

POLLUTANT DISPERSION INSIDE THE BRĂDIȘOR LAKE

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Obiectivul principal al studiilor este de a determina modul de dispersie a poluanților în masa de apă. Lacul Brădișor este un lac artificial format prin realizarea unui baraj. În mijlocul acestuia este amplasată o păstrăvărie, care poluează mediul acvatic cu diverse poluanți. Este absolut necesar să se determine gradul de poluare din interiorul lacului, în special în cazul în care poluanții ajung la baraj, în zona de captare a apei. Modul de dispersie al poluanțului de la păstrăvărie până la baraj (de unde este alimentată stația de epurare din Valea lui Stan) nu este cunoscut. Lucrarea prezintă o nouă metodă de determinare a concentrației de poluanți din lac, metodă bazată pe modelări matematice și simulări numerice.

The main objective of this paper is to determine the spatial dispersion area of the pollutant discharges in the aquatic environment. Brădișor Lake is an artificial accumulation formed by the realization of a dam. In the middle of the lake a trout facility which discharges pollutants in the aquatic environment is situated. It is necessary to determine the manner and the degree of pollutant dispersions inside the lake, especially if these pollutants reach the dam and the captation area of water at alimentation point of Stan Valley treatment station. The pollutant dispersion inside the lake is not known. The present paper proposes a new method for the determination of the pollutant concentration, based on mathematical modeling and numerical simulations.

Keywords: mathematical modeling, numerical simulations, pollutant dispersion.

1. Introduction

Pollutants dispersion processes are often encountered when a quantity of water is discharged into the natural environment, in controlled or uncontrolled regime. By introducing a pollutant in an aquatic environment, its polyphase constituents are dispersed through the whole volume of water. The discharged constituents enhance the aqueous environment with nutrients and organic substances, which are decaying and change the natural characteristics of the environment and make it unsuitable for any use.

In Romania artificial accumulation of water were built in order to supply the water demand to several villages. Artificial lakes formed by impoundment of the rivers, are important reservoir, of water and cover the water needs of many

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towns and villages. In this, the artificial accumulation, were build on Bistrita, Moldova, Olt River, etc.

The present paper offers a solution for the complex problems regarding the pollutant dispersions in an aquatic environment with direct application for Brădișor artificial lake, which is an artificial accumulation formed by the realization of a dam. It is a part of comprehensive appliance of Lotru River. Its main scope is to feed with water the towns and small communities situated along the Olt valley - Brezoi, Călimănești, Râmnicu Vâlcea up to Drăgășani. Near the dam, at Stan Valley a water treatment plant is situated.

In the middle of Brădișor lake a facility for trout raising, which produces about 100 tone of fish every year is situated. This construction contributes to the water quality degradation by pollutant discharges.

To ensure the water needs in the towns mentioned above is absolutely necessary to keep the water clean inside the Brădișor Lake. This fact is desired because the Brădișor Lake (Figure 1) is the main source of drinking water for the city Râmnicu Valcea. Taking into account the fact that the annual average lake phosphorus values are 0.0492 mgP/l, phytoplankton biomass is 4.706 mg/l and chlorophyll "a" is 3. 59 ug/l it results that the water quality can be classified in class IV. Water captation is achieved through an outlet located in the dam area.



Fig. 1. Satellite view of the lake with trout facility

The volume of water in the lake is 39.7 million cubic meters. Distance from the trout facility to the dam is 1091 m. The lake, at the trout facility has a wide area of 667 m and the construction is located at 222 m from the left bank and 445 m from the right.

This construction contributes to the water quality degradation by: food abundance, which goes directly into the lake water; increasing the organic compounds because of the fish excrements; increasing the compound based on phosphorous and nitrogen; pollutant discharges of people who work in the facility. Trout facility from Brădișor produces around 100 tonnes of fish every year. The

main goal is to obtain fish for consumption, but also for restocking mountain waters with trout - 200,000 seedlings per year.

