Water Quality Management Based on the Integral Approach

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We offer a model for integrated water quality management. The proposed model integrates water protection, land and water use, preservation of ecosystem sustainability, preservation of functional unity of catchment and river flow and socio-economic activity in the catchment. The model has been developed on the basis of combining existing models, including balancing, deterministic (2D) and statistical models and ecological assessment systems, which are used for description, evaluation and prognosis of water and ecosystem quality on a catchment scale. The catchment and the river are studied in physical and functional unity of separate elements and their interaction. A scheme for practical application of the model for water quality management in the catchment is presented. The model is applied for water quality management of the Mesta River catchment in Bulgaria.

On the basis of simulation studies using the model, a management solution is proposed for improving the water quality of the Mesta River on the territory of the Republic of Bulgaria. The construction of wastewater treatment plants in the towns of Razlog, Gotse Delchev, Bansko, Yakoruda and Hadzhidimovo is proposed, as well as regulation of the Mesta River runoff by means of constructing a water reservoir in the river gorge above the Nevrokop valley. Regulation is also proposed for some low water tributaries, as well as corrections of river sections and repair of melioration facilities. At present, the model is applied for integrated water quality management of the Struma River in cooperation with the University of Ghent (Belgium).

Key words:
Modelling, action plan, integral approach

Introduction

The EU Water Framework Directive[14] urges member states to develop methods for integrated and sustainable water quality management at a catchment scale.

Management at a catchment scale means that water resources are considered as a complex system of mutually interrelated elements as river flow, catchment and different anthropogenic impacts (water and land use). The application of modelling methods provides the possibility of improving the investigation and facilitating management decision-making.

The concept of integrated management is being developed in the course of a number of years.

In France, the water act of 1992 prescribes an integrated water resources management at the scale of watershed or regional aquifer. The water management plans in the water act are designed by a decision team, which brings together state agents, local representatives and water users in order to manage the resources.[19] The integrated approach takes under consideration different elements of water resources and interactions between them. Integrated water quality management could be realized with certain tools concerned in analyzing spatial and temporal variety of water resources within the catchment and predicting their state for different variants by the plan of action.[26,27,28] Two main ecological factors determine the structure and functioning of aquatic ecosystems: river flow hydraulics and transit time. They are the major limiting factors, which determine the development and adaptation of aquatic organisms.[23] The anthropogenic impact on these factors should not disturb the sustainable development of river ecosystems. Hydroenergy, irrigation, river correction, industrial and drinking water use lead to different river flow hydraulics and transit time.[1,17,22] This study presents a model for integrated water quality management at river basin scale based on the obtained results within the framework of international joint research projects. The management must achieve preservation of ecosystems and water quality considering natural and anthropogenic factors in the river basin. The proposed concept is applied for water quality management of the catchment basin of the Mesta River in Bulgaria. At present the model is applied for integrated water quality management of the Struma River.

