

Water Quality Modelling Using Mike 11

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In Romania, 62% of the surface is occupied by land used in agriculture. This clearly shows the impact of these activities on the environment. Although agricultural activities ensure the living for a considerable part in Romanian population, the agriculture also contributes to environmental damage and decreased quality of life. Fertilizers have been used widely in agriculture, disregarding the specific needs of the crop, the time of their application and the way they should be applied. Therefore, the most intensive polluting effect is caused by excessive use of nitrates. Accumulation and uncontrolled migration in soil and groundwater of the fertilizers can cause significant disturbance parameters of environmental factors. The main function of the chemical fertilizers is to prevent lack of nutrients from the ground. Because the chemical fertilizers are easily washed out by rain they can cause pollution in surface waters. This paper presents an application of the DHI tool, Mike 11, for the simulation of water quantity and quality of river Gladna and Surduc Lake. The results show that this 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 river Gladna and Surduc Lake. 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 modeling, Water Framework Directive, Surduc Lake, fertilizers, nitrate, ammonia

Natural resources are classified into two distinct categories: renewable and nonrenewable. Among the most important renewable natural resources are water, air, soil, flora, fauna, solar and wind energies.

Any anthropogenic intervention on one or the other induces inevitable consequences on the other. Application of destructive methods can cause some irreversible changes of natural resources, really changing their “renewable” character.

Water, air and soil are the most vulnerable environmental resources, but also the most frequently affected by the polluting factors having direct and severe consequences not only on environmental quality, but also on human health and other living organisms. The most frequent factors of environmental pollution are usually a side effect of industry, but in the recent year, there has been noticed a concerning growth of polluters coming from agriculture.

Water pollution by nitrates and nitrites, phosphates and other substances represents a significant impact of agriculture on the environment.

In order to limit the effects of nitrate pollution, there were proposed codes of good agricultural practices. These codes recommend the fertilization periods, use of fertilizers near watercourses and on slopes, methods for manure storage and for spreading, as well as crop rotation and other land management measures [9, 11, 12].

Nitrates are substances commonly found in nature but human activity increases them, particularly in water surface and groundwater.

Because of their relatively unstable characteristic, nitrates tend to turn into nitrites. The main nitrates sources are fertilizers used in agriculture – both natural and synthetic. Manure, decomposition of organic waste and wastewater discharge can all turn into polluters. Application of fertilizers on fields with large slopes can cause nitrogen loss by runoff, which depends on factors like slope, soil

characteristics, cultivation system, erosion control works, and – in particular, rainfall. The risk is greatest if a rainfall follows a recent light applying of fertilizers. [9].

Excessive amounts of sediment or soil transported from agricultural lands affected by erosion, are accumulated in surface water bodies having a strong negative impact on them: capacity of storage is diminished, aquatic organisms are destroyed, in terms of quality cannot be used as drinking water sources [7, 9, 12, 13].

Experimental part

Modeling with MIKE 11 program

The MIKE 11 hydrodynamic module (HD) uses an implicit, finite difference scheme for the computation of unsteady flows in rivers. The module can describe sub-critical as well as super critical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space).

The MIKE 11 model provides a graphical user interface and requires a river network to be drawn on a grid (mesh) of cells that represent geographical area to a referenced scale and /or coordinates [2-4].

The Network editor consists of two views: a tabular view, where the river network data are presented in tables, and a graphical view, where graphical editing of the river network can be performed as well as data from other editors can be accessed for editing.

In this editor, entire network of the river Gladna was drawn. The example of this setup is in figure 1.

Cross sections: The topographical description of the area to be modelled is achieved through the specification of cross-sections of the channel (and flood plain) which lie approximately perpendicular to the direction of flow [2, 3].

A. Single Cross-Section Includes:

A) Raw Data figure 2.

