Water Quality Modeling of Bega River Using Mike 11

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As a result of the requirement to achieve the implementation of the European Water Framework Directive (WFD) in all the member states by 2015, Romanian's water management policies need to carefully look and consider water quality issues. All waters will achieve a good ecological status, therefore simulation of the existing status of the water bodies and analysis of proper adaptation measures for improving water quality is an important part of the implementation process. Water quality models play an essential role in support of the water management decisions. Present paper presents an application of the DHI tool, Mike 11, for the simulation of water quantity and quality of Bega River. The evolution of a pollutant source is traced both in time and space on a segment of the Bega River, from Topolovat to Otelec. The obtained results show that model is able to capture the water quality of the river, as per the observed values, and it is possible to be used in the future to predict the impact of a certain pollutant on the Bega River. The results of this study show the possibility to develop what-if analyses, which can help decision makers to choose the best adaptation strategy.

Keywords: water quality, Water Framework Directive, Bega River, river modeling

Due to the importance of water for life on Earth, it is necessary to protect both - the quantity and the quality of the water. The most important problem for the water in Europe is not the quantitative aspect of it - which depends on a rational and well balanced management of the resources, but the qualitative aspect of it. Water pollution is a general phenomenon, usually invisible, because most of the pollutants dissolve in water.

Through the Water Framework Directive 2000/60 / EC, European countries have agreed a set of measures for river basin management in order to achieve *good status* of water bodies [3].

Description of the river basin

According to the Basin Management Banat Guide, the river Bega springs from Poiana Rusca Mountains at an altitude of 890 m below the peak Pades and the catchment area (4470 km^2) has a general orientation east-west and flows into the Tisza river in Serbia. The Bega River on his length of 170 km to the border, receives numerous affluents, (fig. 1)

The route followed the Bega River, overlaps of siliceous formations with a bed substrate which consists in boulders, gravel and mud. It shows a sinuosity coefficient of 1.34 and an average gradient of 5 ‰. Bega River is divided into two river sections: section springs - upstream Timisoara and the section upstream Timisoara - to the frontier (Otelec) [7].

For modeling the water quality of Bega River we analyzed the inventory of pollution along this river between the years 2000 and 2014. What we observed is that on the section *springs - upstream Timisoara* appear no exceeding's in quality parameters which are translated into *good status* of water. On the section *upstream Timisoara – Otelec* on the other hand, the oxygen regime has suffered modifications generated by the urban waste water coming from economic agents and from the population of Timisoara through waste water treatment plant [3, 4, 7].

From biological point of view, in 2013 Bega River - upstream Timisoara- Otelec section is fit to be considered to have a good potential while considering physio-chemical elements, the Bega River on the section - upstream Timisoara - Otelec has a moderate potential determined by the oxygen level and nutrients. Specific pollutants determined the river to be classified in moderate environmental potential [9].

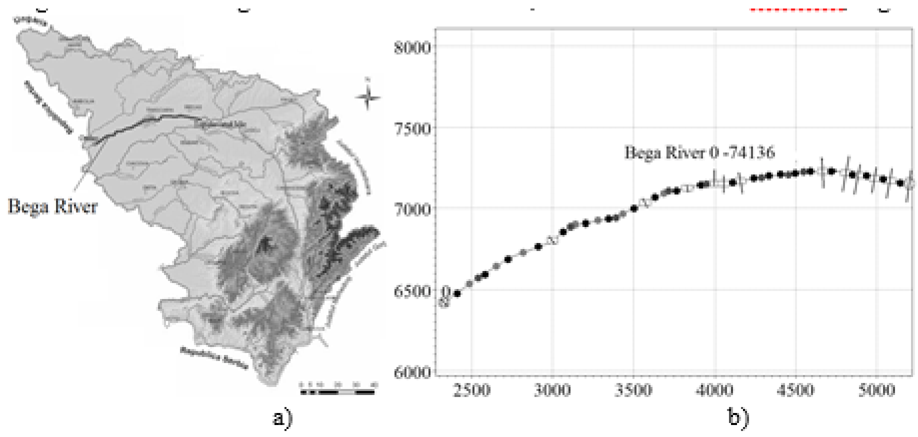

Fig.1. Banat watershed [7] (a) network of Bega river in Mike 11 (b)

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Experimental part

Water quantity and quality modelling

Quantitative and qualitative modeling has been carried out on the section upstream Timisoara to the border. The simulation period was a year for both - hydrodynamic model and water quality model. There have been registered data for flow, temperature, biochemical oxygen demand and dissolved oxygen (fig.2).

