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WATER QUALITY MODELING ROLE IN IMPLEMENTATION OF THE WATER FRAMEWORK DIRECTIVE

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Abstract. *Regarding the complexity of the issue, the mathematical models become increasingly important for implementation of Water Framework Directive, particularly in terms of pollution control and management of water resources quality in river basin areas. The models can be used in all the phases of WFD implementation, especially in evaluation of effects of pressure on water status, analysis of future actions effects on improvement of the aquatic ecosystems status and defining of cost-effective monitoring programs.*
The paper stresses the importance and role of application of mathematical water quality models in implementation of the WFD and a number of models and a software system being developed at the Faculty of Civil Engineering and Architecture of Nis is presented, as well as the fundamental s and principles on whose basis the model and the program system have been developed.

Key words: *integral water resource pollution control, water quality modeling, Water Framework Directive*

1. INTRODUCTION

Numerous conventions and declarations in the last twenty five years promoted a new attitude towards natural resources, including water, on the basis of sustainable development and traced general lines, approaches and methods that should be pursued in the future. This relates, in particular on the International Conference on Water and the Environment in Dublin and the UN Conference on Environment and Development in Rio de Janeiro, held in 1992, where Integrated Water Resources Management – IWRM was proclaimed and adopted.

The adopted IWRM policy on the principle of sustainable development obliges all the world countries to prepare national action plans for conversion of the adopted principles into an operative action strategy at national, regional and local level, and to join the creation of approaches, measures and methods for ensuring the sustainable development.

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Numerous international conventions, agreements and contracts adopted at various levels were in the developed countries of the world a starting ground for undertaking of a number of activities, from harmonization of legal regulations, institutional organization regarding water and environmental protection, provision of finances etc., to the concrete plans regarding preventive protective measures, water resources and ecosystems rehabilitation and realization of water use projects in accordance with the sustainable development principles. Initiatives and activities conducted so far, or are underway, have already created the desired effects in the developed countries, in some regions and international river basins.

The European Union determined its long-term policy of waters by a document "European Water Framework Directive 2000/60/EC, 2000" (WFD). This directive introduces new principles and standards in creation and realization of the sustainable usage and protection of water policy. Regarding that the European Union states went furthest in finding the concrete solutions, and that they have synchronized their activities in the past, the Directive contributes to integration and unification of the water resources management policy on the principles of sustainable development in the European area. The basic principles, contained in the Directive, are implemented not only by the member states of the EU, but all the candidate states and several countries which started the joining process. It is obvious that this document became a basis for undertaking the concrete plans of water resources management within the river basins in Europe.

Irrespective of the fact whether the EU will include all the countries of the Old Continent or not, the WFD will become a fundamental document for management of water in Europe. Having in mind the developing countries' state strategy of integration into the EU, including Serbia, it is obvious that these countries, in order to harmonize with the WFD, must radically reorganize the water resources domain, that is, their manner of managing the water resources, ways of financing, legislature, public participation, education, enhancement of the role of scientific institutions etc.

2. THE ROLE OF WATER QUALITY MODELING IN IMPLEMENTATION OF WFD

The most important characteristic of the WFD is its integral treatment of the issue of waters, on one hand, and the environmental protection on the other hand. In other words, the water resources are considered the most important segment of the environment, so the protection of the environment is inconceivable without the adequate protection of waters. In the preamble of the WFD, it is pointed out that its most important goal is comprised in achieving "good environment status" of all water in the EU territory until 2015.

Considering the extraordinary complexity and long term character of the WFD, the European Union adopted in 2001 a common strategy of implementation of the directive (figure 1). The EU WFD implementation strategy includes the following activities:

- Exchange of information
- Development of guidelines for concrete activities
- Data basis and information management
- Testing and evaluation of obtained data

The first activity comprises application of all contemporary information technologies, based on the computer support and internet communications. Within the EU WFD implementation strategy, the most important is the second strategy, providing for the development of methodological guides for concrete actions in this area. Some of these actions are an absolute novelty in comparison to the current understanding and traditional scientific and professional approach in the area of usage and protection of waters, so a new adequate and single technology for determination of certain new categories of water resources ought to be developed. The third activity comprises data acquisition and processing, model definition and adoption of a common system of river basins coding as well as a synthesis of obtained data. The fourth activity comprises selection of pilot basins, where the applied methodology would be verified and evaluated.