- Information on Section and Radius Type

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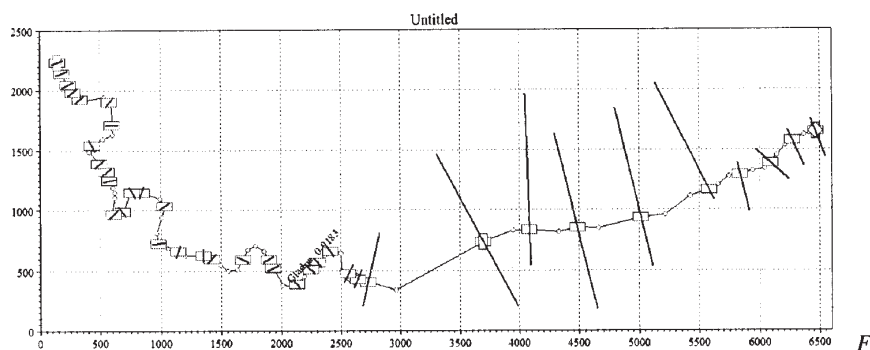


Fig.1. Network Gladna in Mike 11

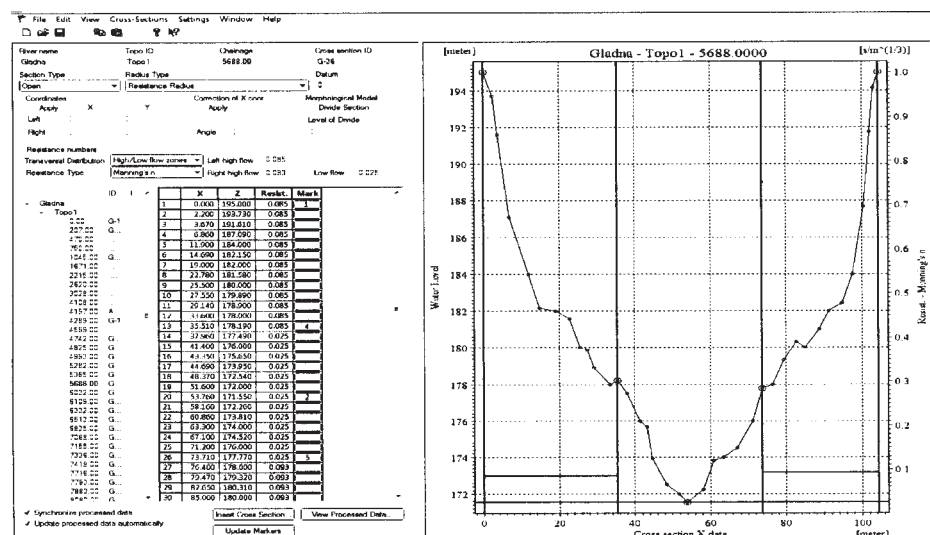


Fig. 2. Gladna River raw cross section information in MIKE 11

- Raw Data (X, Z-values defining the bed level)
 - Information of Lateral Roughness Formulation
 - Markers defining extent of the Cross-Section
- B) Processed Data tables including figure 3.
- Hydraulic Radius
 - Area and Storage Width
 - Conveyance

The Boundary Editor

This editor is the most important part of the modeling system. The boundary editor is used to specify boundary conditions of MIKE11 model. It is used not only to specify common boundary conditions such as water levels and inflow hydrographs but also for the specification of lateral flows along the river reaches, solute concentrations of the inflow hydrographs, various meteorological data and certain boundary conditions used in connection with structures applied in MIKE 11 model, [2,3,10,11].

In figure 4 are presented the boundary conditions along the river within the model domain where time-varying or constant lateral distributed in flows (or outflows) need to be specified or meteorological boundaries applied.

UHM module simulates the runoff from single storm events by the use of the well known unit hydrograph techniques. Unit hydrograph is a hypothetical unit response of the watershed to a unit input of rainfall. In the unit hydrograph module the excess rain is calculated assuming that the losses to infiltration can be described as a fixed initial and constant loss, a proportional loss (the rational method) or by the SCS curve number method figure 5.

The water quality module solve a system of coupled differential equations describing the most important physical, chemical, and biological interactions in the river.

The Water Quality (WQ) module deals with the basic aspects of river water quality in areas influenced by human activities: e.g. oxygen depletion and ammonia levels as a result of organic matter loadings. The WQ-module is coupled to the AD module, which means that the WQ module deals with the transforming processes of