Materials and methods

Realization of integrated water quality management requires development of particular tools.[10] The model elaborated by *Diadovski*[5] for integrated water quality management and preservation of water ecosystems was used as a basis for the proposed model. The model of integrated water quality management has been developed based on a combination of existing models including balancing, deterministic (2D) and statistical models and ecological assessment systems, which are used for description, evaluation and prognosis of water and ecosystem quality at catchment scale. The migration of pollutants from point and diffuse sources along the river course, and the prediction of water quality is described by the deterministic model.[7] The (2D) model proposed is based on advection-dispersion mass transport, the biological processes in the aquatic systems and the river runoff dynamics.[7] The QUALZE model[24] may also be applied for this purpose, since it is almost equivalent with respect to the concept, considered processes and range of the necessary information. A statistical model based on time series analysis[12] is applied for the assessment and prediction of water quality and river runoff dynamics in single points along the river course. To assess the pollution level of waters, sediments and rivers, we propose a system of integral ecological indices.[10,11,12] The integral indices are based on the ratio K_i between the actually measured values of the individual indices and the standard values for a water body, which serves as a standard of pollution (level of trophic pollution I_t, level of pollution with hazardous substances I_n, and level of microbiological pollution I_m). The integral index of the trophic pollution level I_t for a certain period is determined as the arithmetic mean for the ratio K_i of the individual indices K(BOD), K(COD), K(MES), $K(N_{TOT})$, $K(P_{TOT})$, $K(NO_3)$, $K(PO_4)$, $K(O_2)$. The integral index of the level of pollution with hazardous substances I_n is based on the indices for metal content, organic compounds like aromatic hydrocarbons, phenols, detergents. The integral index I_n is determined as the arithmetic mean for the ratio K_j of the individual indices – K(Cd), K(Cr), K(Cu), K(Zn), K(Pb), K(As), K(Phenol), K(Det). The integral index I_m of the level of microbiological pollution is based on the indices overall coli titer and overall number of microorganisms. The integral index I_m is determined as the arithmetic mean for the ratio K_k of the individual indices – K(coli titer), K(microorg). I_p is determined as the geometric mean of the index I_t, I_n, I_m. In order to assess the level of sediments pollution, it is necessary to determine the integral index I_t(sediments), I_n(sediments), I_m(sediments).

For assessment of climate and economic activity impact on the river flow formation we propose a system of integral indices.[6,8,9] The level of climate impact is determined by the index K_i (flow module), the coefficient C_i for the deviation of the average annual water volume Q_i from the flow norm Q_o and the index h_i for the deviation of the average annual rainfall volume H_i from the average multi-annual rainfall volume H_o. A decision support tool for simulating the effects of alternative policies affecting water quality is applied (MULINO-DSS).[20,21] We consider the application of Multiple Criteria Decision Analysis (MCDA) in solving problems for water quality management. The formulated MCDA problem is solved with the help of the MULINO computer interactive Decision Support System. Three alternative methods are realized in MULINO DSS-SWA (simple additive weighting), OWA (order weighted averaging) and TOPSYS (Technique for order Preferences by Stimulant to Ideal Solution) for multiple criteria analysis. The evaluation of the alternative solutions may be performed using the three methods for multiple criteria analysis on the basis of defined ecological criteria.

This study presents the possibilities for coupling different tools for integrated water quality management.

Simulation research of water quality is realized on the basis of information provided by the National Ecological Monitoring network. The goal of this study is to propose a conceptual model for integrated water quality management at river basin scale based on results obtained from existing methods applied for river basins, the integral approach and in conformity with EU Water Framework Directive. The integral approach combines water and ecosystem protection with appropriate surface water, groundwater and land use in accordance with actual socio-economic activity in the investigated area. The integral approach takes under consideration different elements of water resources (quality, quantity, and distribution) and their interaction (Fig. 3).

This approach integrates different objectives and criteria as follows:

– protection of water from pollution

– optimization of water and land use

– preservation of functional unity of catchment and river net

– setting up the socio-economic framework for river basin development

– solving and preventing conflicts in water protection and various economic activities in the river basin

– specific environmental protection objectives in the separate elements of the river basin

The methodology follows the concept of ecological integrity and sustainable development of water systems, described in the Water Framework Directive (Fig. 1, Fig. 2). Ecological integrity can only be achieved when physical, chemical and biological integrity of water system occurs simultaneously.

