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ADVANCED HYDROINFORMATIC TOOLS FOR MODELLING OF ASSOCIATED PROCESSES WITH WATER QUALITY

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ABSTRACT. Water quality expresses the suitability of water to sustain various uses or processes: water for drink, food production, irrigation, animal husbandry, fishermen, recreation etc. Each use will have certain requirements for the physical, chemical or biological characteristics of water. The quality and composition of surface and underground waters is determined by natural factors (geological, topographical, meteorological, hydrological and biological characteristics of catchment) and by human activity (industrial wastes, sewage, runoff from farmland, cities, factory effluents, different hydrotechnical arrangements etc.). The evolution of water quality is also determined by the processes that take place in water bodies: chemical (neutralization, oxidation, reduction, flocculation, precipitation, adsorption, absorption, photochemical decomposition), physical (dilution, mixing, diffusion, sedimentation, coagulation, dissolution of oxygen, release of gases into the air, also influenced by solar radiation IR and UV, water temperature), biological (by its own biocenosis that competes with foreign elements, either directly, by lytic action (bacteriophages), filtration (shells), consumption (by protozoa) or the secretion of toxic substances for intruders (actinomycetes) and biochemicals (within the cycles of nitrogen, sulfur and carbon, based on the activity of specific microorganisms)).

In this context, modeling the evolution of water quality is of particular importance for efficient water management. For the best possible forecast of water quality, the use of advanced hydroinformatic tools, such as the MIKEby DHI (Danish Hydraulic Institute) software package, is needed. The paper presents the possibility of using these tools and conducts a case study on a sector of the Bega River, downstream of Timisoara.

Keywords: water quality, processes, modelling, advanced hydroinformatic tools, Romania, Timis County.

1. INTRODUCTION

Water quality expresses the suitability of water to sustain various uses or processes: water for drink, food production, irrigation, animal husbandry, fishermen, recreation etc. Each use will have certain requirements for the physical, chemical or biological characteristics of water. The quality and composition of

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surface and underground waters is determined by natural factors (geological, topographical, meteorological, hydrological and biological characteristics of catchment) and by human activity (industrial wastes, sewage, runoff from farmland, cities, factory effluents, different hydrotechnical arrangements etc.).

The nature and concentration of chemicals in a freshwater water bodies are determined by various types of natural process: physical, chemical, hydrological and biological. The most important of these processes and the water bodies they affect are show in Fig. 1. (Meybeck et al., 1996)

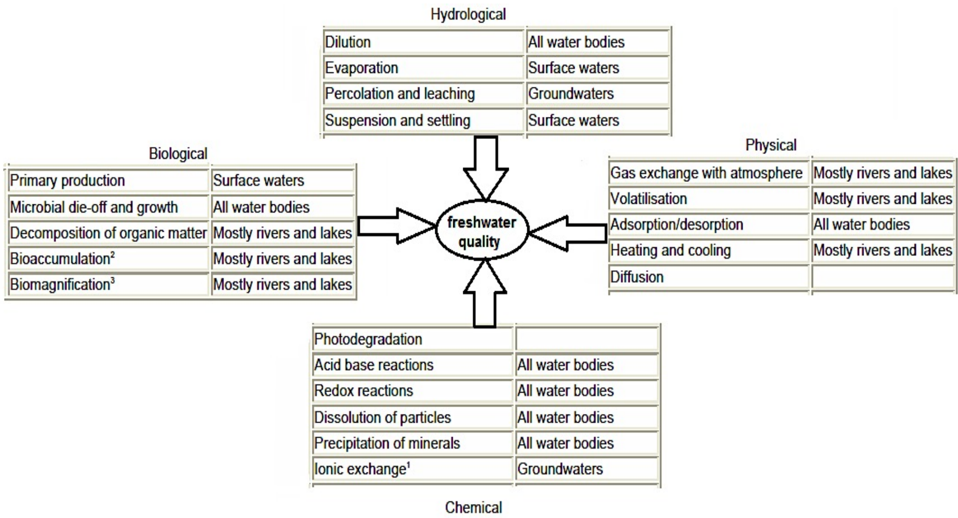

Fig. 1. ***Important natural processes determining freshwater bodies quality***

The effects on water quality of the natural processes will depend to a large extent on environmental factors brought about by climatic, geographical and geological conditions: distance from the ocean/sea, climate and vegetation, rock composition (lithology), terrestrial vegetation and aquatic vegetation. (Meybeck et al., 1996)

Increasing industrialization, the growth of large urban centers and climate changes determine increases in the pollution stress on the aquatic environment. Also, water from rivers, lakes and oceans has been considered as a convenient receiver of waste waters, these having a lower or higher degree of purification.