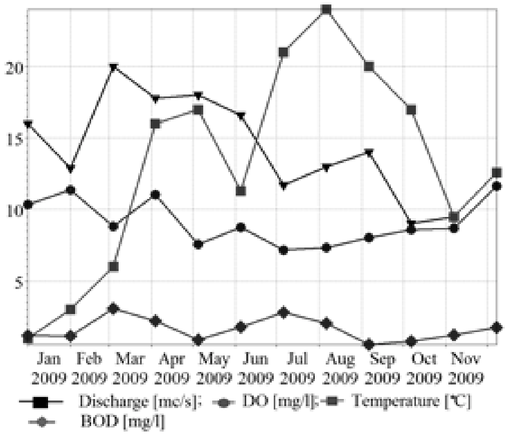

Fig. 2. Time series

For qualitative and quantitative modeling it had been chosen the software Mike 11 (DHI, 2007 Service Package 1).

The hydrodynamic model (HD) uses the St.Venant equations to simulate the flow in the river. Each cross-section is introduced into a database by points of coordinates (x_i, x_z).

Each section is also registered and presented by coordinates that allow plan representation of river and establish the direction of flow. The boundary conditions used are: time series of discharge and levels of discharges taken through limnimetrical keys. Solving equations of continuity and per moment is done by an implicit finite difference scheme [1, 2, 5, 6, 11, 12].

The results of this hydrodynamic module will then be used in calculation of pollutant dispersion, propagation of flood waves, floodplain analysis, morphology analysis of riverbeds, the sediment transport etc.

The advection-dispersion (AD) module is based on the one-dimensional equation of conservation of mass of dissolved or suspended material, i.e. the advection-dispersion equation. The module requires output from the hydrodynamic module, in time and space, in terms of discharge and water level, cross-sectional area and hydraulic radius [6, 7, 11, 12].

The one-dimensional (vertically and laterally integrated) equation for the conservation of mass of a substance in solution, i.e. the one-dimensional advection-dispersion equation reads:

$$\frac{\partial(AC)}{\partial t}+\frac{\partial(QC)}{\partial x}-\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)=-AkC+C_2q \qquad (1)$$

where:

C is the concentration, D the dispersion coefficient;

A the cross-sectional area, k the linear decay coefficient;

C_2 the source/sink concentration;

q the lateral inflo;

x the space coordinate and t the time coordinate.

Water Quality Module (WQ) is coupled with the advection-dispersion (AD), first describing the transformation processes of pollutants and second transport processes.

River water quality status can be described by the relationship between BOD and DO in several situations: CBO-OD relationship in the general case; OD relationship BOD matter if parts of the river bed; CBO-OD relationship where nitrification.

The parameters used are:

1) **Biochemical oxygen demand (BOD)** for degradation of dissolved organic matter [1, 2].

The equation that describes the degradation of dissolved organic matter is:

$$\frac{dBOD_d}{dt}=K_dBOD_d\cdot\theta_d^{(T-20)} \qquad (2)$$

where:

BOD is the biochemical oxygen degradation of dissolved organic matter [mg O_2 / L];

K_d constant degradation of organic matter dissolved at 20 ° C [L / day];

θd, temperature coefficient.

The equation that describes the reaaerare is [1, 2, 8]:

$$\frac{dDO}{dt}=K_2(Cs-DO) \qquad (3)$$

where:

-K2, reaeration constant at 20 ° C;

Cs, oxygen saturation concentration [mg / L];

Study of the oxygen regime is important because dissolved oxygen content determine the life processes of aquatic ecosystems. Oxygen regime indicators show us the degree of organic load and intensity phenomena that occur to their decomposition and mineralization. More important than the value of these indicators is the evolution of the indicators in space and time, because they will inform us about quality of the river to purify itself [1, 2].

Results and discussions

The length of the studied section is 74,136 km starting from the locality Topolovatul Mic and ending to Otelec (frontier settlement with Serbia).

Modeling was carried out in three stages:

In the first stage using the hydrodynamic module are calculated levels and velocities of river used then by water quality module (AD-WQ) for dispersion evaluation.

In figure 3 is presented hydrograph of observed and simulated discharges rates obtained in calibration and validation phases. To these results, we also applied statistical measures in order to quantify the accuracy of the model and to estimate errors in the simulated results.