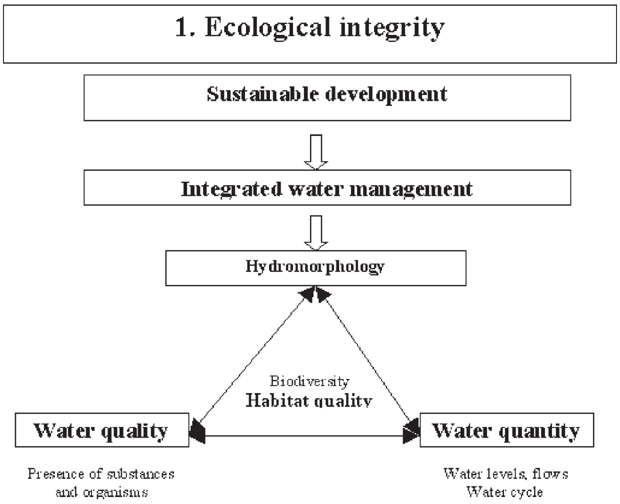

Fig. 1 – *Schematics of ecological integrity*

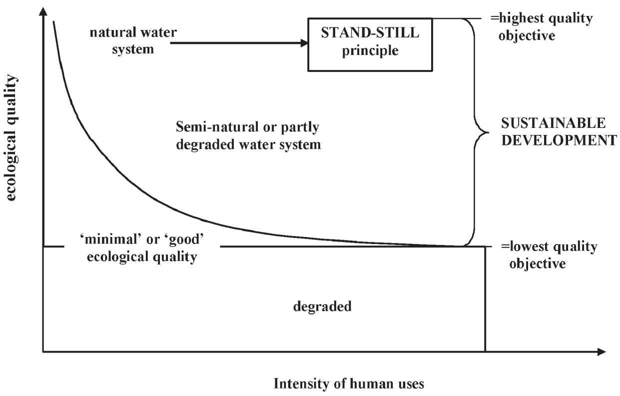

Fig. 2 – *Schematics of water-system sustainable development*

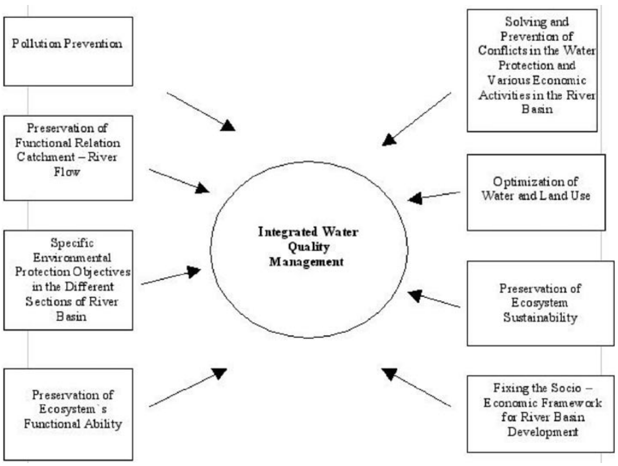

Fig. 3 – *Schematics of integrated water quality management based on the integral approach*

For the realization of this concept, water resources and water users are considered as a complex system – a set of mutually interrelated variables as water quantity and quality, intensity of point and diffuse pollution, water and land use. The ecological state of rivers as a result of this complex system functioning is determined according to hydromorphological, hydrobiological and physico-chemical parameters within the framework of the river catchment.[14] These parameters are used in the deterministic and statistical models of water quality and in the system for determining the level of river pollution.

Results and discussion

We propose a conceptual model for the realization of integrated water quality management. The model consists of 6 mutually related modules, by means of which the water quality management at a catchment scale is realized (Fig.4). The first module includes description of the catchment – river flow system. Catchment and river flow will be investigated in physical and functional unity of their elements and their interaction.[14,19] In this module (work package) we collected the necessary information and carried out simulation investigations with concrete models. The components of this module are as follows:

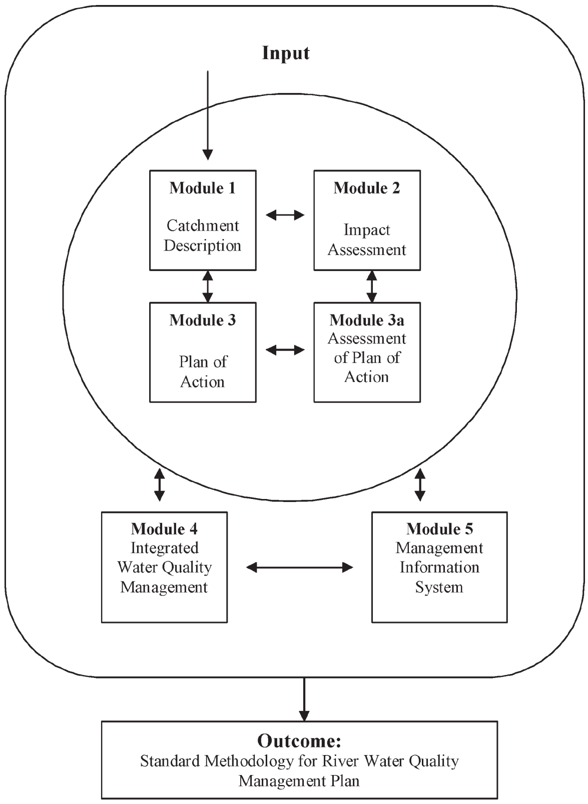

Fig. 4 – *System modules diagram*

– gathering and assessment of information about the catchment – river flow system

– description of the state of the catchment – river flow system

– simulation investigations with integrated models for water quality

– quantitative assessment of ecological deficit in the river ecosystem

– evaluation of limiting conditions and parameters

The above-mentioned goals were realized with the help of GIS, models for water quality and indices for determining ecological deficits in river ecosystems.[7,13] For the realization of the first module for the Mesta River we applied a 2D model and a statistical model for water quality assessment and prognosis.[7,13]

The quantitative assessment of ecological deficit in the river ecosystem is based on the standard of river pollution and on the stand-still principle of ecological quality[7] (Fig. 2). The second module contains the ecological assessment of the anthropogenic impact on the catchment – river flow system including:

– point and diffuse pollution sources

– land use and changes in the vegetation cover

– operative exploitation of hydrotechnical outfits, such as dams, weirs, sewers, etc.

– surface water use

– simulation study with the help of statistical models for water quality and water pollution level assessment

The system of integral ecological criteria and indices, models for assessment and prognosis of river pollution is a necessary tool for implementing these tasks.[10,11,12,13]

The ecological assessment must clarify the tendencies in the dynamics of water and ecosystem qualities and extrapolate them for a future prognosis. For realizing the goals of the second module for the catchment basins of the Mesta River, a system of integral ecological indices of river pollution[10,11,13] and a method for integral assessment of climate and economic activity in the catchment area have been applied.[6,9] The third module contains an action plan concept. Two criteria have to be taken into consideration:

– physical and functional continuity of the catchment and river net

– sustainable development of water ecosystems

This concept for sustainable development of water ecosystems is in conformity with the EU Water Framework Directive.[14] The sustainable development is based on the water quality standards and on the stand-still principle of ecological quality. The plan of action envisages concrete measures for decreasing pollution, water and land use optimization, preservation of ecological prosperity, etc. "Hot spots" in the action plan are defined in the river flows by retrospective analysis and prognostic assessment. Hot spots are the sites representing the highest pollution or polluted areas of the river net, as well as the hydrotechnical outfits influencing the hydraulics and the transit time of surface waters.[3,7]

The action plan has the following basic goals:

– decrease the negative consequences of economic activities in the catchment – river flow system

– achieve sustainable development of aquatic ecosystems

– preserve water quality and ecosystem

– develop a monitoring system for control and assessment of water quality and ecosystems functioning in the catchment