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2. Pollutants dispersion

The problem rising in the present study is to demonstrate the negative environmental impact of the trout facility situated in the middle of the lake. The paper establishes the pollutant dispersion inside the Bradisor Lake. It is obvious that the problem is complex because the water movement in the lake is generated by the power/velocity of river/water current and by the discharging area existing near the dam.

To build the mathematical model the general equation of dispersion [2, 4, 5] is considered:

$$\begin{aligned} \frac{\partial \bar{C}}{\partial t} + \frac{\partial}{\partial x}(\bar{u}\bar{C}) + \frac{\partial}{\partial y}(\bar{v}\bar{C}) + \frac{\partial}{\partial z}(\bar{w}\bar{C}) = & \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial \bar{C}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial \bar{C}}{\partial y}\right) + \frac{\partial}{\partial z}\left(\varepsilon_z \frac{\partial \bar{C}}{\partial z}\right) + \\ & + D_m \left(\frac{\partial^2 \bar{C}}{\partial x^2} + \frac{\partial^2 \bar{C}}{\partial y^2} + \frac{\partial^2 \bar{C}}{\partial z^2} \right) + S(x, y, z, t), \end{aligned} \quad (1)$$

Where ε_x , ε_y , ε_z are longitudinal, transversal and vertical dispersion coefficients. A complete solution of this equation, where the equations of motion and continuity must be attached, is impossible to obtain because of the dependence of dispersion coefficients on the flow regime, the nature, form and size of dispersed particles. Because of this, a simplified model was applied.

To simplify the equation the orthogonal Cartesian system Oxy is considered and the dispersion equation becomes [1, 5]:

$$\frac{\partial \bar{C}}{\partial t} + \frac{\partial}{\partial x}(\bar{u}\bar{C}) + \frac{\partial}{\partial y}(\bar{v}\bar{C}) = \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial \bar{C}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial \bar{C}}{\partial y}\right) \quad (2)$$

where quantities are averaged over a period of time.

The equation builds the image of the lake in Cartesian coordinate system. It is similar with the one identified by the satellite. It is a very delicate matter that requires attention, because the contour of the lake is drawn from short polygonal lines that lead to the irregular shape of the banks.

The restriction is to not have exchange between aquatic environment and lake banks. A Neumann type condition, which is expressed by $\frac{dC}{dn} = 0$ [1; 3] is used.

Then, the contour for the trout facility is plotted, which consists of regular rectangular - region 2 of the simulation program. The trout facility is positioned in the second half of the Lake, closer to the left bank. Across the contour, which obviously comes in contact with aquatic environment, the pollutant concentration value $C = a$ (constant) is provided. This is a Dirichlet condition and the value for C was determined following several experimental measurements on quality indicators of water. Thus, C is considered to be *COD* and the determined values are situated between 20 and 24 mg/l. The trout facility contributes to an increased pollutant in aquatic environment.

Pollutant released by the trout facility is dispersed in the aquatic environment due to the fluid movement. Inside the lake, a general flow appears from downstream up to the dam. The overall flow contributes to the dispersion of pollutants in the lake. Depending on the values of horizontal and vertical velocities and the coefficients of dispersion different responses to the degree of dispersion and distribution in the area of water accumulation result.

To determine the vertical pollutant dispersion a vertical section of the lake, including the trout facility was constructed.

3. Mathematical modelling and numerical simulations

The method used to determine the dispersion area is based on mathematical and numerical simulations. The simulations were realized using FlexPDE5 program and the general equation of dispersion (simplified form) was utilized. The pollutant dispersion inside the lake (chemical oxygen demand) was studied. The simplified equation for dispersion was introduced in program FlexPDE5, and the results presented below were obtained. Changes that occur in the distribution of COD concentration in the horizontal and vertical plane depend on the values adopted for flow velocities and for the dispersion coefficients.

Horizontal flow velocities to the dam were taken in the range $u = 0.01 \dots 0.10$ m/s, while those in the vertical plane have the values in the range $v = 0.001 \dots 0.005$ m/s [5] - values considered as normal inside the lake Brădișor.