From human activities result particulate, dissolved and volatile materials which may eventually reach water. Dissolved materials and many particulates are discharged directly to water bodies, while the particulate and volatile materials that pollute the atmosphere are picked up by rain or snow, and then deposited on land or in water. Some sources and the polluting material released are listed in Table 1. (Meybeck et al., 1996; Meybeck and Helmer, 1996)

Water quality and human health are closely linked and influence each other. Water can be a carrier of many diseases. Water makes possible the personal hygiene measures that are essential to prevent the transmission of enteric diseases. Infectious water-related diseases can be categorized as waterborne, water-hygiene, water-contact and water-habitat vector diseases. Health effects of chemicals in water occur when a person consumes or comes in contact with water that contains a harmful amount of a toxic substance. (Meybeck et al., 1996)

Table 1. ***Sources and significance of pollutants resulting from human activities***

Sources	Bacteria	Nutrients	Trace metals	Pesticides and herbicides	Industrial organic micro-pollutants	Oils and greases
Atmosphere transport	x	xxxG	xxG	xxG		
Point sources						
Urban sewage	xxx	xxx	xxx	x	xxx	
Industrial effluent		x	xxxG	x	xxxG	xx
Diffuse sources						
Agriculture	xx	xxx	x	xxxG		
Urban waste andrun-off	xx	xx	xxx	xx	xx	x
Industrial waste disposal		x	xxx	x	xxx	x
Dredging		x	xxx	x	xxx	x
Navigation and harbours	x	x	xx		x	xxx
Internal recycling		xxx	xx	x	x	

x Low local significance
xx Moderate local or regional significance
xxx High local or regional significance
G Global significance

In this context, modeling the evolution of water quality is of particular importance for efficient water management. For the best possible forecast of water quality, the uses of advanced hydroinformatic tools are needed.

2. ADVANCED HYDROINFORMATIC TOOL MIKE11

MIKE11 advanced hydroinformatic tool, part of the DHI software products, is a professional engineering software package for the simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. MIKE11 is a user-friendly, fully dynamic, one-dimensional modelling tool for the detailed analysis, design, management and operation of both simple and complex river and channel systems. The used modules for modeling are Hydrodinamic Module and ECOLab module. (DHI, 2014a)

The MIKE11 hydrodynamic module (HD) uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. The MIKE11 HD module solves the vertically integrated equations for the conservation of continuity and momentum, i.e. the Saint-Venant equations. The basic forms of the equations used in MIKE 11 are shown in equations 1 and 2.

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \qquad (1)$$

$$\frac{\partial Q}{\partial t} + gA\frac{\partial h}{\partial x} + \frac{\partial\left(\alpha \dfrac{Q^2}{A}\right)}{\partial x} + \frac{g|Q|Q}{C^2 AR} = 0 \tag{2}$$

where: Q is discharge, x is longitudinal channel distance, A is cross-sectional area, q is lateral inflow, t is time, h is flow depth, C is the Chezy coefficient and R is the hydraulic radius.

The advection-dispersion model (AD) is based on 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:

$$\frac{\partial(AC)}{\partial t} + \frac{\partial(QC)}{\partial x} - \frac{\partial}{\partial x}(AD\frac{\partial C}{\partial x}) = -A \cdot K \cdot C + C_2 q \tag{3}$$

where: C is the concentration, D the dispersion coefficient, A the cross-sectional area, K the linear decay coefficient, C2 the source/sink concentration, q the lateral inflow, x the space coordinate and t the time coordinate. The advection-dispersion equation is solved numerically using an implicit finite difference scheme which, in principle, is unconditionally stable and has negligible numerical dispersion.

The equation reflects two transport mechanisms:

- advective (or convective) transport with the mean flow;
- dispersive transport due to concentrations gradients.