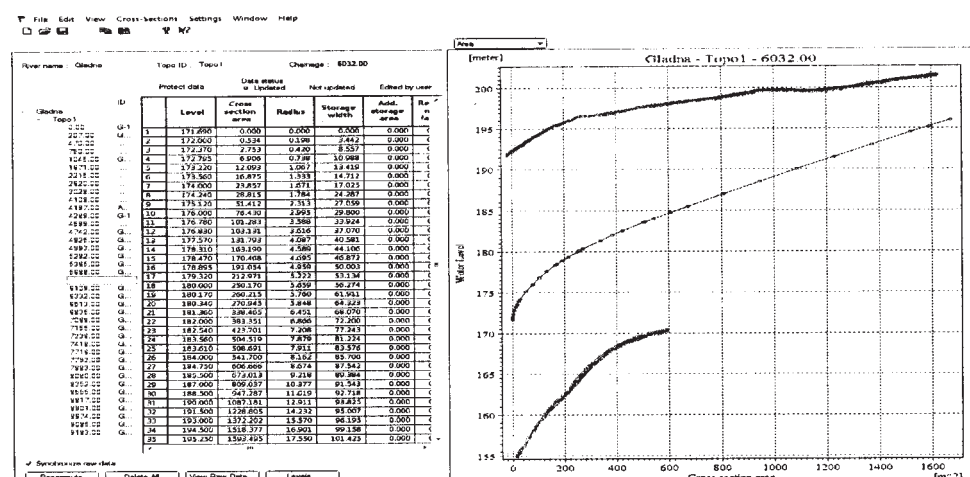


Fig. 3. Gladna River processed cross section information in MIKE 11

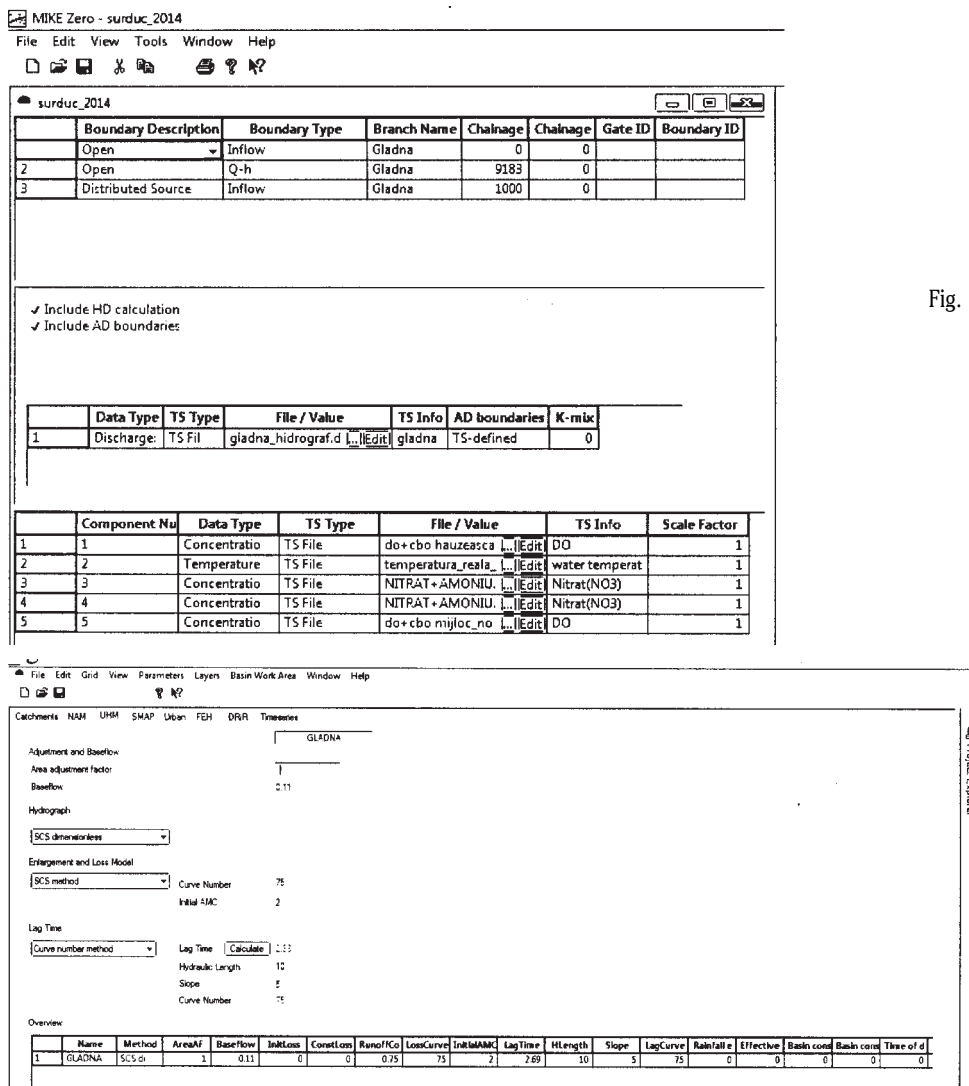


Fig. 4. The boundary editor in Mike 11

compounds in the river and the AD module is used to simulate the simultaneous transport process, [1, 3, 5].