The dispersion coefficient values varied in the range $\varepsilon_x = 0.05 \dots 1$ m²/s, $\varepsilon_y = 0.01 \dots 0.1$ m²/s [2; 3]. It is considered that these values are normal for the movement of water inside the accumulation (compared with the constant value of oxygen diffusion from air into water $D_m = (0.13 \dots 0.2)$ m²/s, depending on temperature). For the vertical section of the lake the same equation was used, where the values

for u and w were modified. Also the values for dispersion coefficients were modified.

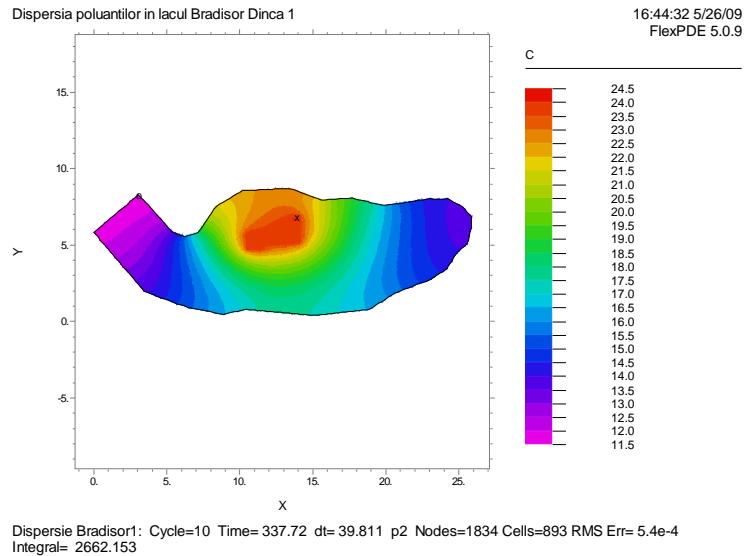


Fig. 2,a. Concentration of the pollutant (COD)

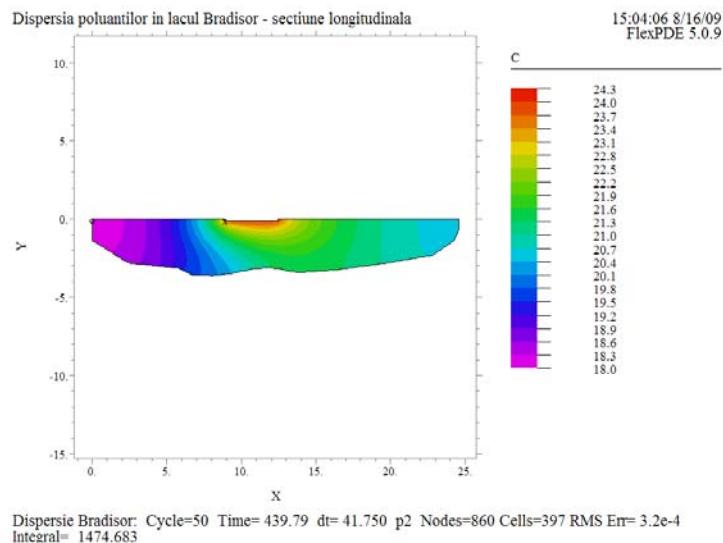


Fig. 2,b. Concentration of the pollutant – vertical view (COD)

For the simulations represented in Fig. 2 the following values of velocity $u = 0.01$ m/s, $w = 0.001$ m/s and dispersion coefficients $\varepsilon_x = 0.2$, $\varepsilon_y = 0.1$ were

considered. The real values for dispersion coefficients are not known for the case of Brădișor Lake. Thus, in this situation several simulations with different values for these coefficients are made. The range values for these parameters are presented above. Pollutant dispersion can be observed in both sections (horizontal and vertical) of the Brădișor Lake.

