

# **a Decision Support System for Water Management in River Basins**

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**Paper and Poster presented at the  
International Workshop on Monitoring and Assessment in Water Management  
20-23 September 1994, Beekbergen, the Netherlands**

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**KEYWORDS:** decision support system, water management, water quality, models

## **ABSTRACT**

An integrated approach has been developed which enables the assessment of impacts of managerial actions on the quantity and distribution of water and the quality of water, sediment and biota in rivers and coastal areas. The integrated approach includes the quantification of the discharges of pollutant compounds into the water system as a function of human activities or natural events. All major point and diffusive sources are identified. The developed DSS has been applied to various river basins and inland water networks, such as the river Hron in Slovakia, the Lower Vistula in Poland and the Maipo/Mapocho basin in Chile. The DSS runs under MS-WINDOWS in the DOS environment and works at any 386 or 486 PC.

## **AN INTEGRATED APPROACH FOR WATER MANAGEMENT**

Throughout history, river basins have provided the foundation for socioeconomic development. Rivers provide water for use in domestic, agricultural and industrial activities. Moreover, rivers offer routes for navigation and provide water power for electricity production. Rivers can provide recreational opportunities and ecological resources such as fisheries.

The issues of water supply and flood protection have been concerns for centuries in river basins. Only in recent decades it has become apparent that the quality of the water is also of vital importance for its use. Due to human activities in the catchment area of rivers, large amounts of pollutants are often discharged into rivers and subsequently transported downstream into estuaries and coastal waters. Pollution may interfere with the many functions of the river such as drinking water and industrial water supply, irrigation, and recreation. Also, pollution has a direct impact on the ecology in river basins. These issues have resulted in a great interest in River Basin Water Quality Management.

Pollutant transport and Water Quality Management in River Basins deals with a variety of functions and environmental aspects of the rivers and coastal waters. An integrated approach has been developed which enables the assessment of impacts of managerial actions on the quantity and distribution of water and the quality of water, sediment and biota in rivers and coastal areas. Depending on the specific situation and issues involved, a comprehensive approach and a variety of tools are applied to the problem. These range from providing expert opinions to performing sophisticated analyses using computer information systems and decision support systems with modern visualization facilities.

The integrated approach includes the quantification of the discharges of pollutant compounds into the water system as a function of human activities or natural events. All major point and diffusive sources are identified. The pollutants of interest generally include oxygen consuming compounds, nutrients, heavy metals and organic micro-pollutants. Other parameters of concern can be suspended solids, radionuclides, and bacteria.

The transport of the pollutants through rivers and estuaries and their dispersion in the coastal waters is analyzed and evaluated using a computational framework known as a Decision Support System. The Decision Support System consists of series of computer programs which analyze the hydrologic, chemical

and biologic aspects of the River Basin. Water quality processes which affect the fate of the pollutants are taken into account.

The Decision Support System for the river Hron has been developed for the analysis, description and quantification of the impacts of pollution on the surface water quality. The results can be used to quantify the efficiency of managerial actions aimed at improving this situation. The Decision Support System enables the manager to assess the environmental impacts of certain human activities. For example, the results of activities such as reducing pollutant loads or providing waste water treatment can be evaluated.

If several different activities are proposed for improving water quality, different scenarios may be evaluated within the Decision Support System. The results can be compared with each other, with the present situation or with water quality standards. Also, evaluations can be made based on various predictions of future population, and developments in industry and agriculture. In this manner, a River Basin Water Quality Management Plan can be established. Such a plan may contribute to an optimal use of the River Basin water resources and to a sustainable development of the environment. It can also be part of a Total River Basin Management Plan (Master Plan) including other components such as flood protection and management of water user demands.

### A DECISION SUPPORT SYSTEM FOR RIVER WATER MANAGEMENT

Generally, a Decision Support System or DSS consists of mainly three subsystems (see Figure 1):

- an information system with databases, data files and a database management system;
- a computational framework with models to simulate hydrodynamics, waste loads and water quality;
- an analysis system to evaluate management measures, and to perform a risk assessment analysis.