The nitrogen cycle starts with an assimilation of free nitrogen from the atmosphere (e.g. by blue green algae) or uptake by algae and plants of ammonia from the water. Degradation of dead organic matter leads to a release of the organic bound nitrogen in the form of ammonia (ammonification). The water quality modules of MIKE 11 consist of coupled differential equations. In order to solve these equations taking the interactions between each differential equation into account a numerical integration is applied [3, 4, 6].

Three different build-in integration routines exist in MIKE 11: RKQC: Fifth order Runge-Kutta with Quality Control, RK4: Fourth order Runge-Kutta, EULER: Euler or Linear Solution. The most accurate result will be calculated when using RKQC (Default routine).

The equation describing the evolution of processes related to ammonium concentration is, [3]:

$$\frac{dNH_3}{dt} = Y_p K_p - BOD_p \theta_p^{(T-20)} \quad \text{BOD for organic matter from sediments}$$

$$+ Y_d K_d - BOD_d \theta_d^{(T-20)} \quad \text{BOD for dissolved organic matter}$$

$$+ Y_s K_s - BOD_s \theta_s^{(T-20)} \quad \text{BOD for suspension organic matter}$$

$$- K_4 NH_3 \theta_4^{(T-20)} \quad \text{nitrification}$$

where: Y_p is the ammonium content from sediments organic matter; Y_d is the ammonium content in dissolved organic matter; Y_s is the content of organic matter in suspension.

Reactions related to the evolution of nitrate concentrations are given by the following equation [3]:

$$\frac{dNO_3}{dt} = K_4 NH_3 \theta_4^{(T-20)}$$

nitrification process

or

$$- K_6 NO_3 \theta_5^{(T-20)}$$

denitrification process

where: K_4 is the denitrification rate [1/day] or [(g/m³)^{1/2}/day]; θ_5 , the temperature coefficient.

Results and discussions

In river basins with intense agriculture, pollutants (originating from the application of fertilizer, manure or pesticides) are transported from the fields to the rivers by rainfall runoff. This type of pollution is called non-point (or diffuse) pollution. The main sources of pollution along the river Gladna is the agriculture and domestic waste water. According to the Corine Land Cover (CLC 2000) in the Banat watershed, the largest area is occupied by forest, followed by arable agricultural areas and then mixed agricultural areas. It should be noted that urban and industrial areas occupy an area of 3.89% of the Banat watershed. Agricultural area is approx. 50.00 % of the total area of Banat watershed, [7].

In this study, nitrogen dynamics are modeled on river Gladna and Surduc Lake localised in watershed Banat. Simulation of water quality in river Gladna and Surduc Lake was performed using MIKE 11 program. It was taken into consideration the nitrogen sources from agriculture due to runoff. Based on this input, concentrations of ammonium (NH₄-N) and nitrate (NO₃-N) in the river water are modeled in MIKE 11 by taking into consideration advection and