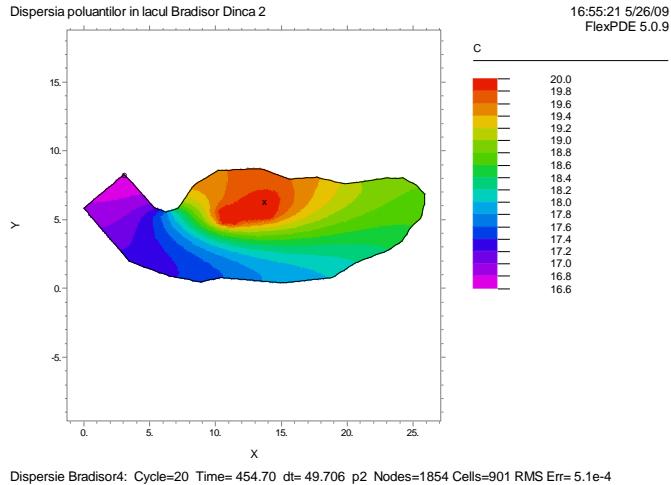


Fig. 3,a. Concentration of the pollutant (COD)

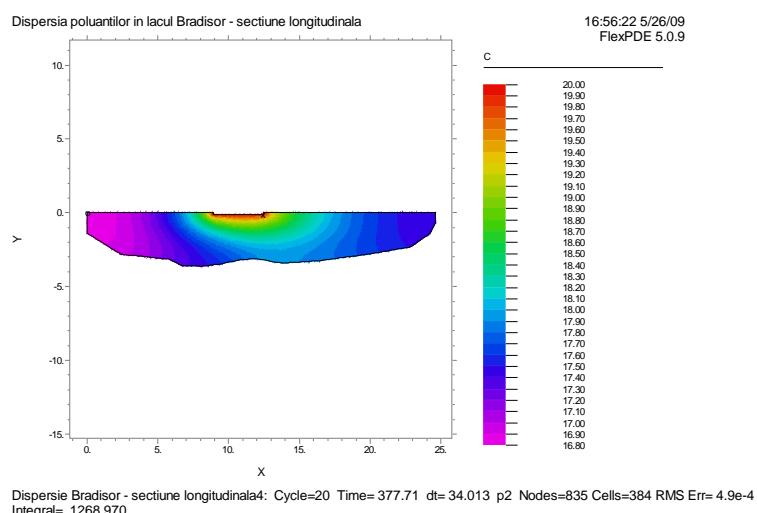


Fig. 3,b. Concentration of the pollutant – vertical view (COD)

Compared to the previous case it was considered that inside the lake, the flow velocities are higher $u = 0.05$ m/s and $w = 0.005$ m/s. Pollutant dispersion increases in intensity by the tail of the lake, near the dam. Thus, the water quality at the catchment area is significantly lower compared to the previous case. It is noted that in this case the pollutant reaches higher depths at the tail of the lake.

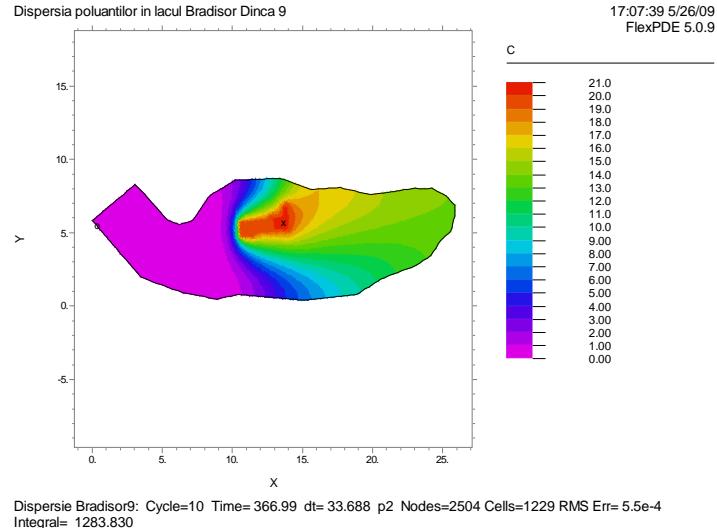


Fig. 4.a. Concentration of the pollutant (COD)