The main assumptions underlying the advection-dispersion equation are:

- the considered substance is completely mixed over the cross-sections, implying that a source/sink term is considered to mix instantaneously over the cross-section;
- the substance is conservative or subject to a first order reaction (linear decay);
- Fick's diffusion law applies, i.e. the dispersive transport is proportional to the concentration gradient.

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. (DHI, 2014a)

ECOLab is a numerical lab for Ecological Modelling. It is an open and generic tool for customising aquatic ecosystem models to describe water quality, eutrophication, heavy metals and ecology. The module is mostly used for modelling water quality as part of an Environmental Impact Assessment (EIA) of different human activities. (DHI, 2014b)

The user can use predefined ECOLab (WQ) templates or can choose to develop own model templates. The Water quality (WQ) module deals with the basic aspects of river water quality in areas influenced by human activities and containing the mathematical descriptions of ecosystems. The WQ-module is coupled to the AD module. The WQ module solves the system of coupled differential equations describing the physical, chemical and biological interactions in the river. The module is developed to describe chemical, biological, ecological processes and interactions between state variables and also the physical process of sedimentation of components can be described. (DHI, 2012)

Dependent on the nature of the water quality problem under consideration, the model can be adjusted to different levels of detail. There are six basic Model levels, which in turn can be completed for maximize the applicability of the model.

For the case study we used Model level 4, which is very applicable to general studies of the effects of discharges from municipal and industrial waste and agricultural run-off. The model was completed with phosphorus. State variables are BOD, oxygen, ammonia, nitrate and temperature.

When calculating the BOD balance, the suspended and deposited components are not applied, only the immediate oxygen demand is considered. When calculating the nitrate balance, the denitrification component is excluded. At this level the effects of ammonia on the oxygen concentration can be studied and so can the concentrations of ammonia itself. When the pH value of the river water is known then the potential concentrations of free ammonium can be estimated; all processes concerning these five state variables are included. This means that the denitrification process (a sink for nitrate) is also included. At this level BOD-DO problems including the nitrogen compounds and including the sediment/water interactions can be studied. The BOD is still described by only one state variable (DHI, 2012).

3. STUDY CASE

The associated processes with water quality was modelled on Bega River sector (City of Timisoara to Romanian - Serbian border, Bega River is transboundary water course), in order to Bega River sustainable development.

The data required for hydrodynamic modelling are: longitudinal profile of studied river sector (Fig. 2); 13 cross-sections (where was performed over time bathymetric measurements by Banat Water Basin Administration) (Fig. 3); time series: discharge hydrograph – average monthly discharge for 2005 in cross-section upstream of Timisoara – duration of simulation 1 year; boundary conditions: Q-H curve in cross-section situated downstream, on the state border (Fig. 4). (ANAR)