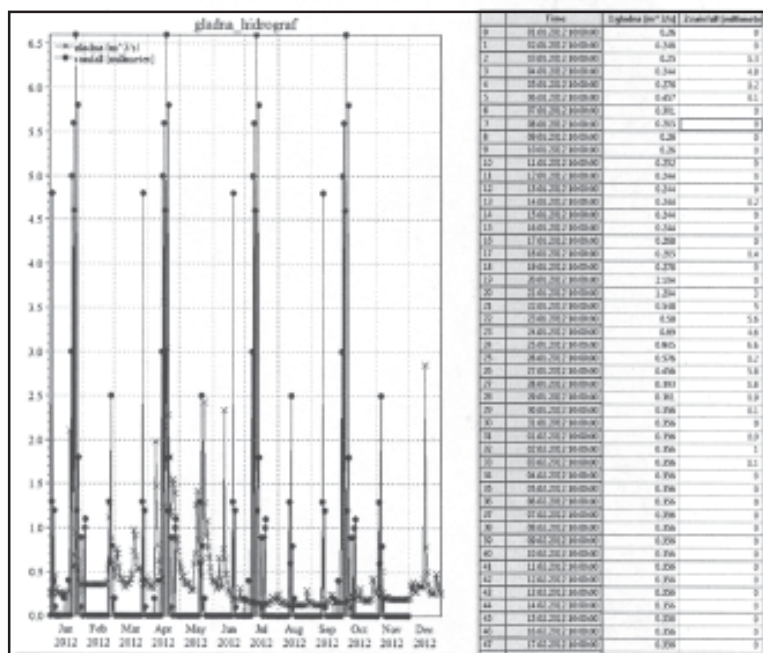


Fig. 6. Meteorological and hydrological data from Gladna river

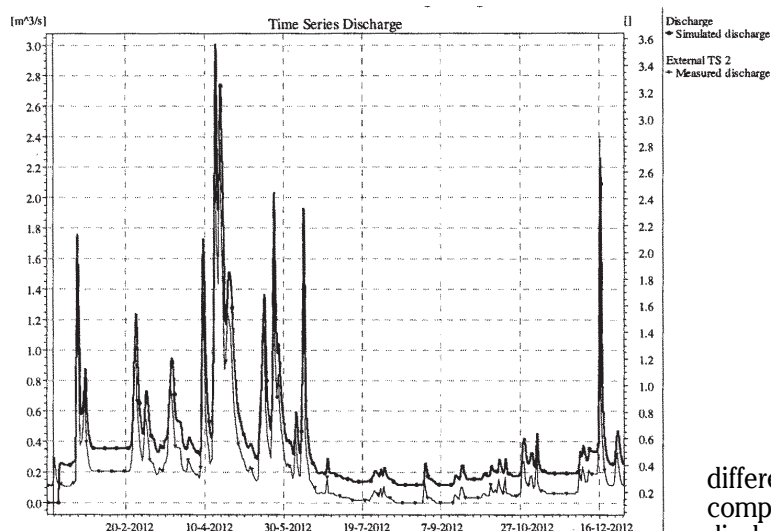


Fig. 7. Comparison between measured and simulated discharges on river Gladna

dispersion and the most important biological and chemical processes. We used a template of Mike 11, WQ Level 4. This model level is very applicable to general studies of the effects of discharges from municipal and industrial waste and agricultural run-off.

The main factors considered for water quality analysis were: Dissolved oxygen (DO); Water temperature; Ammonium (NH₄-N); Nitrate (NO₃-N); Biochemical oxygen demand (BOD₅). The build-in integration routines used for water quality modelling on river Gladna is RKQC: Fifth order Runge-Kutta with Quality Control, [2- 5, 7, 8].

The calibration of the model was done on the basis of available measured water quality data. We chose to study river Gladna and lake Surduc because according to the Banat basin management plan, river (Gladna) upstream and downstream of Surduc Lake is located in a sensitive area vulnerable to nitrate and nutrients.

The simulation period was one year for the hydrodynamic model and 7 months for model WQ. Observed flows, rain and temperature daily data were hereby used figure 6.

The hydrodynamic and advection dispersion modules of MIKE 11 model were calibrated and validated by comparing simulated results with the observed values at

different points along river Gladna. Figure 7 shows the comparisons between the measured and the simulated discharges on Gladna River.

Statistical measures were applied to these results to quantify the accuracy of model and to estimate the errors in the simulated results. Coefficient of determination (R²) describes the degree of co-linearity between simulated and observed data. R² describes the proportion of the variance in measured data explained by the model, [10]. The value of R² ranges from zero to 1. A high value of R² indicates less error in variance, and typically values greater than 0.5 are considered acceptable [10]. Based on the results, there is a satisfactory agreement between observed and simulated discharges figure 8.

The coefficient of determination is computed as [10]:

$$R^2 = \frac{n(\sum XY) - (\sum X)(\sum Y)}{[\sum X^2 - (\sum X)^2][\sum Y^2 - (\sum Y)^2]}^{1/2}$$

where: R² = Coefficient of determination

As it can be seen in the figure 8 and 10, the coefficient of determination (R²) is 0.884 for observed and simulated discharges and 0.998 for NO₃-N which can be characterized as good.

After an analysis between the simulated and the measured data for NO₃-N indicate that the general performance of the Mike 11 is satisfactory (fig. 9).

The processes simulated using WQ module from Mike 11 along the river Gladna can be seen in figure 11.