Prognostic assessment of the expected measures in the action plan has to be developed with the help of modelling and simulation investigation. Module 3a contains a concept for assessment of the action plan. The main criterion for assessment of the action plan is the sustainable development of water ecosystems on a catchment level. The assessment of the envisaged measures in the action plan is realized with the help of a decision support system.[20,21,25] As a final result, a concept for water quality management (module 4) coupling outputs of other modules[1,2,3,3a] is made. On the basis of the integral approach (Fig. 3), the results from the other modules[1,2,3,3a] and the requirements of the Water Framework Directive,[14] a programme with measures for water quality management is proposed at a catchment scale. The programme includes technical, socio-economic and administrative measures that have to be undertaken for basin water management.[14] The fourth module contains different goals and levels of integrated management of water and ecosystem quality, performed by an integrated approach (Fig. 3). The fifth module contains an information system for integrated management. Various data types, including water-related monitoring data, time-dependent and space-dependent data, simulated models data, standards and criteria for water quality and ecosystem sustainable development will be integrated. The outcome of model realization yields a standard methodology of the plan for the integrated water quality management.

We propose this integrated water quality management to be realized at the fourth level:

– Investigation of the actual condition of water and perspective – description, assessment and prognosis of catchment – river flow system (module 1, module 5).

– Ecological assessment of the anthropogenic impact in the river basin, including point and diffuse sources of pollution, land and water use, basic economic activities. This assessment must clarify the tendencies and dynamics of water and ecosystem quality and identify existing negative processes within the catchment (module 2, module 5).

– Creation of alternative action plans, solving and preventing conflicts in water protection and various economic activities in the river basin (module 3, module 3a, module 4 and module 5). Different scenarios will be evaluated by means of simulation with previously developed models and the decision support tool. The action plan will identify hot spots in the river ecosystem through retrospective analysis and prognostics assessment.

– Simulation of the action plan in the river basin. Testing of measures for integrated management (plan of action) in the catchment area, approach validity limits (modules 1, 2, 3, 3a, 4 and 5).

Fig. 5 presents an application scheme of the integrated water quality management model for a particular catchment. The concept for integrated water quality management is applied for the catchment area of the transboundary Mesta River with an area of 2768 km^2, altitude of 1318 m and length of 125.9 km in the Bulgarian part of the river (Fig. 6). The river catchment follows a mountain pattern and is characterized by relatively low density of popula-

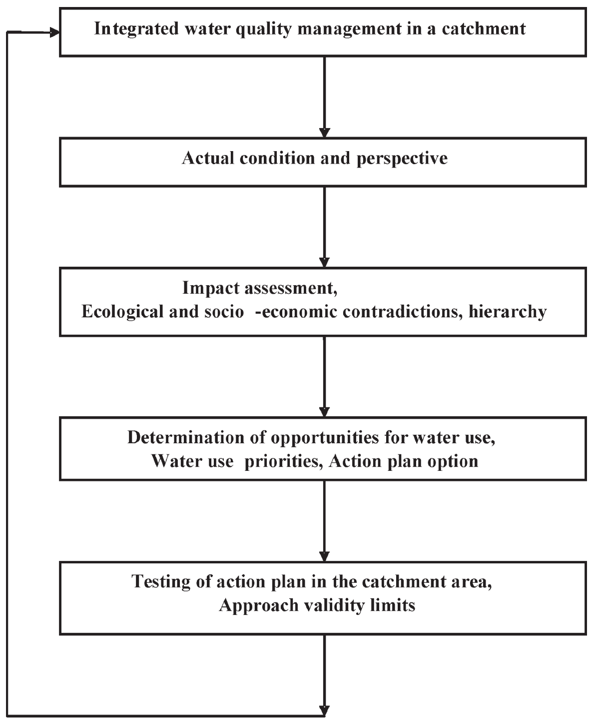

Fig. 5 – *Schematics of the integrated water quality management model application in the river basin*