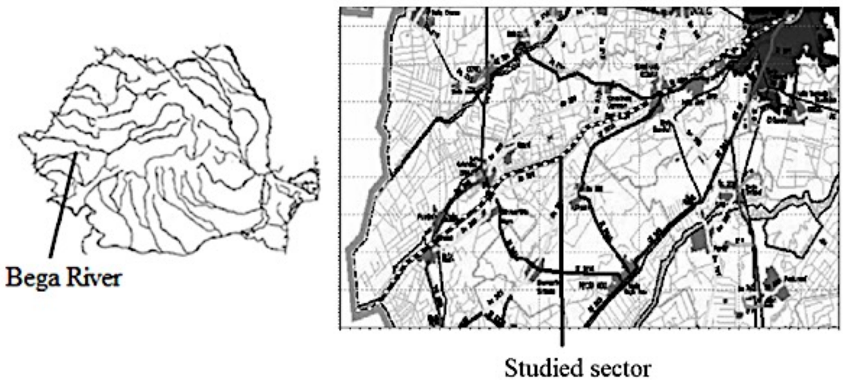

Fig. 2. Area plan of Bega River and studied sector

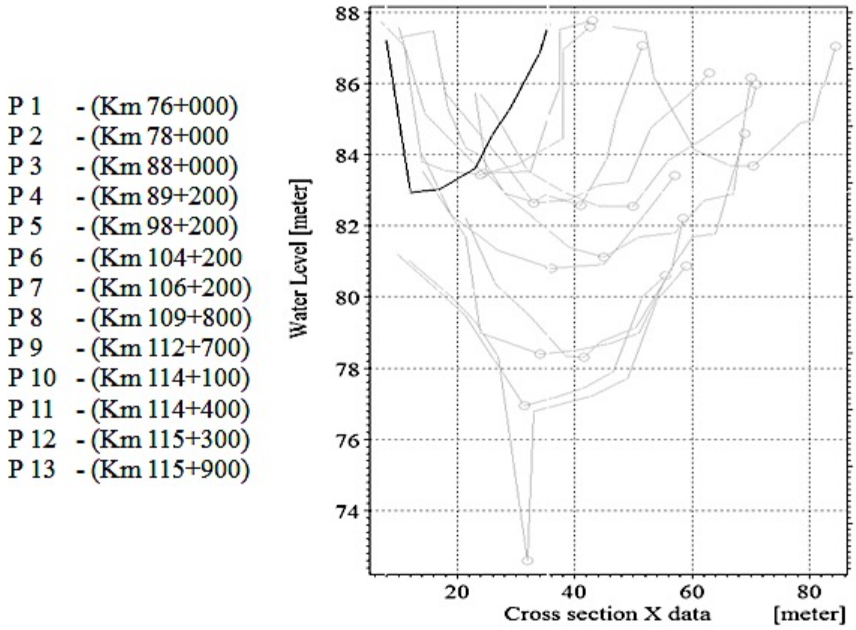

Fig. 3. Cross-sections between upstream Timisoara and RO-SRB border

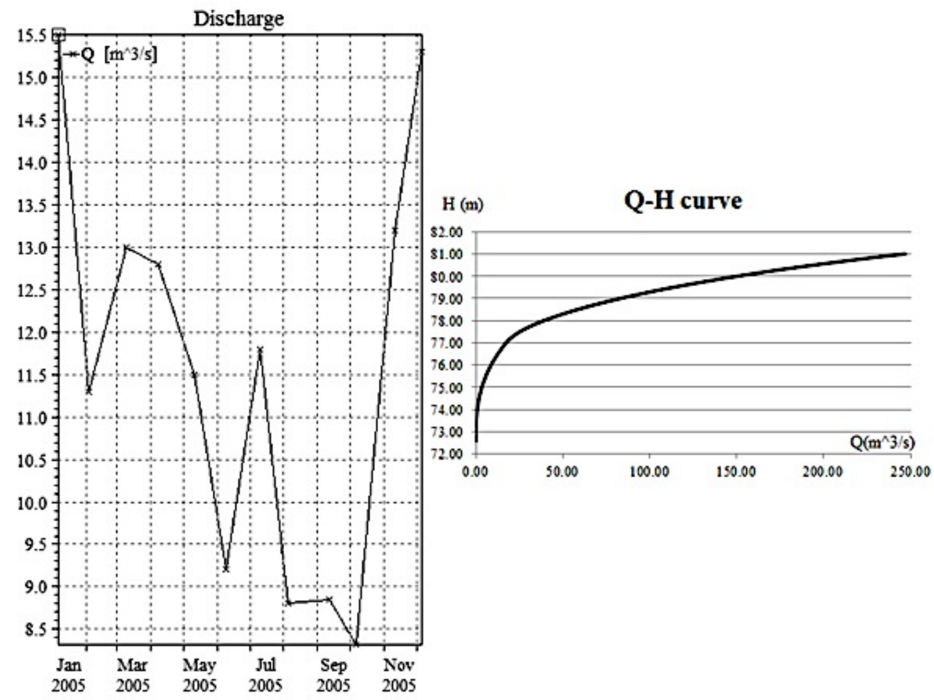

Fig. 4. Discharge and Q-H curve on studied sector

The data required for the associated processes with water quality modelling are the time series of: biological oxygen demand (BOD), water temperature, dissolved oxygen, ammonia, nitrate and phosphorus in the corresponding cross-sections upstream of Timisoara and the state border (Fig.5 and Fig.6).