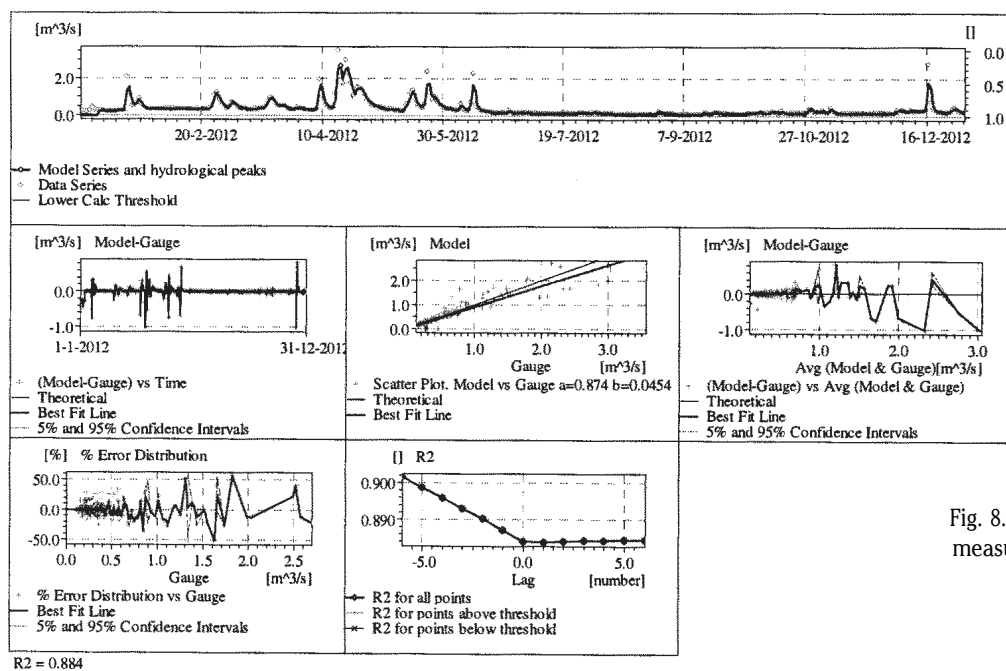


Fig. 8. Statistical analyses for discharges measured and simulated discharges on river Gladna