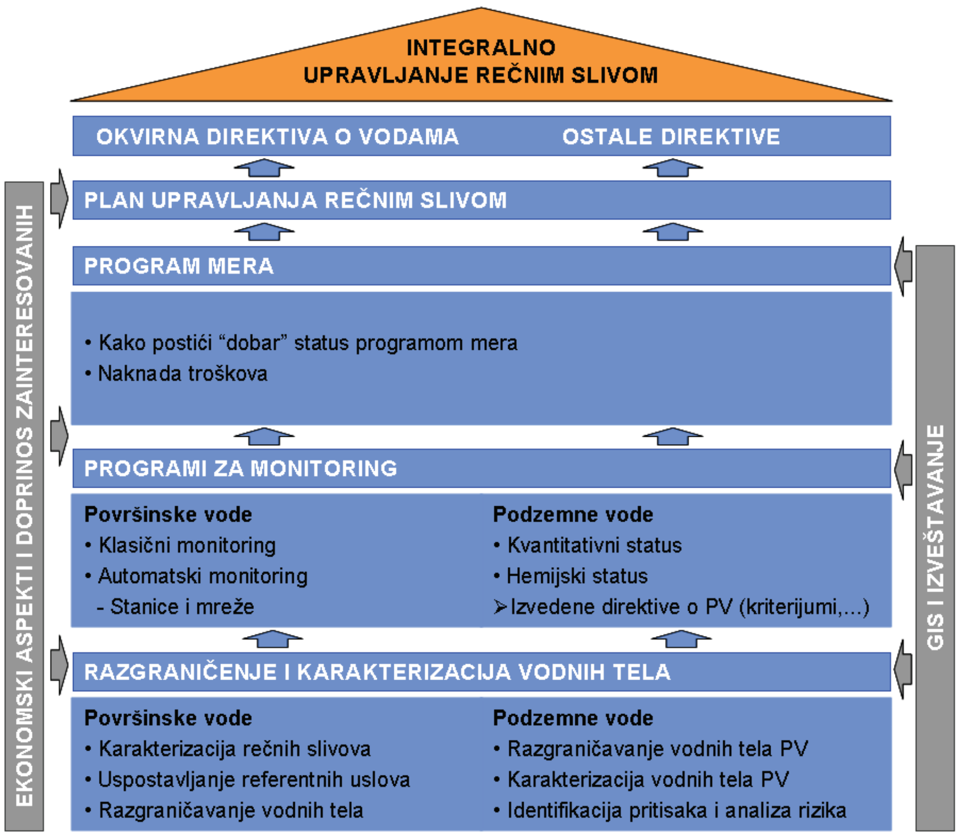

Fig. 1 Implementation of the Water Framework Directive

Realization of the mentioned activities for implementation of the WFD, requires application of integrated tools for river basin water resources management, including simulation and optimization models and systems for support to decision making, which changes the classical approach to model application and decision making (Figure 2).

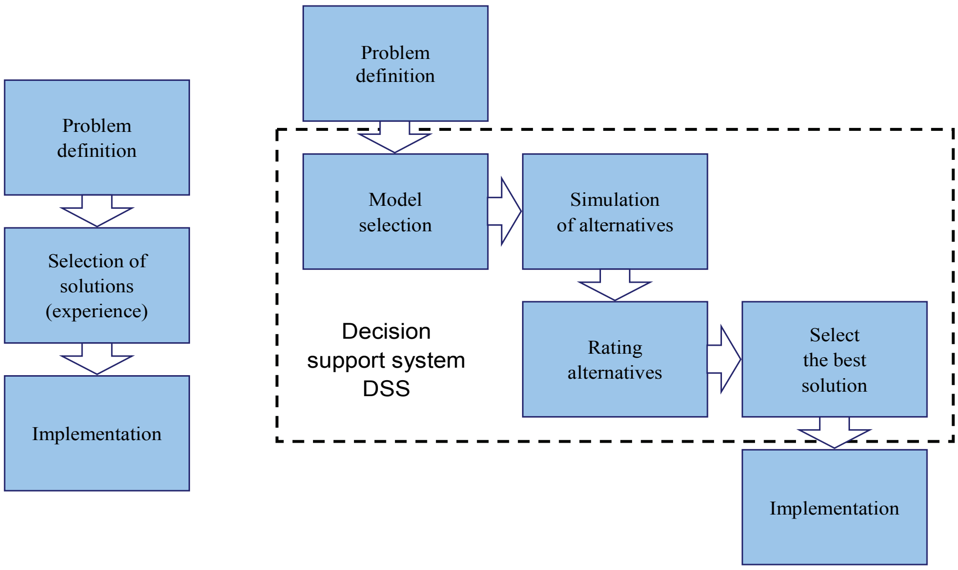

Fig. 2 Decision making patterns: A. classic decision-making pattern,
B. modern decision-making pattern – decision making support system

In the practice up to now, the mathematical models of water quality have been rarely used for support to river basins management and implementation of water policy. These models have been most frequently used for simulation and presentation of the water quality status in the water course of the basin, and the management decisions have been mostly made on the basis of experience. However, the contemporary approaches to this issue ascribe a greater importance to the application of these models, so they now have several very interesting possibilities of application. The summary of potential application of water quality models in river basins management in WFD implementation was presented in figure 3. (Goethals et de Pauw, 2001).

