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COMPARISON BETWEEN NUMERICAL SIMULATION AND MEASUREMENTS OF THE POLLUTANT DISPERSION IN A RIVER. CASE STUDY

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România, țară membră al Uniunii Europene, s-a angajat ca până în anul 2015 să amelioreze, până la „o stare ecologică bună”, calitatea apelor de suprafață. Sectoarele de râu în care se descarcă ape uzate (epurate parțial sau neepurate) sunt cele mai expuse riscului de a nu atinge standardele de calitate. În articol se compară rezultatele măsurătorilor unor indicatori de calitate a apei pe Oltul superior cu simularea numerică realizată prin aplicarea unui pachet de programe. În concluzii, se arată că modelarea matematică reprezintă un mijloc important de investigare, în condițiile în care se beneficiază de date experimentale in situ.

Romania, as European Union member country, has undertaken that by 2015 to improve the surface water quality to „good ecological status”. The most at risk of failing to meet quality standards are the rivers in which wastewater (partially treated or untreated) are discharged. In the paper it is compared the results of measurements of water quality indicators on the Upper Olt River with the numerical simulation obtained using a software package. The conclusions show that the mathematical modeling is an important tool of investigation under the conditions of existence experimental data obtained in situ.

Keywords: water pollution, dispersion, water quality indicators, measured data, mathematical modeling

1. Introduction

Climate changes emerged in recent time have generated many reviews and debates: scientific forums and specialists concluded that solving environmental problems is a priority worldwide. In context the EU requested Member States the implementation of the Directives Frame specific to environmental factors. Romania has undertaken that by December 2015 to achieve „good ecological status of water bodies”. Significant amounts of money allocated by the European Union to solve environmental problems caused involvement of numerous

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professional and consulting firms in the process of raising funds to finance these projects.

Analyzing a series of investments in Covasna County we found that problems arise mainly post-execution, namely at the operational level of sewage systems. Based on modern but expensive technical solutions, wastewater treatment plants generate high prices per unit of product, unattractive now and even prohibitive in the current economic context and in perspective. Extrapolating these observations to the existing wastewater treatment systems that require upgrading to achieve the quality of water courses recommended by the Water Framework European Directive [1], one showed that the price is a decisive factor. If the local authorities make an investment in "Greenfield", they should reach a major impasse with negative repercussions upon population, environment, the communal operator, etc., because of high costs.

However, to achieve a viable technical solution, it must know in detail the effects of partially treated or untreated sewage discharged into rivers. For this purpose, one may appeal to mathematical modeling of pollutant dispersion in terms of integrated monitoring system of water bodies [2], [3], and [4].

2. Mathematical modeling of pollutant dispersion in rivers

In normal conditions for flow in rivers and channels relatively straight, the main mechanisms of pollutant dispersion are differential convection and turbulent diffusion. Due to relatively small depths of water courses, the vertical turbulent diffusion effects manifest only over a relatively short distance downstream of the pollutant source (vertical concentration distribution becomes uniform rapidly). Also, longitudinal turbulent diffusion effects are negligible compared with convective transport, if the local velocities are significant. In these conditions, the effects of lateral turbulence occur mainly in the intermediate zone. Generally, one does not consider the mixing produced by transverse circulation of water in rivers, which is generated by meandering and irregular bed formations. Therefore, mathematical modeling is usually applied in a two-dimensional flow scheme, sometimes one-dimensional.

However, one-dimensional models, relatively simple and widely used for global evaluation of water quality are applicable only after a certain distance downstream from the source of pollution, called the mixing length, distance over which the pollutant dispersion is done completely on the whole cross-section, so that the local deviations from the mean concentration become negligible [5].

Among the possible existing software packages, Surface Water Modeling System (SMS) was chosen which consists of several modules for specific classes of the water motion [6]. Interfaces specifically designed to facilitate the utilization of several numerical models comprise the modules of SMS.

For our purposes, we used RMA2 and RMA4 models. The first one calculates hydrodynamic data for a given geometry, while the latter computes contaminant migration in a given velocity field.

a) RMA2. This is a 2D depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields. RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning/Chézy formula, and eddy viscosity coefficients are used to define turbulence characteristics.