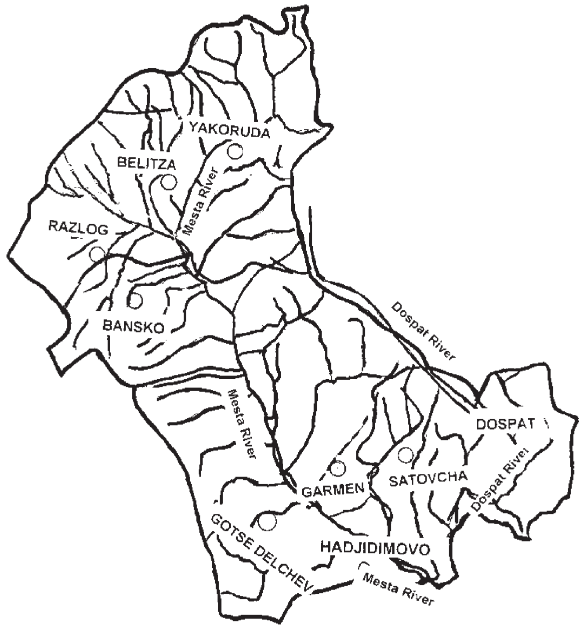

Fig. 6 – *Catchment area of the Mesta River in the Bulgarian section*

tion – 93 settlements with 135 000 inhabitants in total. Forests cover 50 % of the catchment area. The annual water quantity varies between 9.5 and 57.0 m^3 s^{-1} for the period 1955 – 2001. River water is used for drinking and industrial water supply, as well as for irrigation in agriculture. The main pollutants of the Mesta River are wastewater from settlements, diffuse pollution from agriculture, dung-hills, waste depots, and soil erosion. There are no wastewater treatment plants in the area. Catchment description, impact assessment and an action plan have been made.[6,11,12,13] Water quality management plan based on the model of the decision support tool for simulating the effects of alternative policies is proposed. As an end result from the action plan, a program for preserving the waters of the Mesta River has been developed, in which concrete measures for pollution decrease, water and land use optimization have been proposed. The construction of wastewater treatment plants is envisaged for decreasing pollution. The settlements that need wastewater treatment plants are Gotse Delchev (20 000 h), Razlog (20 000 h), Bansko (9 000 h), Yakoruda (6 000 h) and Khadzhidimovo (7 000 h) (Fig. 6). A change of the Mesta River flow regime due to hydrotechnical construction, above the town of Gotse Delchev, is proposed for water quality management. The regulated runoff will contribute to the river water quality management in the Nevrokop Valley and to optimization of the water use for water supply, irrigation and power generation. Annual runoff regulation is proposed for improving the water quality of small low-water tributaries by building compensating basins. The water quality of the water intake will be managed by means of the regulated water, thus increasing the resort potential of the settlements. At present, the proposed model is applied in co-operation with the Laboratory of Environmental Toxicology and Aquatic Ecology (Ghent University) for the trans-boundary Struma River basin.

The development of the model is directed towards improving the quality of information necessary for integrated management, optimizing the system for monitoring the ecological status of water. Planned is the use of new methods for evaluating and predicting the ecological status based on multivariable statistics, as well as application of various software programmes for multiple criteria decision analysis.

Conclusions

1. A model for integrated water quality management is presented. The single modules (components) of integrated water quality management are applied for water status assessment, for identifying existing negative processes and evaluating the efficiency of the measures taken within the Mesta River catchment. The integral assessment allows a complex view for the physico-chemical, biological and hydro-morphological indices, describing the state of the water.

2. The organic and biogenic loading (trophic pollution) of the Mesta River in the Bulgarian section does not result in any negative trends and does not exceed Bulgarian standards.

3. The development of the model is directed towards improving the quality of information, optimizing the system for monitoring the ecological status of water, using new methods for evaluating and predicting the ecological status, as well as applying various computer software for multiple criteria decision analysis.

4. Sustainable water quality management and ecosystem protection need different purposes, criteria and requirements, not only at a national level, but also at a regional and European level. As a result of the model, a program for water quality management of the Mesta River in the Bulgarian section has been developed, in which concrete measures for pollution decrease, water and land use optimization are proposed.

5. This study presents an approach to solving the problem in river basin management: upstream-downstream conflicts of interests.

Moreover, it offers an example for water quality management and can promote further international co-operation.

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