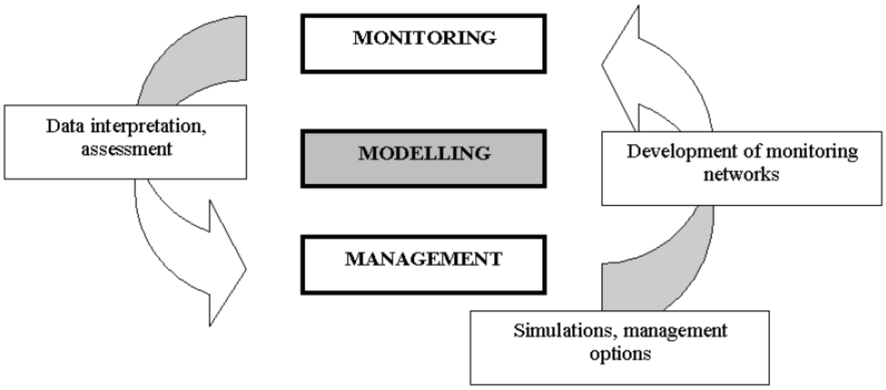

Fig. 3 Potential application of the model for river basins monitoring and decision making

Primarily, water quality models can serve for a quality interpretation of water resources status, and the causes of the status change can be detected. Further, the evaluation methods can be optimized. Secondly, these models can facilitate an analysis of the effects of future actions on the aquatic ecosystem and can be support to the selection of the most sustainable options. Third, these models can assist in filling in the gaps in our knowledge of river basin and defining of cost-effective monitoring programs (Vanrolleghem et Al., 1999).

One of the most important segments of the WFD refers to the determination of pressures, as they are the main causes of water pollution and their influence on water bodies of surface and ground waters. The basic concepts and their relations to this issue are defined by the DPSIR scheme (Driving force-Pressure-State-Impact-Response scheme). The water bodies pressure and impact determination is very complex, and comprises a series of tasks defined by the documents accompanying the WFD.

Regarding that the issue is very complex, the water quality models can prove to be very useful for evaluation of pressures impact on the water status and research of efficiency and probable effects of various measures on the environment (Figure 4).

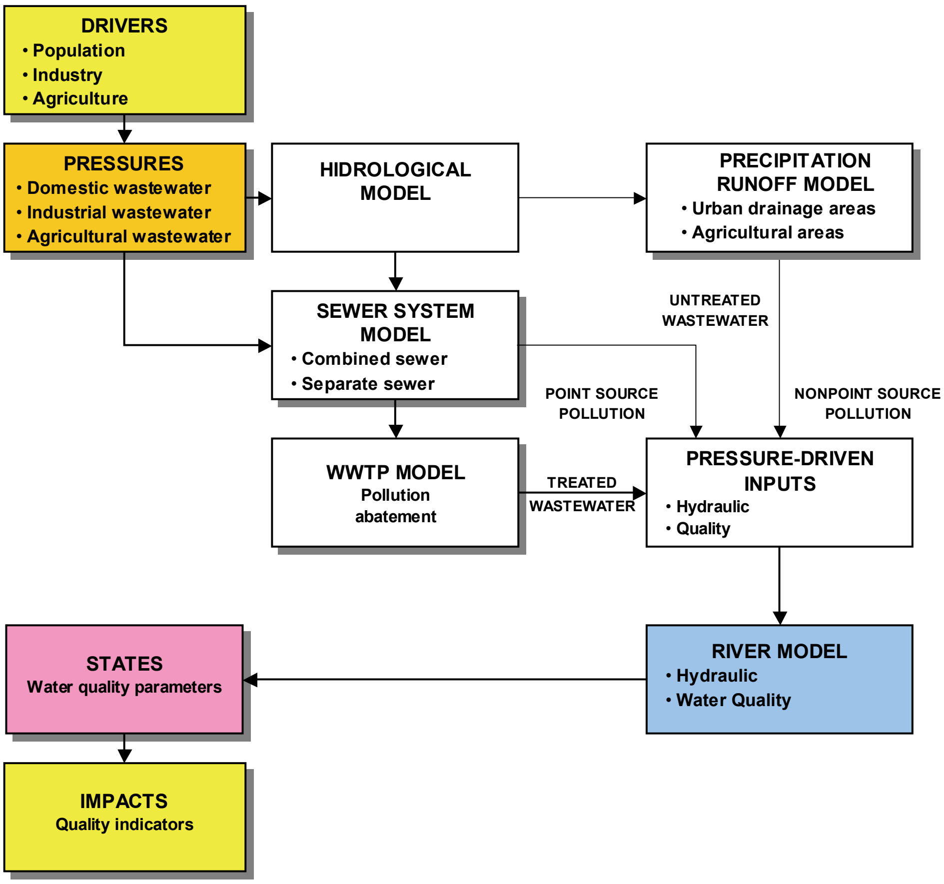

Fig. 4 Integration of mathematical modelling in the DPSIR scheme

The mathematical models for river basis water course quality monitoring may include population, industry and agriculture as driving force and hygienic and sanitary systems, systems for waste water treatment and terrain runoff as Pressures.