The system of equations used by RMA2 consists of two equations of motion (1) and (2), on *x* and *y* Cartesian coordinates respectively, and one continuity equation (3) for incompressible fluid, unsteady flow:

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)+gh\left(\frac{\partial z}{\partial x}+\frac{\partial h}{\partial x}\right)+ \\ +\frac{gun^2}{\left(h^{1/6}\right)^2}+\left(u^2+v^2\right)^{1/2}-\zeta V_a^2\sin\psi+2h\omega v\sin\phi=0 \tag{1}$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right)+gh\left(\frac{\partial z}{\partial y}+\frac{\partial h}{\partial y}\right)+ \\ +\frac{gvn^2}{\left(h^{1/6}\right)^2}+\left(u^2+v^2\right)^{1/2}-\zeta V_a^2\sin\psi+2h\omega v\sin\phi=0 \tag{2}$$

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0 \tag{3}$$

where: *h* is water depth; *u, v* - local velocities in the Cartesian directions *x, y*; *t* - time; ρ - fluid density; *E* - eddy viscosity coefficient; *g* - acceleration due to gravity; *z* - bottom elevation; *n* = Manning's roughness coefficient; ζ - empirical wind shear coefficient; V_a - wind speed; ψ - wind direction; ω - rate of Earth's angular rotation; φ - local latitude.

Equations (1), (2), and (3) are solved by finite element method using the Galerkin method of weighted residuals. The elements may be one-dimensional lines, or two-dimensional quadrilaterals or triangles, and may have curved (parabolic) sides. The shape functions are quadratic for velocity and linear for depth. Integration in space is performed by Gaussian integration. Derivatives in time are replaced by a nonlinear finite difference approximation.

Boundary conditions are:

- Upstream - flow rate or water level;
- Downstream - water level or rating curve.

Note that the effect of turbulence considered by eddy viscosity coefficients is also a tool of ensuring stability for the numerical solution (pseudo-numerical dissipation effect).

b) RMA4. Once developed the mathematical model of the water motion (local velocities *u* and *v*, and depth *h*), for determining the pollutant dispersion is used a different model, RMA4, specific for contaminant transport.

RMA4 model solves the convection-diffusion equation (4) and get the concentration field:

$$h\left(\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}-\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x}-\frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y}-\sigma+kc+\frac{R(c)}{h}\right)=0 \qquad (4)$$

where: h is water depth; c - pollutant concentration; t - time; u, v - local velocities in the Cartesian directions x, y; D_x, D_y - diffusion coefficients on x, y directions; k - reaction/ attenuation coefficient; σ - local source term; $R(c)$ - precipitation/ evaporation.

The equation (4) is solved using finite elements with Galerkin weighted residue. The model allows the same types of elements as RMA2 and integration of the equation is made with the same Gaussian quadrature.

Boundary conditions can be imposed by specific concentration and/or zero-derivative.

2. Case study: Pollutant dispersion in Upper Olt River

The studied area is at the confluence between the Upper Olt River and Sambrezii Brooklet, loaded with partially treated wastewater discharged from WWTP Sfantu Gheorghe (Fig. 1).

Fig. 1. Studied area.

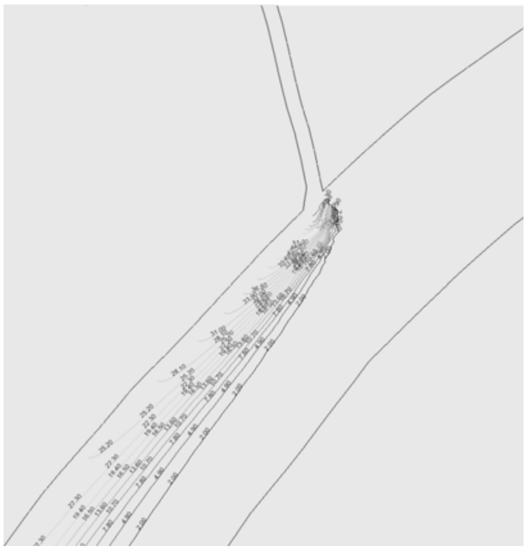

Fig. 2, a. Confluence detail (isoconcentration curves).

Fig. 2, b. Confluence detail (dispersion).

