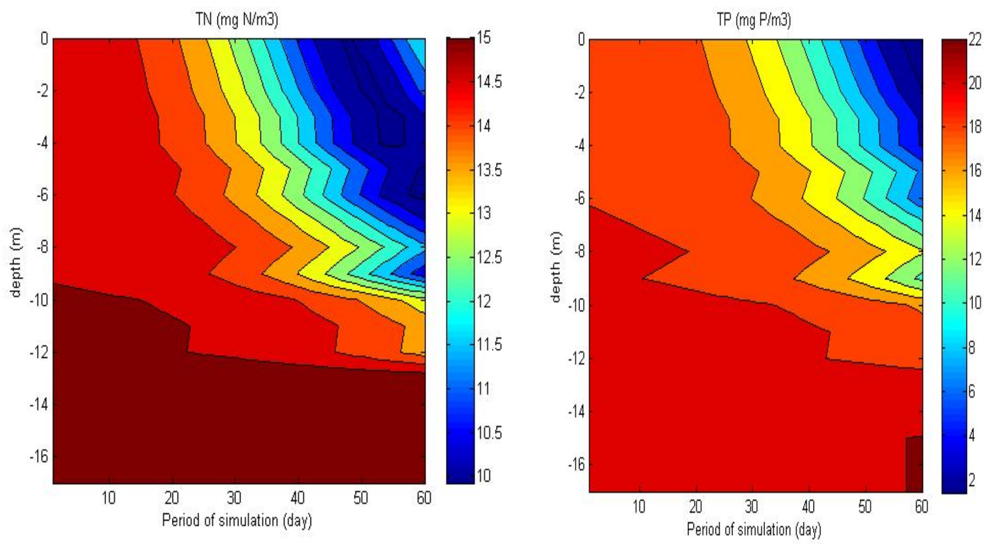

Fig. 3. Numerical time variations of concentration values of total phosphorus and total inorganic nitrogen.

The diminishing of photosynthetic processes at hypolimnion level is the reason of small variation over time of the phosphorous forms (fig. 4). During the hot season, direct thermal stratification appears, the exchange of substances between the two layers is limited and, due to decomposition of insoluble phosphorous in hypolimnion, the concentration of soluble form increase. Although production is relatively high, phytoplankton biomass in epilimnion is not very high, as a result of nutrient limitation, loss by sedimentation and herbivorous zooplankton pressure.

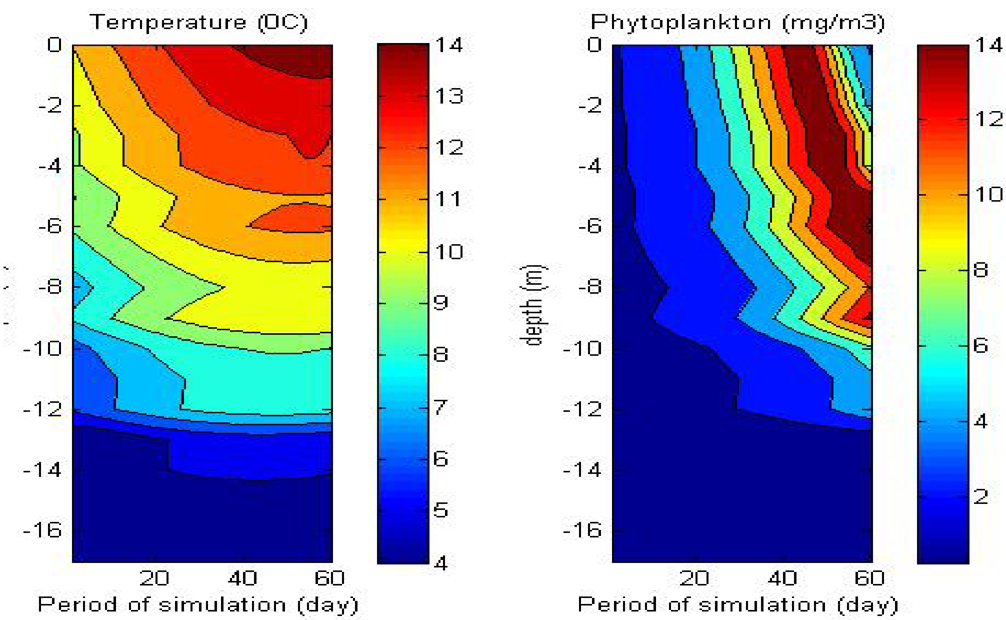

Fig. 4. Numerical time variations of concentration values of water temperature and chlorophyll a biomass.