Mathematical modeling of water quality facilitates prediction of quantitative reaction and status of aquatic environments (State) and impacts for defined pressures on aquatic environments, that is, human and natural activities in its surrounding. When correctly selected and used under strictly defined conditions and limitation, the mathematical model can be a very powerful tool in planning and management processes, both water quality in river basins, and of water resources in general.

Analyses of pressures and impacts can be carried out applying a detailed, process-oriented, numerical model of the entire system of surface and ground waters, but such a model requires a large, relevant set of input data and information, which cannot be always provided. Therefore, in practice simple hydrological-hydrogeological, models are often used comprising the most important elements of the entire system.

Clearly, the models should be used with caution, that is, the user must understand the assumptions and information used for building and calibration of a model, as well as uncertainties in model prediction. Yet, a correctly developed and managed in interaction with decision makers, it could give an efficient platform for analysis, understanding and discussion, with the goal of decision support.

The first step in the development of a model for monitoring and management of water quality in the water course by the "pollution propagation" method is development and calibration of a hydraulic model and verification of hydraulic data (figure 5). This model represents a necessary support for provision of water mass flow parameters and pollution wave propagation.

After that, the quality model is developed and calibration of temperature and dissolved oxygen is preformed, and then of all other parameters of water quality.

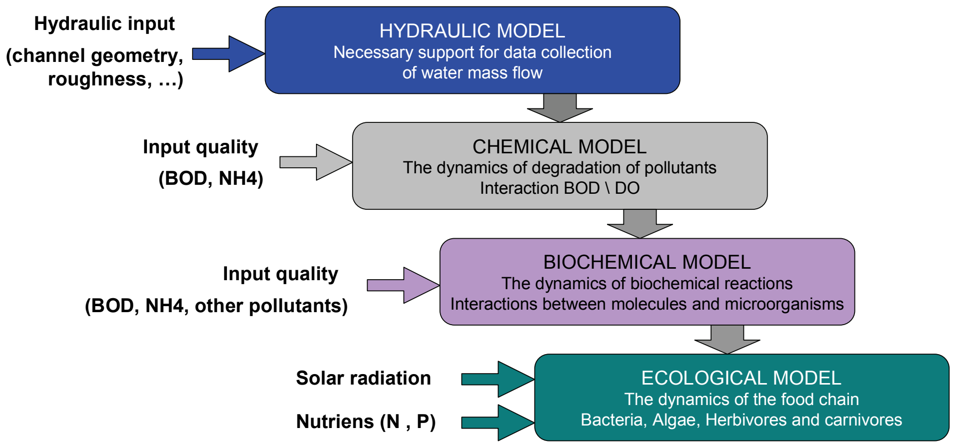

Fig. 5 Water Quality Model Structure

When modeling the water course water quality status, the water course should be observed along its entire length, taking into account the status of its tributaries, which facilitates the analysis of impacts of existing concentrated polluters on the water course, not only at the location of pollution discharge, but further downstream and in the wide basin area (figure 6). Such an approach to the problem, ensures a realistic picture of the water quality status in water courses, monitoring and control of the established picture, planning and defining of new relationship and requirements in the system polluter – water course – downstream user to all the organs and institutions managing and organizing usage of water in the basin.

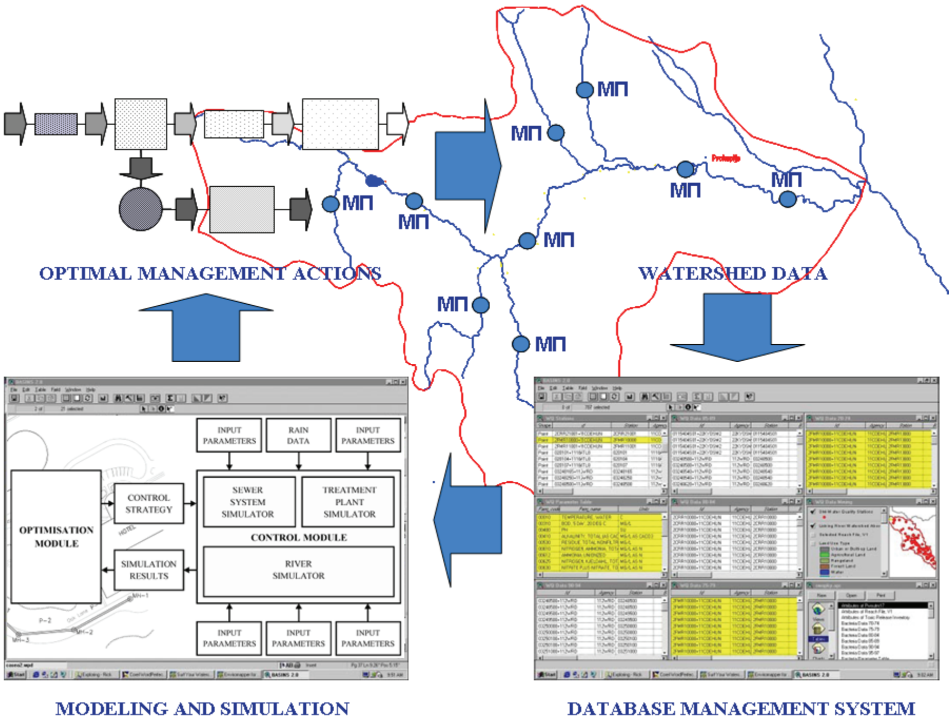

Fig. 6 Scheme of an applicative model for simulation and management of water quality in the water course in the basin