Coefficient of determination (R^2) describes the degree of co-linearity between simulated and observed data. R^2 describes the proportion of the variance in measured data explained by the model, [9]. The value of R^2 ranges from zero to 1. A high value of R^2 indicates less error in variance,

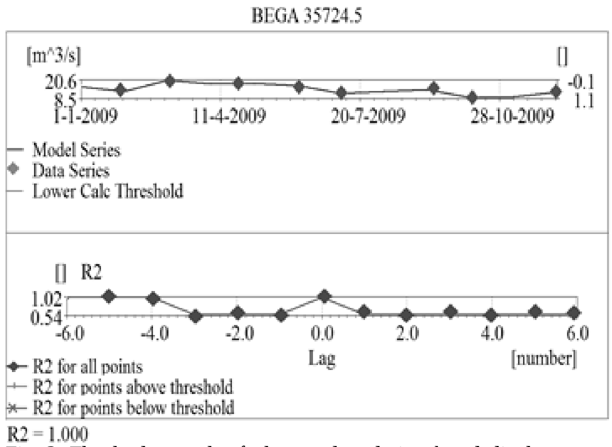

Fig. 3. The hydrograph of observed and simulated discharges to which was added statistical analysis

and typically values greater than 0.5 are considered acceptable [9, 10].

The coefficient of determination is computed as, [5, 9, 10]:

$$R^2 = \left[\frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]}}\right]^2 \qquad (4)$$

where:

R^2 = Coefficient of determination
X = parameters value observed
Y = parameter value simulated
n = total number of observations

As shown in figure 3, the coefficient of determination (R^2) has the values for measured and simulated discharge 1.00.

In the second stage it was modeled river water quality condition described by the relationship between BOD and DO. Dissolved oxygen and biochemical oxygen are indicators that contribute to assess the environmental status / ecological potential of water bodies and also for monitoring human impact on water resources (in particular the impact of urban wastewater). Simulated and measured concentration for BOD and DO is shown in figures 4and 5. The model simulates accurately measured status as seen by matching the measured and simulated results. In this case it has been applied statistics. The coefficient of determination (R^2) is 0.978 for values for BOD and for DO, R^2 is 0.975.

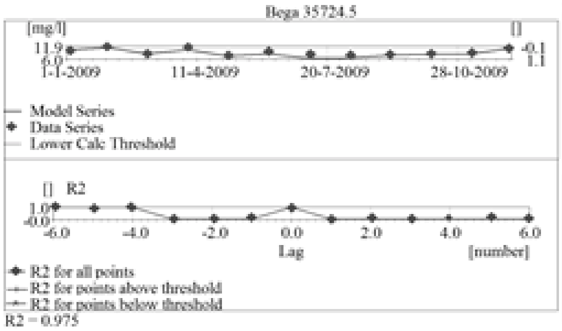

Fig.4. Statistical analysis for DO in Mike 11

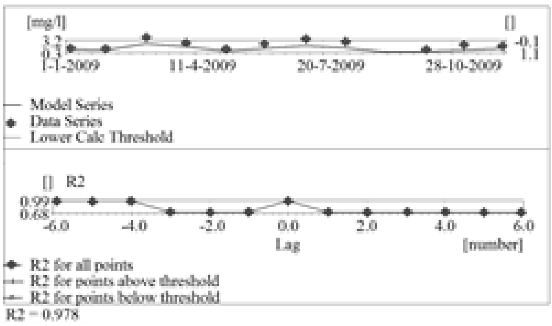

Fig.5. Statistical analysis for BOD in Mike 11

In figure 6 it can be seen variations of biochemical oxygen demand (BOD), dissolved oxygen (DO) and water temperature on the river studied using module – ECOLAB.

Simulated processes using the ECO LAB module from Mike 11 along the Bega River are shown in figure 7.

In **the third stage** have been modeled three scenarios.

1) In **the first scenario** was considered only water quality modeling pollution-free water.

2) **In the second scenario** was simulated a breakdown of a wastewater treatment plant, for one year by exceeding 10 times the allowed limit of BOD and a constant discharge 10 m³ / s .

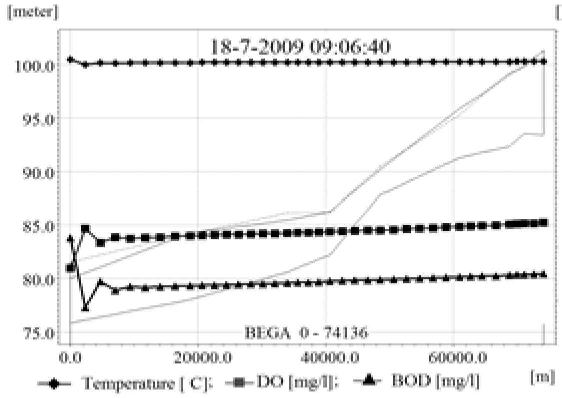

Fig.6. Variation of biochemical oxygen demand (BOD), dissolved oxygen (DO) and water temperature