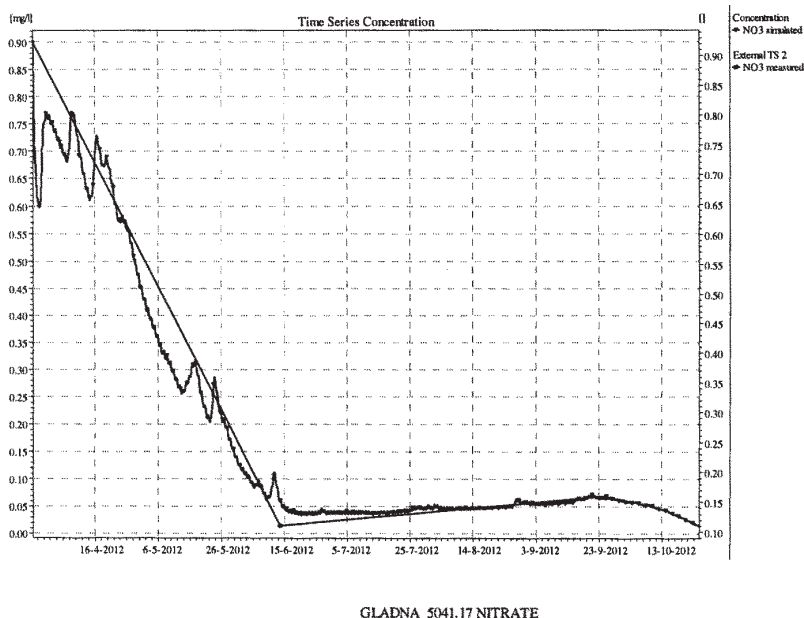


Fig. 9. Simulated and measured $\text{NO}_3\text{-N}$ at the Gladna river

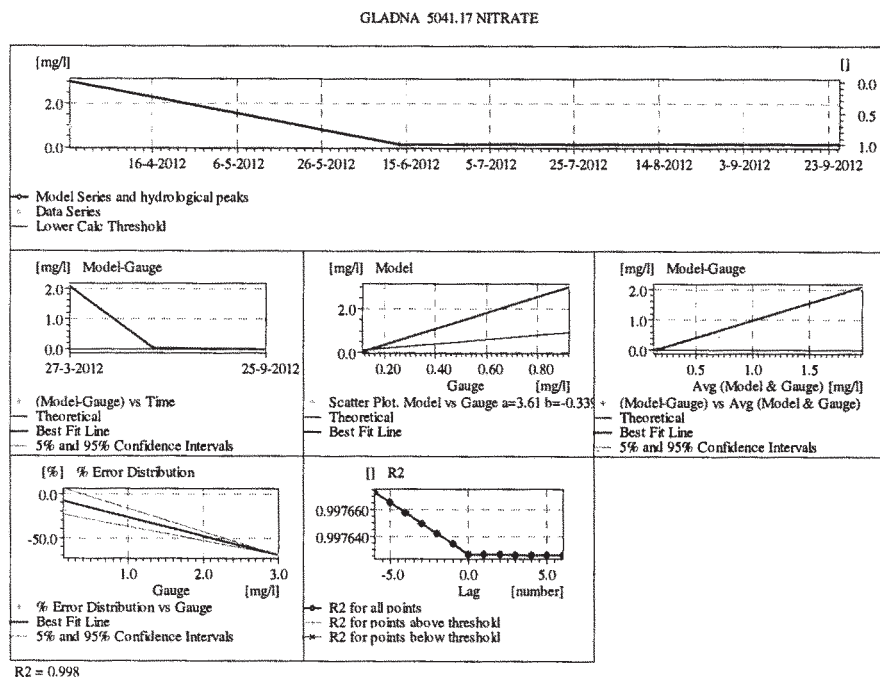


Fig. 10. Statistical analysis for $\text{NO}_3\text{-N}$ on Mike 1

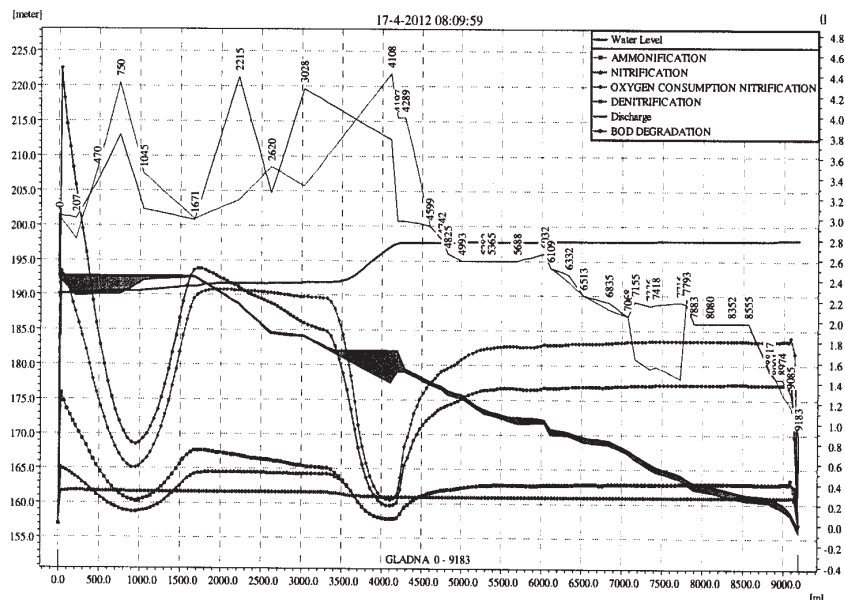


Fig. 11. Simulation of processes along river Gladna

Conclusions

The identification of potential problems with N losses quickly leads to a list of potential solutions. The calibrated model responses are in good agreement with the field data and can be used as scenario generators in a general strategy to conserve or improve the water quality. The comparative analysis between measured and simulated data showed that MIKE 11 is able to predict sufficiently accurate $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ loads. The results of the water quality model indicated that the nitrate concentrations increase along the course of the river in this downstream part of its catchment as a result of the significant pollution pressures (mainly agricultural and urban waste).

Variation in time of processes such as nitrification, ammonification and denitrification present a sharp variation at the beginning sector of the river then having approximately linear variation, and for processes such as decomposition of BOD_5 and oxygen consumption for nitrification process, increase where the water level is small and decrease where the water level is high.

After the simulation of water quality in the river Gladna, it can be concluded that standards regarding NH_4 , NO_3 are met.

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