The information obtained in this way can be used for purposes of planning and undertaking of necessary measures for protection and preservation of the existing water resources, which, on one hand, when it comes to the existing concentrated polluters, comprises assessment of the required degree of waste water treatment in order to retain the water courses water quality within the planned category, or if it is not possible, transition to "cleaner technologies" and even dislocation of the critical polluters to some more favorable locations, from the aspect of the receiving capacity of a water course, and on the other hand, it comprises planning of development of the existing and the optimal selection of new concentrated polluters in relation to the receiving capacity of a water course, which was not paid due attention until now.

3. Preparation of Data for Water Quality Modeling

Regarding the complex issue to be solved, the requirements of water quality modeling are extremely complex and specific and connected to the action of a number of variables, indeterminacies, randomness and changes in the course of time, in terms of input parameters, required output statues of the system, goals, criteria, limitations etc. successful satisfaction of these requirements calls for provision of a very wide set of quality and reliable data and information about the basin, water resources and processes taking place in it, water resource structures and systems, users and polluters of water resources, etc.

For the purpose of correct modeling, it is necessary to conduct research composed of four basic activities: (1) collection, processing and formation of datasets about social and economical factors and water consumption in a considered area; (2) recording of characteristics of river water quality status characteristics, its tributaries, and all the significant polluters; (3) processing of research results and definition of all the necessary coefficients for quality modeling; (4) measurement of characteristic water quality parameters at a defined sections of a water course, for the purpose of calibration, verification and testing of the model.

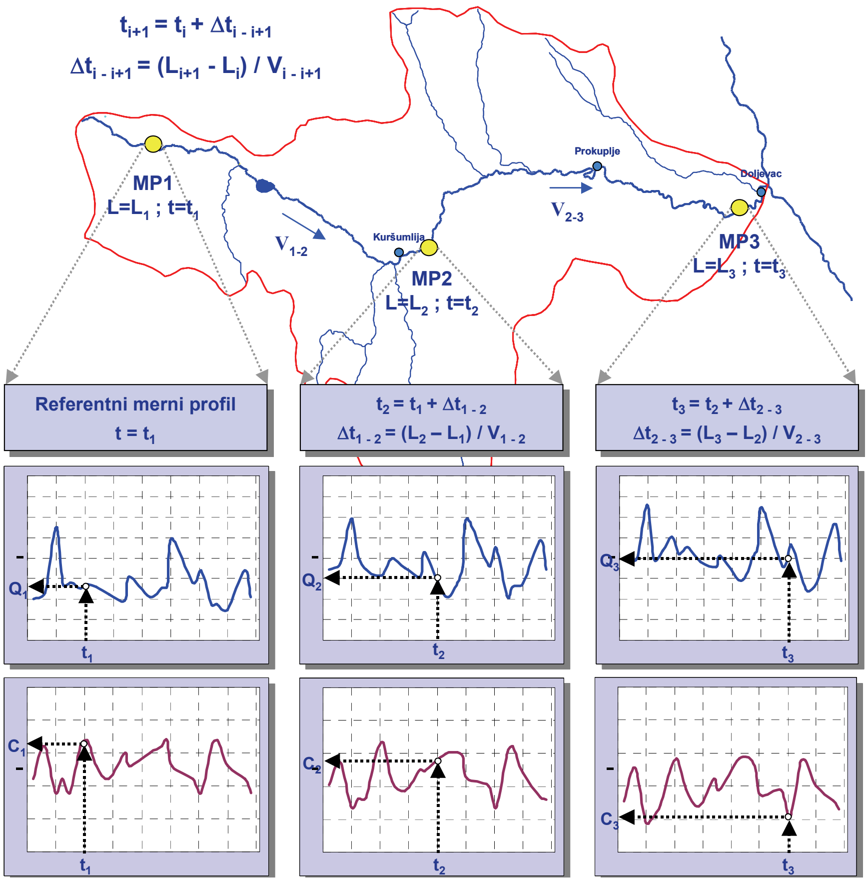

Fig. 7 Pollution propagation method

In the analyses of social-economical factors, it is necessary to collect all the necessary data on population, industry, waste waters, atmospheric waters, land use in the basin, usage of artificial fertilizers and pesticides and a number of other important data. The biggest problem in such analysis is collection of realistic development plans of considered areas. Within these plans, all the available data on the river basin water quality and polluters in it are collected.

Recording of river water quality must be performed on the pre-defined sections, and on the occasion of taking samples, care must be taken of the rate of water mass transport and propagation of pollution wave, in order to continuously monitor the same mass of water (figure 7). For this goal, it is necessary to provide water flow rate measuring.