In order to show the ecosystem mass conservation, the concentrations of the state variable were expressed in equivalent carbon units, using the following relations:

$$C_A = A \times a_{ca}; \quad C_P = P / a_{pc}; C_N = N / a_{nc}; \tag{5}$$

Since just the herbivorous zooplankton is considered in the model a delay between zooplankton peak and phytoplankton peak is natural to appear (fig. 5).

The model reproduces temporal distribution of concentration of water quality constituents such as soluble phosphorus, total phosphorus and phytoplankton biomass.

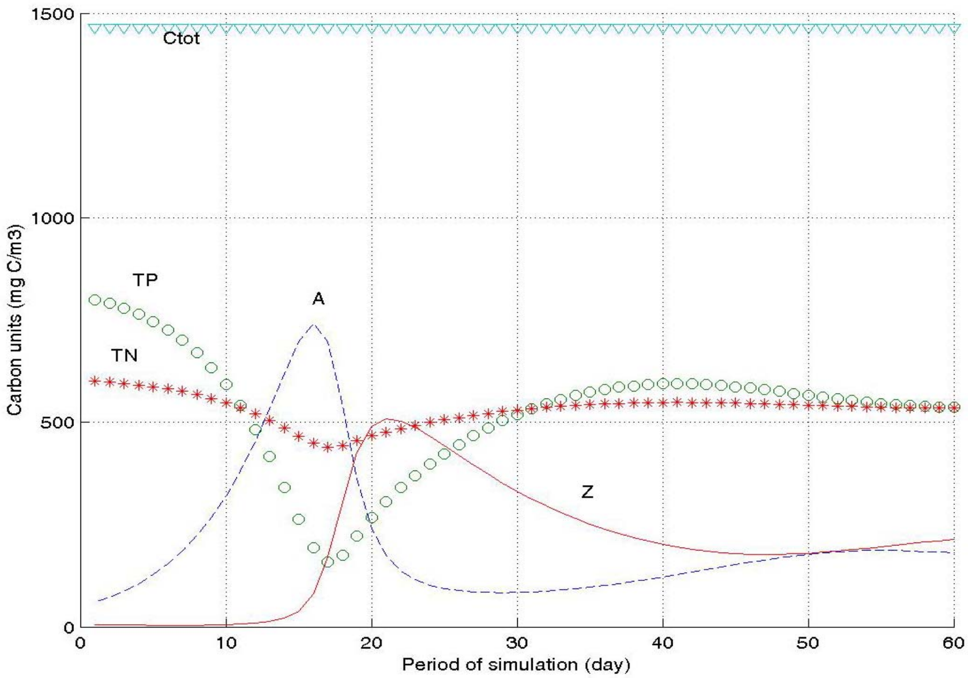

Fig. 5. Variation of the concentrations of the state variable, in equivalent carbon units

The comparison between simulated and observed values for Stanca-Costesti Lake is represented (fig. 6). It can be seen that the model provides reasonable results.