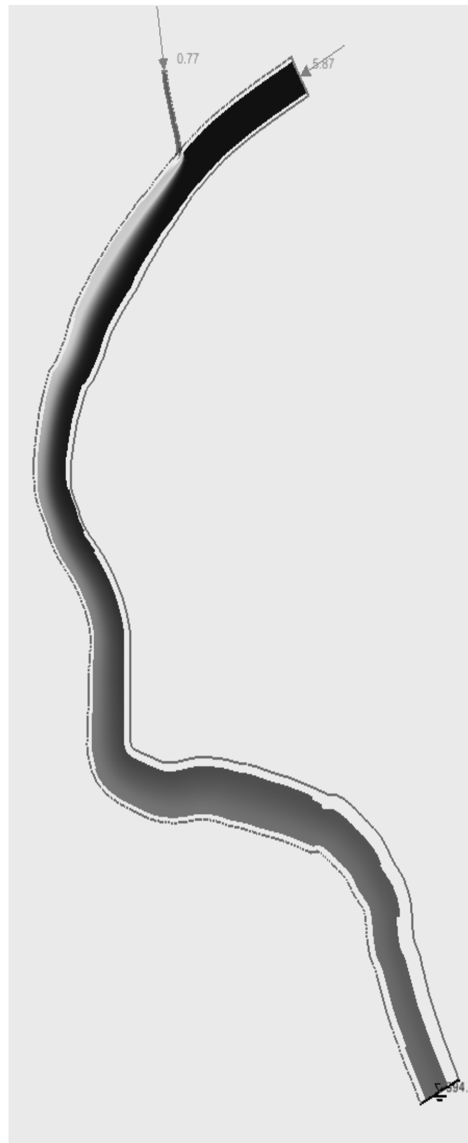

Fig. 2,c. General view (dispersion).

The pollutant dispersion simulation was performed with RMA4 program using RMA2 hydrodynamic data.

In order to calibrate and validate the mathematical model water quality indicators (conductivity, COD-Mn and BOD_5) were analyzed in two measurement campaigns (June and September 2007). The water samples were taken upstream and downstream of the confluence Upper Olt River-Sambrezii Brooklet.

The measurements of the campaign in June 2007 were used to calibrate the mathematical model and those in September 2007 for its validation.

The mathematical modeling has begun with building the river geometry using satellite and topometric maps. For the water hydrodynamics were used RMA2 program with 4 assumptions that has computed depth *h* and local velocities *u* and *v* averaged over the vertical in all the finite elements of the field.

In this way we managed to calibrate the mathematical model, even if the methodology for water sampling and subsequent laboratory determinations could not be considered of a very high degree of accuracy. Model validation by comparing numerical simulation with the second set of measurements of quality indicators was done. Figure 2 presents an example of the dispersion simulation for COD-Mn.

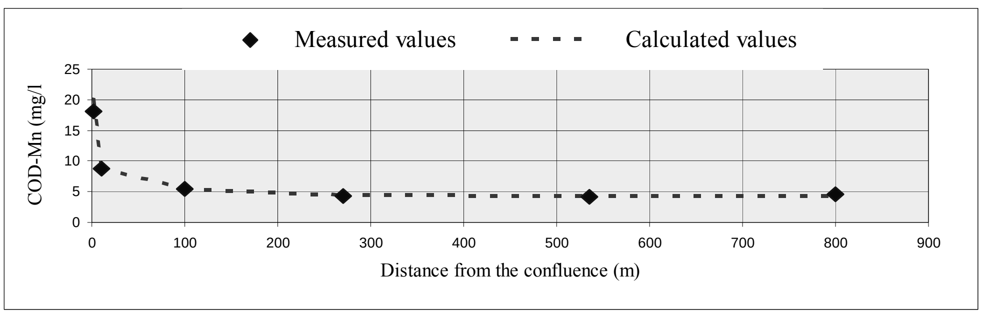

Fig. 3, a. Measured and calculated values of COD-Mn at right river bank (June 2007).

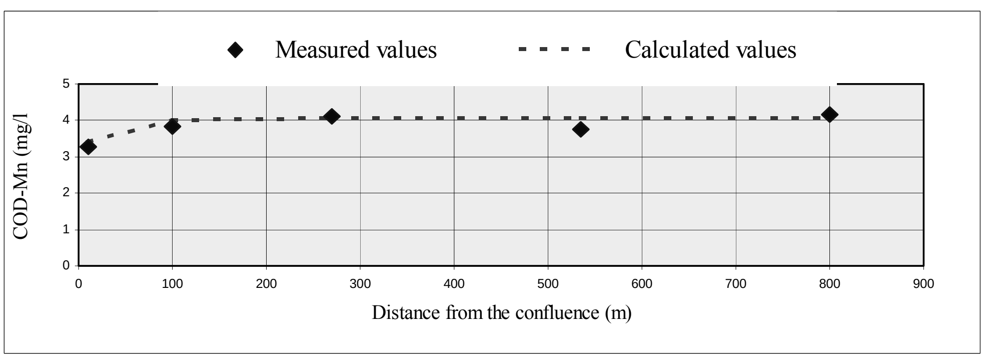

Fig. 3, b. Measured and calculated values of COD-Mn in the middle of the river (June 2007).