Water quality analysis must include, apart from the physico-chemical parameters, also bacteriological and biological parameters. These analyses must be accompanied by the flow rate measurements.

The model calibration is done on the basis of one or more cycles of field research aimed at bringing the model into such a state, to present a precise presentation of the observed river system within boundaries of imposed criteria. It is necessary to conduct the research in such a way the results of terrain research can be used for calibration, verification and testing of the model. Calibration, verification and testing of the model are the necessary procedures to obtain an authentic forecast.

After completion of the mentioned research procedures, one may commence simulations on the model and forecasting of river water quality (Figure 7).

Experience has shown that in the river basins where there is no network of water quality monitoring, for the correct water quality modeling, it is necessary to perform no less than four cycles of field research, for various hydrological cycles. It is very important to include various hydrological cycles, because at low water table, rivers are dominated by the pollution originating from the concentrated sources, whereas at high water table, the pollution is dominated by the non-concentrated polluters.

In those river basins, where there is a network of monitoring stations for water quality monitoring, from the data obtained by the measurement when for the modeling the input data chosen should be in accordance with the pollution propagation method. When it comes to the classic monitoring, regarding the manner and time of sample taking for water quality measuring, it is often very difficult. Adequate and reliable data in accordance with the pollution propagation method can be obtained from the automatic monitoring stations.

4. CONTINUOUS WATER QUALITY MONITORING

Monitoring is carrying out the long term standardized measuring and monitoring of water with the goal of defining the status and water quality changes.

International Organization for Standardization (ISO) defines monitoring as: "programmed process of sampling, measurement and later recording or signaling, or both, of various water characteristics, most often with the aim of evaluation of their compliance with the defined goals.". Monitoring can be:

- Monitoring is a long-term, standardized measuring and observation of water medium, for the purpose of defining its status and trends,
- Surveys is an intensive program of measuring and observation of water quality with a specific intention

- Surveillance is a continuous, defined measuring and observation with the goal of water quality management and performing of operational activities.

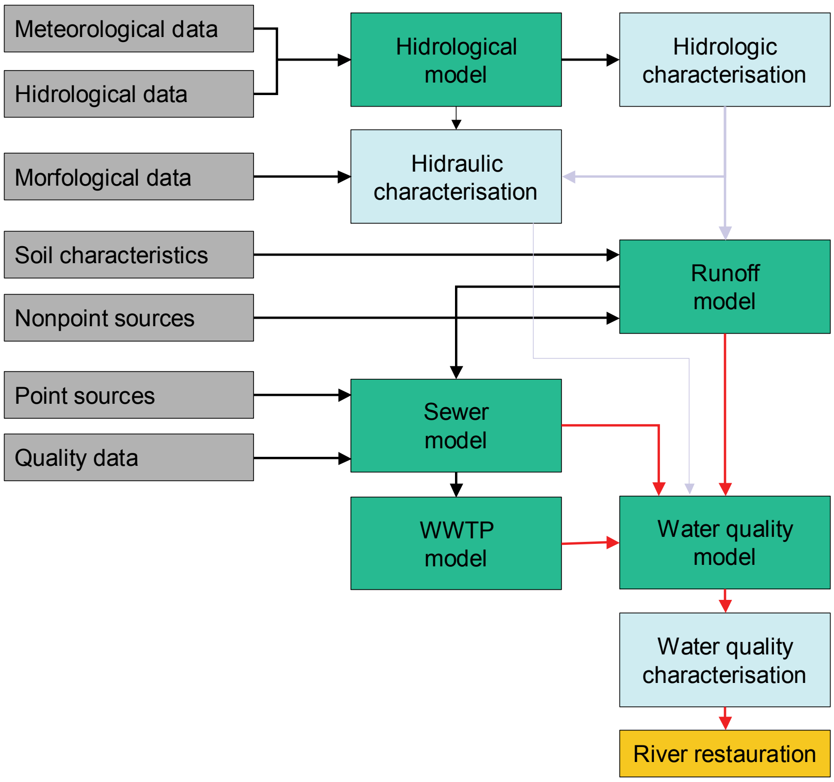

Fig. 7 Methodological scheme of the river basin watercourses water quality monitoring model

Field sampling and monitoring are strategically important for water quality modeling and more sustainable integrated water resources management. One of the vital first steps in IWRM is the collection of an inventory that characterizes existing watershed conditions. Relevant features include geographic and environmental aspects (e.g., land use, topography, wetlands), infrastructure (e.g., supply, sewerage and drainage), municipal data (e.g., numbers of people, growth rate, regulations, by laws), pollution sources/discharges (point and nonpoint sources, e.g., landfills, underground storage tanks), and the characteristics of receiving surface waters and groundwaters (indicators of flow rates and physical, chemical, biological, and microbiological quality) [11].

Figure 8 shows stages in sampling/monitoring as an adaptive process and its input data.