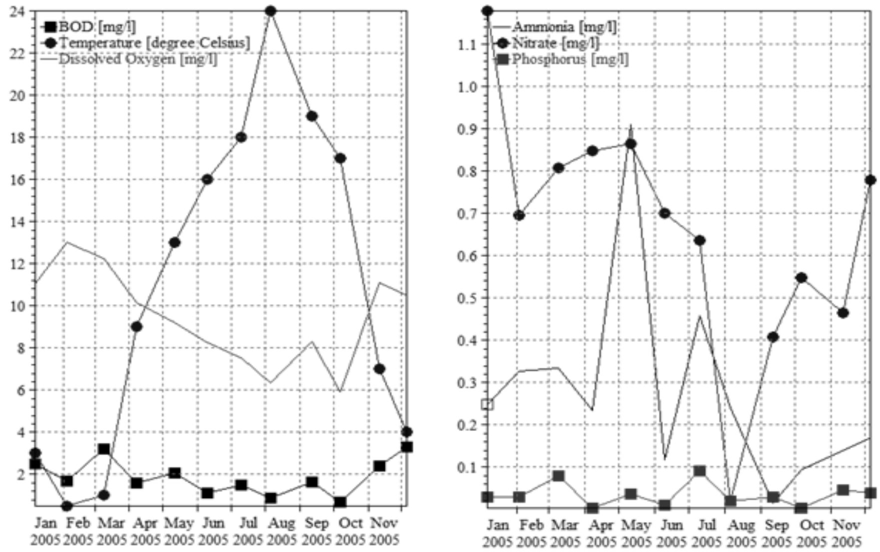

Fig. 5. Time series upstream Timisoara

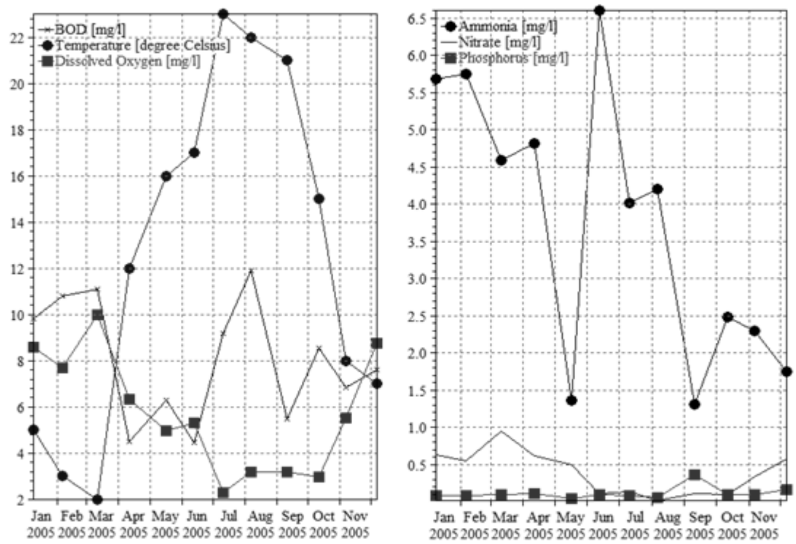

Fig. 6. Time series state border

The simulation hypotheses:

- Time step: fixed time steps, 10 seconds
- Simulation period: 1/8/2005 1:00:00 PM – 12/5/2005 1:00:00 PM

4. RESULTS AND DISCUSSION

The simulation results can be seen in the Figures 7-17. The figures show the variation of different parameters and processes along the studied river sector.

Graphs show the minimum and maximum values achieved by different parameters. From the graphs we can see the variation of all the analyzed parameters and processes, at each step of time, in each cross section along the studied sector. The analysis of the variation of the concentrations of the different nutrients is also important from the point of view of the eutrophication of the watercourse.

At each analyzed feature, important variations occur in the border section, probably due to the large slope variation of the bottom of the bed.