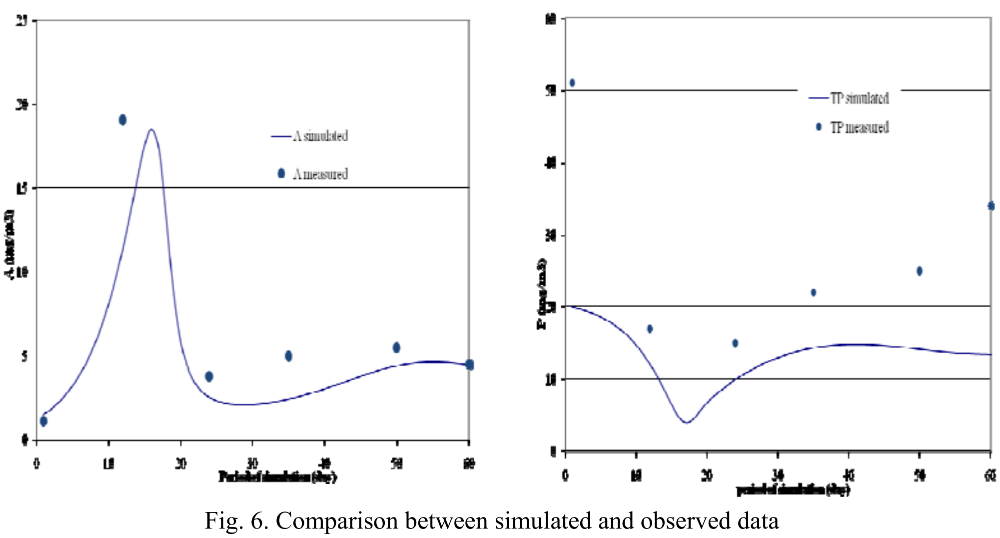

Fig. 6. Comparison between simulated and observed data

5. Conclusions

The need for water quality prediction has arisen largely as a result of increased eutrophication of lakes throughout the world. An ecological model was configured for the Stanca-Costesti Lake from Romania. The model reproduces temporal distribution of concentration of water quality constituents such as total phosphorus and phytoplankton biomass. The nutrients concentration is in indirect correlation with the algal production. Due to algae bloom, the nutrients concentration starts to decrease, and, when the phytoplankton peak is reach, the decomposition processes, along with the resuspension ones, generate a growth of the phosphorous concentration.

The model reproduces spatial and temporal concentration distribution of water quality constituents such as differed forms of nutrients and plankton biomass. 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 nutrients.

As it was mentioned before, the Stanca Costesti Lake is used not only for energy production, but also for irrigation, industrial and drinking water supply. During the study period, in summer 2010, the primary production was dominated by blue-green algae, which have a toxic potential and also are often too large to be grazed by zooplankton and therefore constitute the end of trophic web. Beside the eutrophication phenomenon, in Stanca Costesti area two catastrophic floods were registered, in late July 2008 and 2010. Those events occurred on the Prut River, upstream of the accumulation Stanca-Costesti, both of them generating floods in Romania as well as in Moldova Republic, with major damage and even life losses. In terms of raw water for drinking supply, those aspects rise the questions of treatment plant efficiency and treatment costs. Blue - green algae removals are difficult and give a musty tastes and odors of drinking water [8]. The extreme events causes high increases in turbidity and organic load, affecting directly the treatment efficiency (in very severe cases, the failure of the treatment plant is possible) and rising the costs [9].

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Nomenclature

A - algal biomass;
P – total phosphorous;
N – total inorganic nitrogen;
Z - herbivore zooplankton;
t - temporal coordinate;
k_{ra} - the loss of phytoplankton rate, which include respiration, excretion, natural mortality (day^{-1});
k_{dz} - the loss of zooplankton rate, which include respiration, excretion, natural mortality (day^{-1});
c_{za} - specific zooplankton predation rate, (m^3/mgC day);
a_{ca} - phytoplankton carbon – chlorophyll ratio (mgC/mgChl);
ε - zooplankton assimilation efficiencies;
a_{pa} - phosphorus – phytoplankton transformation rate (mgP/mgChl);
a_{pc} is phosphorus – carbon transformation rate (mgP/mgC);
C_A - concentration of algal biomass in equivalent carbon units (mg C/m^3);
C_P - concentration of total phosphorus in equivalent carbon units (mg C/m^3);
C_N - concentration of total nitrogen in equivalent carbon units (mg C/m^3);

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