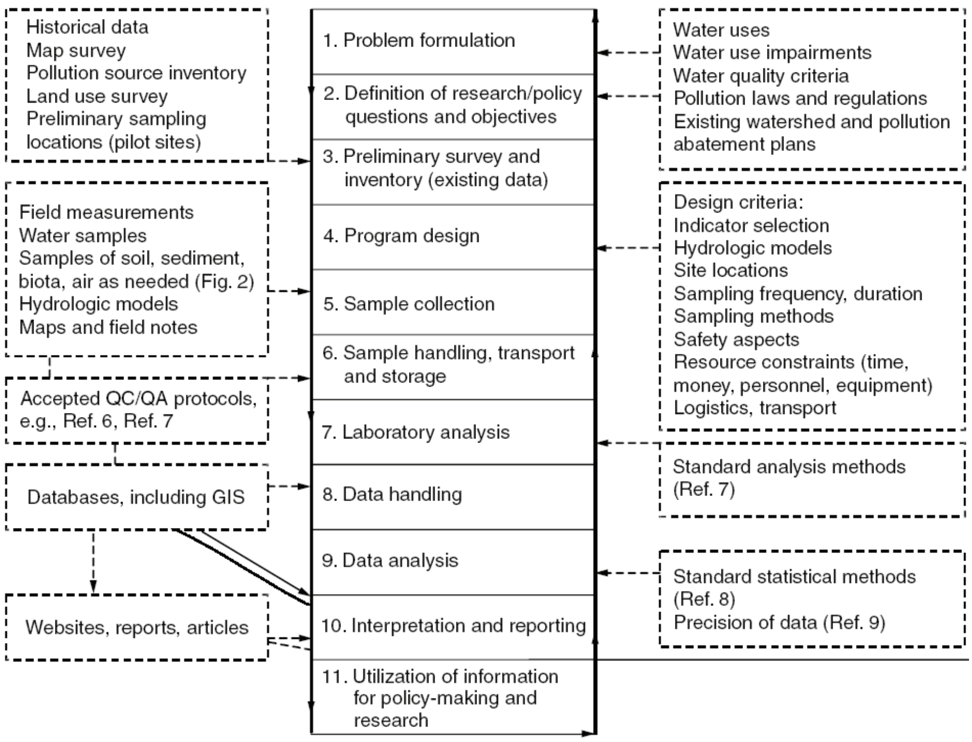

Fig. 8 Stages of water quality monitoring [11]

Automatic monitoring stations (figure 9) are constructed with the following goal:

- Indication of short term and long term changes in the quality of waters, as a basis for taking measures within water management
- Early detection of incidents and illegal discharges
  – Assessment of danger potential of some discharges
  – Assistance in identification of polluters/sources of water pollution
- Sampling Platform for various purposes, e.g.:
  – Detection of incidents and illegal discharges
  – Standard monitoring program
  – Special options
- Prevention: continuous monitoring of water courses has a deterrent effect on the polluters, and assists in prevention of illegal discharges of pollution
- Other, e.g. verification of water conservation success.

Automatic monitoring should ensure a part f the database of sufficient capacity so as to allow:

- Evaluation of ecological status of water bodies (chemical and biological),
- Determination and evaluation of water pollution,
- Determination of load and substance transport.