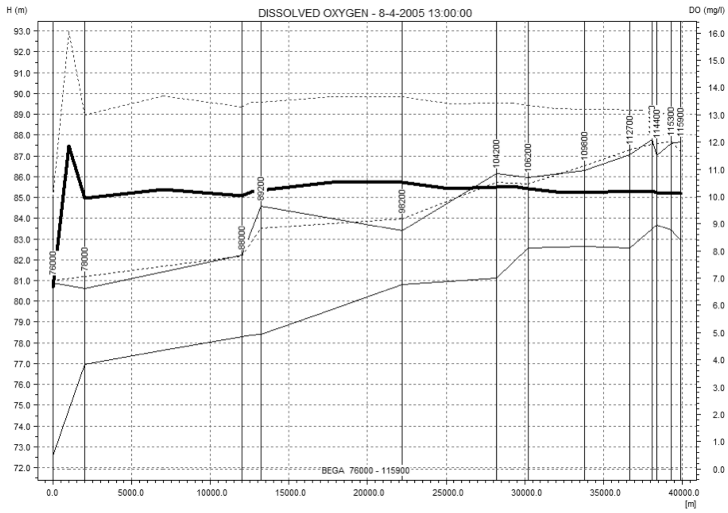

Fig. 7. Dissolved oxygen variation

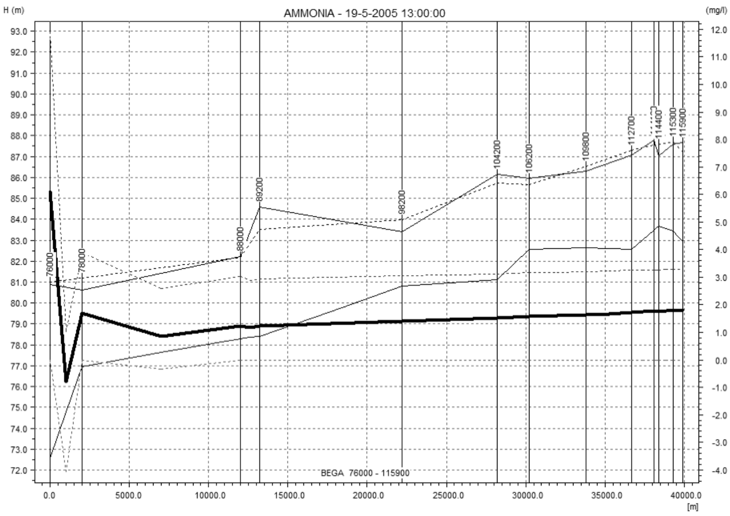

Fig. 8. Ammonia variation

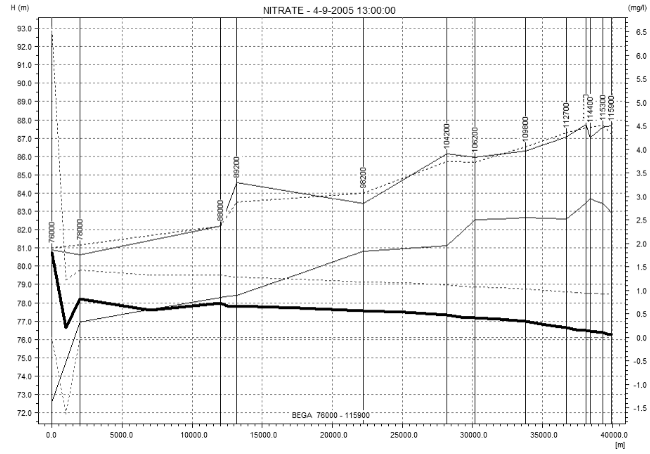

Fig. 9. Nitrate variation

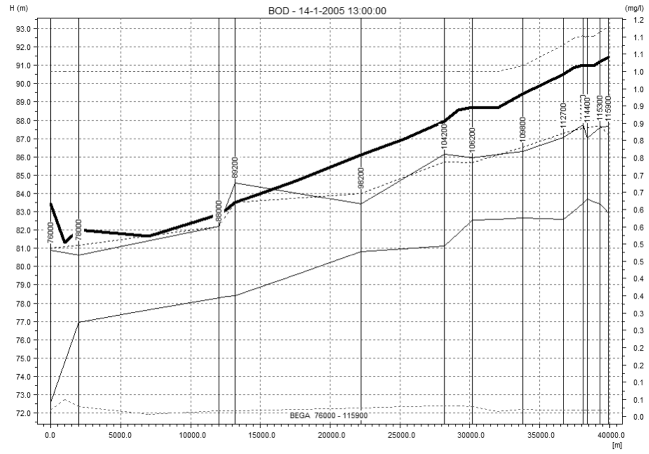

Fig. 10. BOD variation

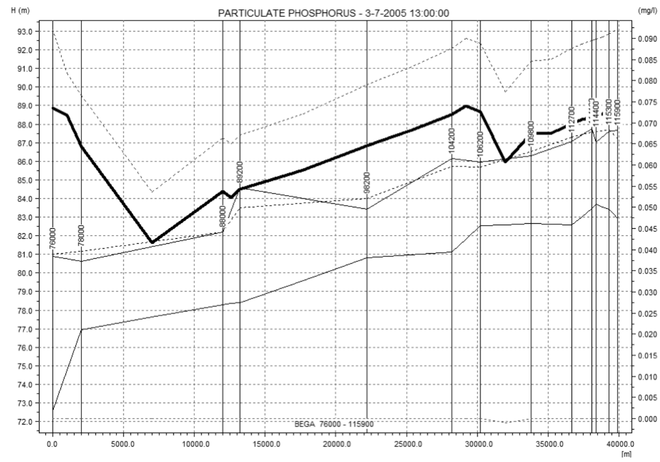

Fig. 11. Particulate phosphorus variation

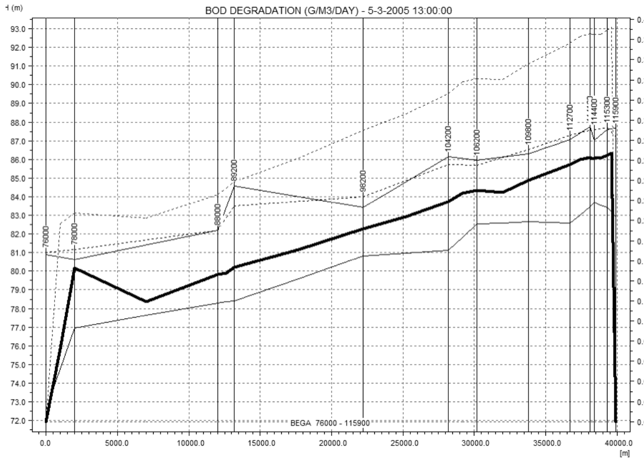

Fig. 12. BOD degradation variation

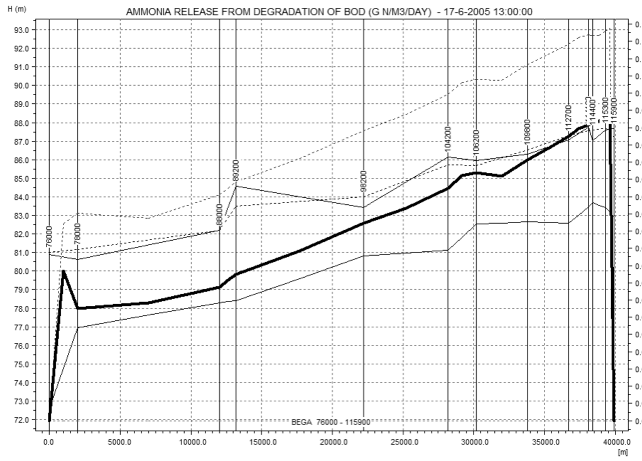

Fig. 13. Ammonia release from degradation of BOD

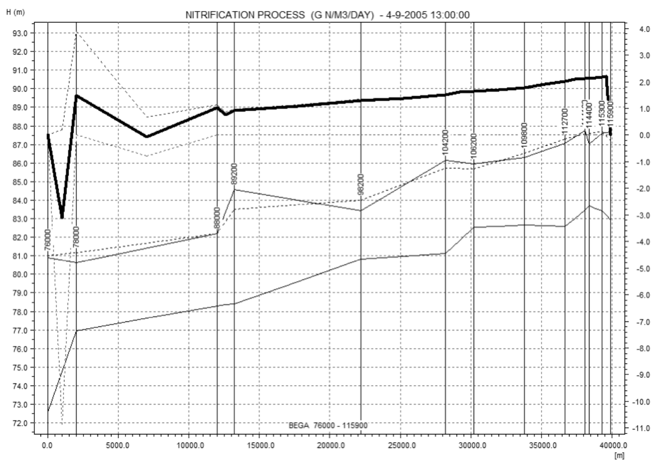

Fig. 14. Nitrification processes

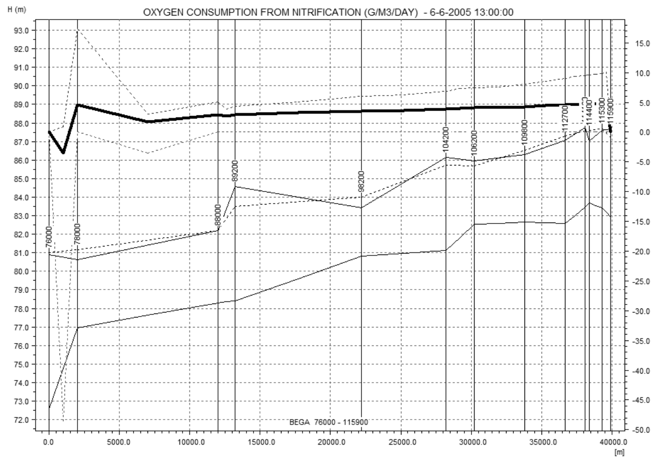

Fig. 15. Oxygen consumption from nitrification

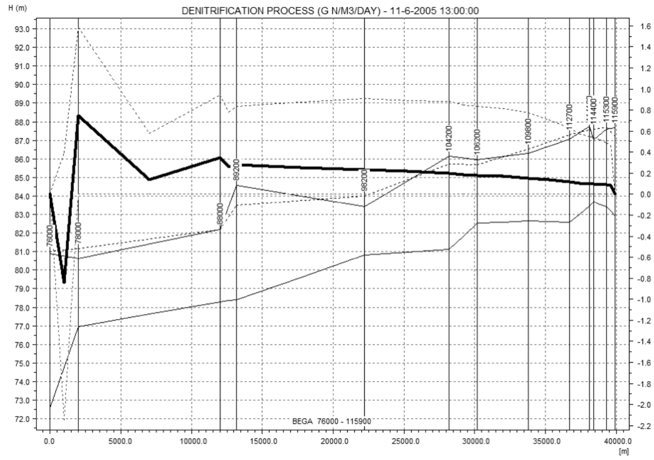

Fig. 16. Denitrification process

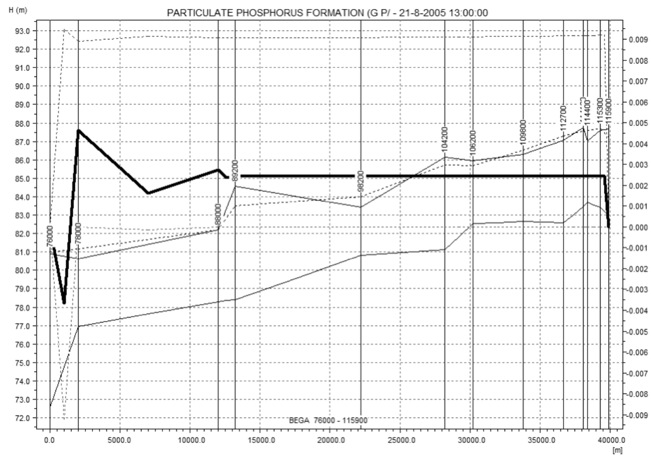

Fig. 17. Particulate phosphorus formation

The tracking of the water quality evolution on the Bega channel is of particular importance because it is a cross-border watercourse and must fall within the limits set by the international treaties between Romania and Serbia.

5. CONCLUSIONS

Understanding of physical, chemical and biological processes in water bodies plays an important role in the design, development and implementation of performant and durable water resources management plans. An important step to achieve management plans of water resources is water quality evolution forecast in watercourses. This requires the creation and use of complex water quality models and, respectively, the development of advanced hydroinformatics tools to solve these models and provides satisfactory results with regard to the status of water quality both in normal periods and in case of accidental pollution. The ECOLab model used is a high-performance model, because it can integrate and simulate a series of processes that take place in water, not only the forecast of the evolution of the concentration of different chemicals. The mechanism of development of various processes associated with water quality determines the state of flora and fauna in water bodies, which in turn influences water quality (eg eutrophication).

The detailed results obtained from modeling and forecast increase general understanding of the evolution of water quality in water bodies and related ecosystems and support authorities to act (in time and space), in case of accidental pollution, according to the plans of action in emergency situations, based on plans risk management of pollution of watercourses. These results can also be used to optimize the operation of water treatment plants for drinking and use in various industries, and of wastewater treatment plants for wastewaters coming from various users.

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