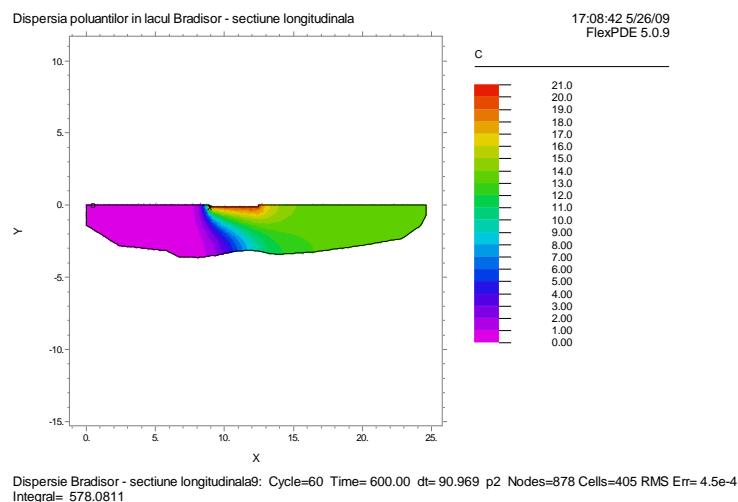


Fig. 4.b. Concentration of the pollutant – vertical view (COD)

Compared to the previous case, flow velocities were also increased (Fig. 4). Due to dam water movement, it is noted that the influence of the trout facility is perceptible only in the second half of the lake. In this case, the influence of the facility to the bottom at the lake can be noticed. In Fig. 5, values of $u = 0.05$ and $w = 0.005$ m/s were considered.

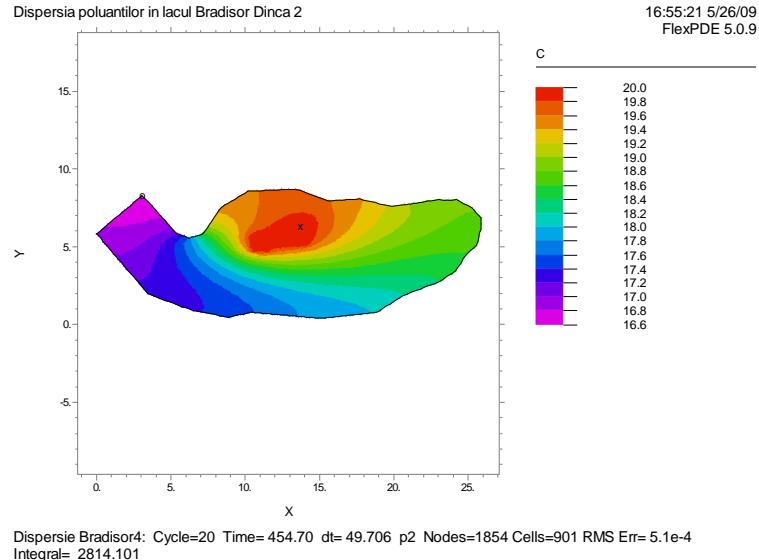


Fig. 5.a. Concentration of the pollutant (COD)

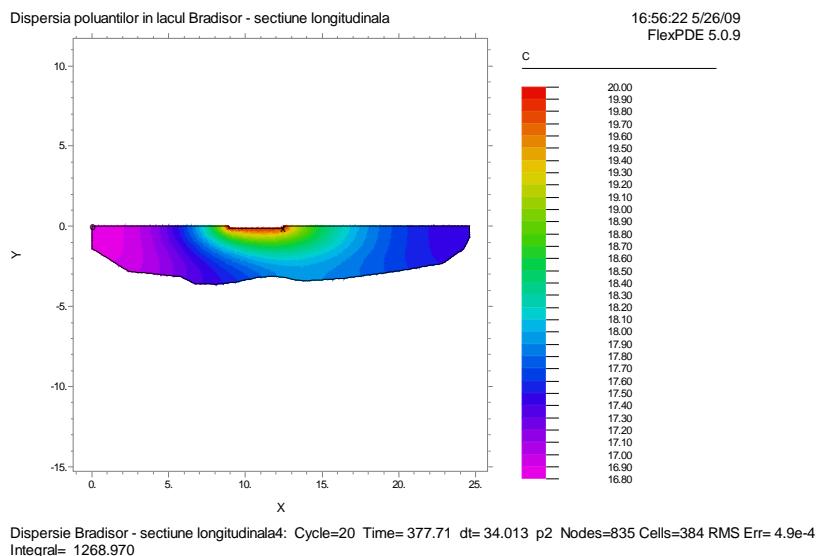


Fig. 5.b. Concentration of the pollutant – vertical view (COD)

4. Experimental results

During the study several measurements were realized. Samples of water were taken from different locations and depths. The analyses were made by a certified laboratory. Some of the results, where COD is measured, are listed in Table 1.