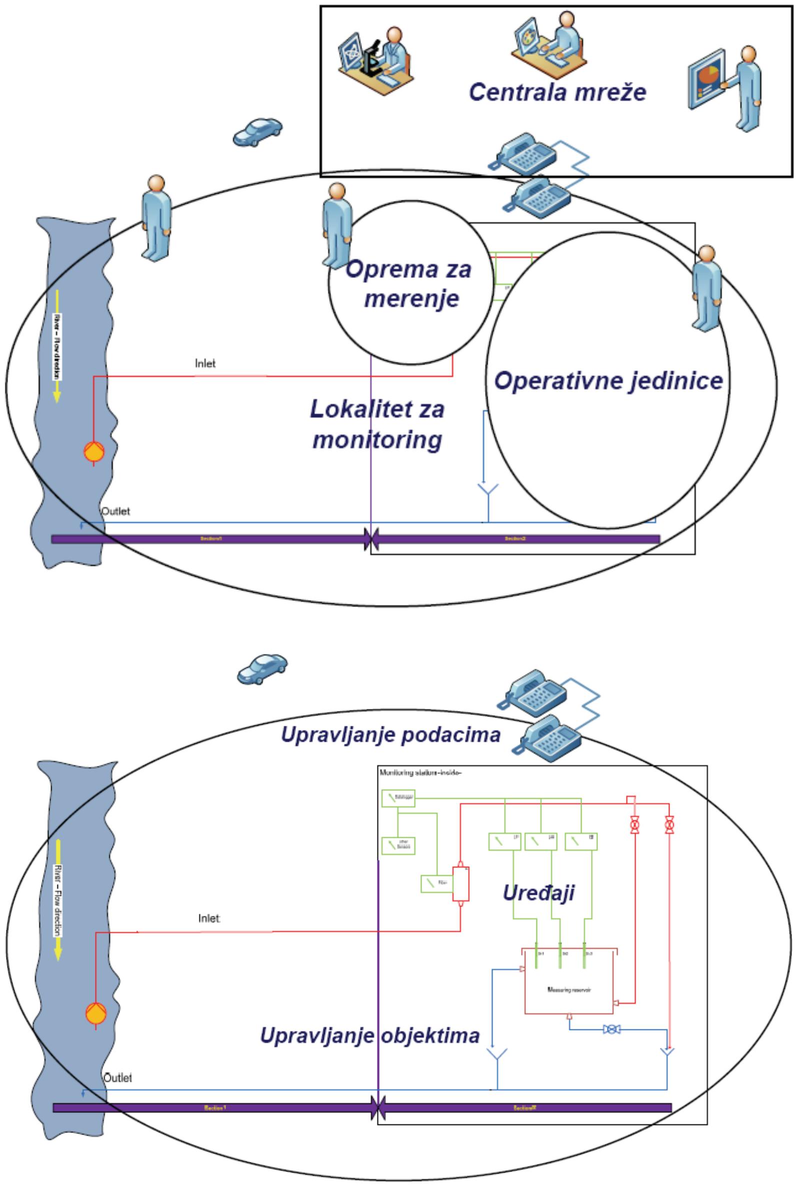

Fig. 9 Automatic monitoring station

The automatic monitoring stations are planned for long-term usage (longer than 20 years) at the locations where it is necessary to:

- Have long term-monitoring of water courses water quality, including pollutions, their level/extent and trends;
- Have compliance with international national legal obligations (e.g. EC directives, national regulative, inter-state agreements);

- Have monitoring in compliance with the previously determined requirements such as the goals/standards of the water quality, e.g. according to the directives 76/464/EEC and 2000/60/EC;
- Detect and monitor the critical events in waters, and collect evidence in the cases of unforeseeable events;
- Analysis of substance transport and loads;
- Monitor water usage impact.

In conceiving the monitoring program, the results of pressures and impacts analyses are used, so they provide appropriate information or validation of the analysis, and evaluation of action program efficiency

In the water management, the research programs are enhanced by adding the measuring stations for recording and display of water quality dynamics.

Continuous water course water quality monitoring in river basins and at polluters' effluxes not only provides a correct modeling of the water quality status, but also management of the water quality based on the model in real time.

5. CONCLUSION

Successful common solution of the water supply issue and discharge of waste water in accordance wit the principles of WFD can be attained applying a systemic analysis, whose integral and important part is the mathematical model for calculation of pollution of a receptor.

Such approach facilitates numerous analyses, primarily planning and taking actions for protection and conservation of existing water resources, which on one hand, when it comes to the existing concentrated polluters, comprises assessment of the required degree of waste water treatment in order to retain the water courses water quality within the planned category, or if it is not possible, transition to "cleaner technologies" and even dislocation of the critical polluters to some more favorable locations, from the aspect of the receiving capacity of a water course, and on the other hand, it comprises planning of development of the existing and the optimal selection of new concentrated polluters in relation to the receiving capacity of a water course, which was not paid due attention until now.

All this creates a realistic basis for implementation of WFD with rational usage of material and professional potentials, in accordance with the sustainable development principles and integral management of water resources in the river basins.

Mathematic modeling is accompanied by the significant field research activities which are as basis of any successful river water quality simulation and forecast .

Continuous water course water quality monitoring in river basins and at polluters' effluxes not only provides a correct modeling of the water quality status, but also management of the water quality based on the model in real time

Even though the development of the continuous river basin water quality monitoring system is a long lasting and expensive process, an immediate action is called for, especially if the increasing lack of quality water for industry and population is considered.

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ULOGA MODELIRANJA KVALITETA VODE U IMPLEMENTACIJI OKVIRNE DIREKTIVE O VODAMA

Dragan Milićević, Slobodan Milenković, Olivera Potić

S obzirom na složenost problematike, matematički modeli postaju sve značajnija za implementaciju Okvirne direktive o vodama, posebno u domenu zaštite od zagađenja i upravljanja kvalitetom vodnih resursa na prostorima rečnih slivova. Modeli se mogu primeniti u svim fazama implementacije WFD, posebno pri proceni uticaja pritisaka na vodni status, analizi efekata budućih akcija na poboljšanje statusa akvatičnih ekosistema i definisanju cost-effective monitoring programa.

U ovom radu ukazuje se na značaj i ulogu primene matematičkih modela kvaliteta vode u implementaciji Okvirne direktive o vodama i daje se prikaz modela i programskog sistema, čiji je razvoj u toku na Građevinsko-arhitektonskom fakultetu u Nišu, postavki i principa na osnovu kojih su model i programski sistem razvijani.

Ključne reči: *integralna zaštita vodnih resursa od zagađenja, modeliranje kvaliteta voda, okvirna direktiva o vodama*