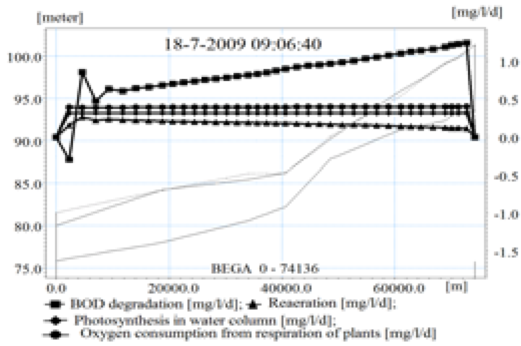

Fig.7. The variation of modeled processes

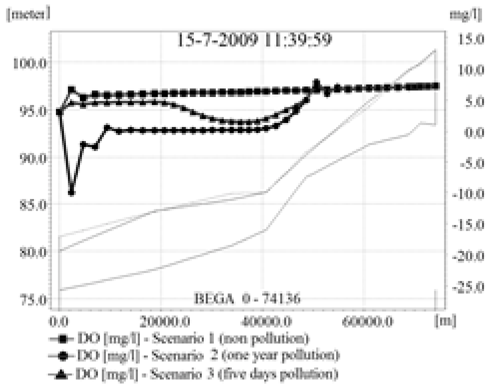

Fig.8. Oxygen dissolved modeled in three scenarios

3) **In the third scenario** it was simulated a breakdown of a waste water treatment plant for 5 days by exceeding by 10 times more than the allowed limit of BOD and a constant discharge 10 m³ / s. In this case it was considered only parameter BOD.

The period chosen for breakdown of the plant is 15.07-20.07, and coincides with the highest water temperature of the year. In figure 8 the oxygen demand simulated on the Bega River in July 15, shows that the concentration drops suddenly at the point source pollution (chainage 48000) the water quality in many sections of the river being affected.

In figure 9, the biological oxygen demand increases where the pollution appears – to the chainage of 48,000.

In figure 10 it can be seen that in scenario 2 (5 days accidental pollution) DO increases after several days as a result of a raised flow rate which also increases flow dilution. The increasing of DO in the river appear approximatively after 2 days from the termination date of pollution more exactly in 21.07, and it stabilized around 6 mg / L, while in scenario 3 remains around 0.

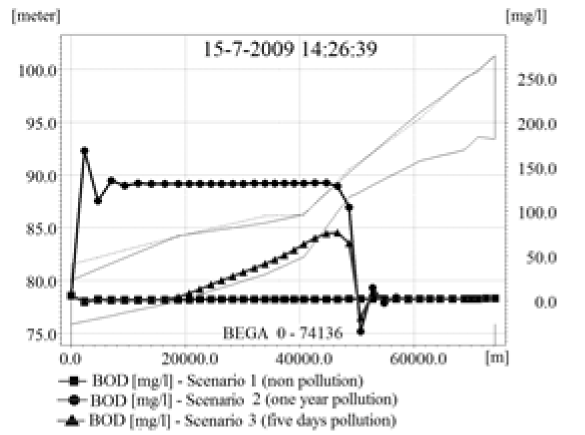

Fig.9. Biological oxygen demand modeled in three scenarios

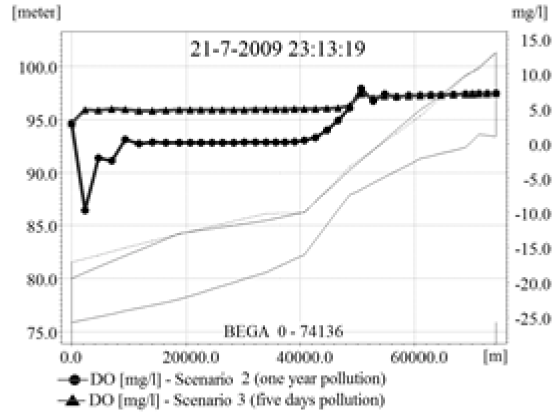

Fig.10. Oxygen increasing after 2 days when pollution stopped

Conclusions

All Romanian Basin Administrations require methods for evaluating water quality status under different scenarios, such as, for example, long-term impact of planned measures and the impact of climate change.

For this purpose, there can be created detailed models for water quality on the river to simulate physical, chemical and biological processes that could occur along the river.

A proper understanding of the effect of different management strategies in this watershed depends on an accurate representation of flow processes and water management.

The calibration of the model is very important in developing the water quality analysis. The purpose of model calibration is to provide a reasonable estimation of water quality parameters on watershed for long-term simulation period.

With calibrated hydrodynamic and advection-dispersion models it can be provided information about propagation time of the pollution, its duration in a certain controlled section and the maximum concentration to be reached in the analyzed section. In this way the authorities are able to analyze the effects of pollution event and take necessary measures to stop pollution or decrease the effects of pollution.

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