Comparing the measured data with the calculated values it is possible to conclude that is a good correlation between them. For example, these values are presented graphically for the right bank area and the middle of the river (Fig. 3).

As shown in Fig. 3, a and b, correlation between measured data in June 2007 and those obtained by numerical simulation are practically the same, this being the role of mathematical model calibration.

In order to validate the mathematical model the measured data for the same indicator COD-Mn in September 2007 campaign were compared with those calculated. From Fig. 3, c and d it is shown that the right bank values are in very good correlation, however, there are some differences in the middle of the river.

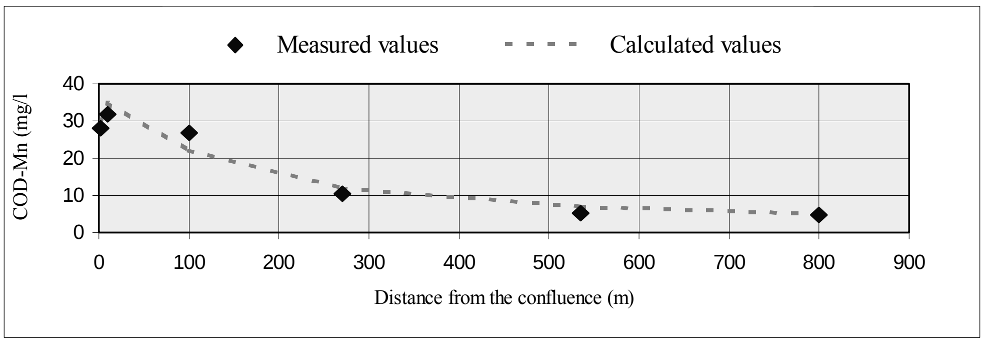

Fig. 3, c. Measured and calculated values of COD-Mn at right river bank (September 2007).

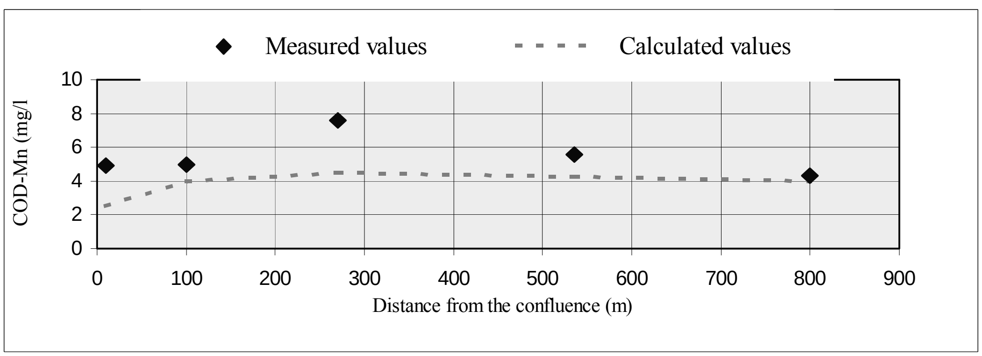

Fig. 3, d. Measured and calculated values of COD-Mn in the middle of the river (September 2007).

Of course, there is at least one explanation: in order to identify the influence of lateral dispersion coefficient, we used here a lower value for D_y with respect to that used for calibration, which underline the need to operate with proper values of this coefficient obtained from measurements.

Hence, a comprehensive program of such measurements in the frame of integrated monitoring system of water quality is strongly required.

4. Conclusions

Romania has undertaken to comply the European Directive 2000/60/EC regarding the water policy and to achieve a “good ecological status” for its water bodies. For this purpose the integrated monitoring system is involved, it is identified viable technical solutions for construction / rehabilitation of the water waste treatment plants and it is aimed to enforce environmental education of the population.

The paper emphasizes that mathematical modeling of pollutant dispersion in rivers and channels is a suitable tool for rapid identification of pollution effects and the required measures for environmental recoveries, to the extent that there are experimental studies *in situ*.

R E F E R E N C E

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