Table 1

Measured values for COD [mg/l]

Data	Sample 1 CS	Sample 2 MS	Sample 3 MMZF	Sample 4 MLZF	Sample 5 BS	Sample 6 BMZF	Sample 7 BLZF
25.05.2008	12.8	18.3	18.3	20	20	10.2	10.2
19.06.2008	14.4	19.2	19.2	19.2	24	19.2	19.2
26.08.2008	9.68	9.68	19.36	19.36	9.68	21.78	19.36
13.10.2008	4.8	4.8	9.6	9.6	9.6	14.4	14.4
11.11.2008	9.6	9.6	9.6	4.8	9.6	9.6	4.8
23.03.2009	9.4	9.4			9.4		

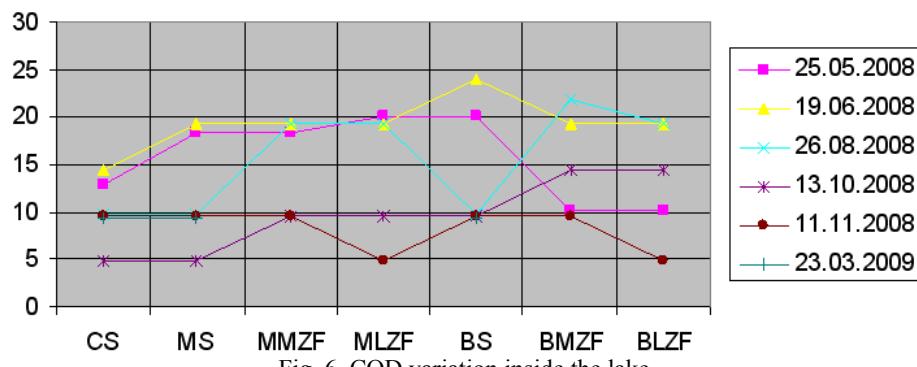


Fig. 6. COD variation inside the lake

Analyzing the curves of variation of COD (Fig. 6), one can notice that increased values are observed at the point where the river enters the lake up to the dam, especially after mid-lake in order to facilitate damming it up. It is obvious that the increase is due to trout facility, which is located after the middle of the lake. COD has values situated in the range 20 ... 24 mg/l after the facility and 10 - 12 mg/l identified up to the trout facility. The maximum values measured in the lake where adopted in modeling and simulation. The way that COD changes correspond with the results obtained from modeling and simulation.

4. Conclusions

The influence of the trout facility is perceptible in the area between it and the left bank of the accumulation. It is the effect of the reduced flow velocities of waters in this region. The water prefers to move directly, on the road with minimum distance up to the dam.

There are situations in which water accumulates in the lake and speeds are low, and others - in times of high water (flood) - the speeds inside the lake are high due to the discharge of water from dam. If the horizontal velocity u increases the pollutant reaches the dam where water captation is made. Also by increasing the horizontal velocity, the reduction in the influence upstream of the facility position is remarkable. In concordance with the results obtained during simulations, the optimal position of the raising trout facility referring to captation area of water for the treatment plant can be specified.

Theoretical researches have been followed by water quality measurements. In this way it was showed that the model was correct calibrated and it can be used, respecting simulation value limits, to evaluate water quality from Brădișor Lake. The increase of water velocity on a vertical plane from 1 mm/s up to 5 mm/s contributes to the enlargement of the area influenced by the pollutants. In this case, the pollutants reach up to the dam and water with non-adequate quality is captured. This polluted water raise the investment costs of the treatment plant.

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