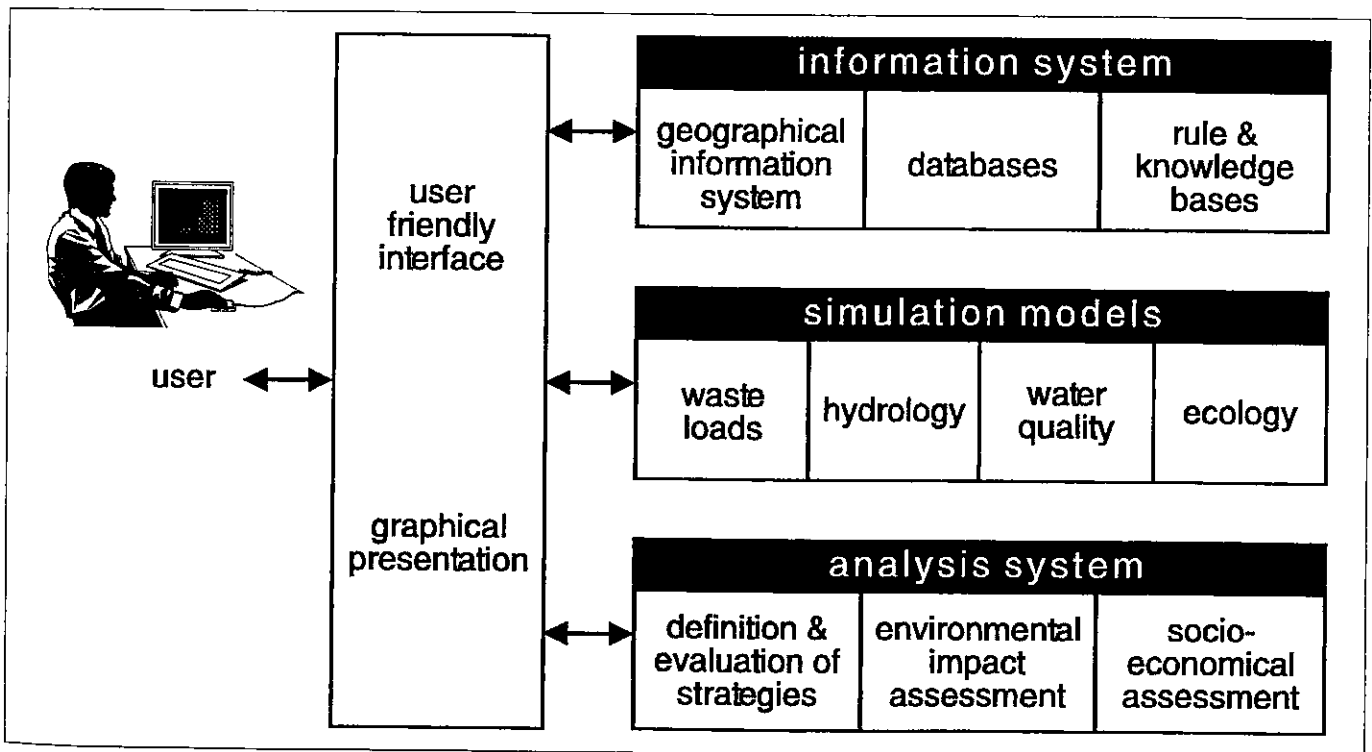


Figure 1: General outline of a Decision Support System.

The *information system* stores all relevant data for analysis, calibration and validation of the computational framework. The information is aligned in a two-layer data structure: one layer contains the data itself while the second layer contains information related to the stored data in the first layer (e.g. executive institute, location, reference, sampling and analysis methods, etc.). A data quality control procedure may be included in the data entry part of the system to verify the accuracy of the entered data. The *computational framework* consists of a set of coupled mathematical models to enable a quantitative analysis of the relation between the input of pollutants and the assimilation capacity of the water system. In this set of mathematical models the following aspects are included: hydrodynamics, waste load calculation, pollutant transport, water quality processes. In the *analysis framework*, strategies can be defined and evaluated in order to support the development activities for the river basin.

Based on this general outline, a DSS may be tailor made for each specific river basin depending on the main water management problems in the basin. In general, a DSS for water management is a complex system. Therefore, the final system must be easy to use and understand by the water manager, and easy to be applied and maintained by the different system engineer(s). Due to the Case Management Tool (CMT), users at different levels will be able to perform their tasks.

### APPLICATION TO THE HRON RIVER BASIN (SLOVAKIA)

The Hron river (Figure 2) is one of the smaller left bank tributaries of the Danube between Bratislava and Budapest, draining the central part of Central Slovakia and part of the Danube lowland in Southern Slovakia. It is one of the bigger Slovak rivers draining 11% of the Slovak territory and accounting for 13% of the total runoff from Slovakia. It flows between the Lower Tatra's and the Slovak Ore Mountain in western direction, till it reaches Kremnice mountain where it bends to the south. The upper and middle part of the Hron have a pronounced mountainous character with steep slopes and high runoff rates. Down to its outflow into the Slovak Danube plain, narrow valleys, basins and ravines determine the character of the river basin. After a stretch of about 80 km through the Slovak lowlands the Hron river enters the Danube river at Štúrovo, just opposite the Hungarian town of Esztergom. The total population in the Hron river basin as per end of 1990 amounted almost 500,000 persons, with 5 cities larger than 20,000 inhabitants.

The Hron river basin can be characterized as a moderate polluted area in general terms, although there is hardly information available with regard to micro-pollutants and a number of heavy metals. The main problem in this area is the pollution due to domestic and industrial waste production. Generally, waste water is collected and (partially) treated by waste water treatment plants that will only partly remove specific pollutants. The situation in most sub-basins of the Hron is still relatively good compared to other industrialized basins in Slovakia.

### CURRENT ENVIRONMENTAL SITUATION

The economic activities are mainly focusing at industrial production, in the middle and upper basin, and agriculture in the lower Hron basin (livestock farming and crop cultures). For both sectors relatively intensive production takes place in the area, resulting in rather serious conditions regarding the pollution of air, water and soil.

Industries in the Hron basin comprise wood processing, sawmills, paper factories, metal and machine factories, amongst which several large ones. In addition there are a big aluminium factory (Žiar nad Hron), a major chemical factory (Petrochema Dubova), a large pharmaceutical plant (Biotika, Slovenská Lubca), a textile factory (Levitex, Levice), and a sugar factory (Pohronský Ruskov).

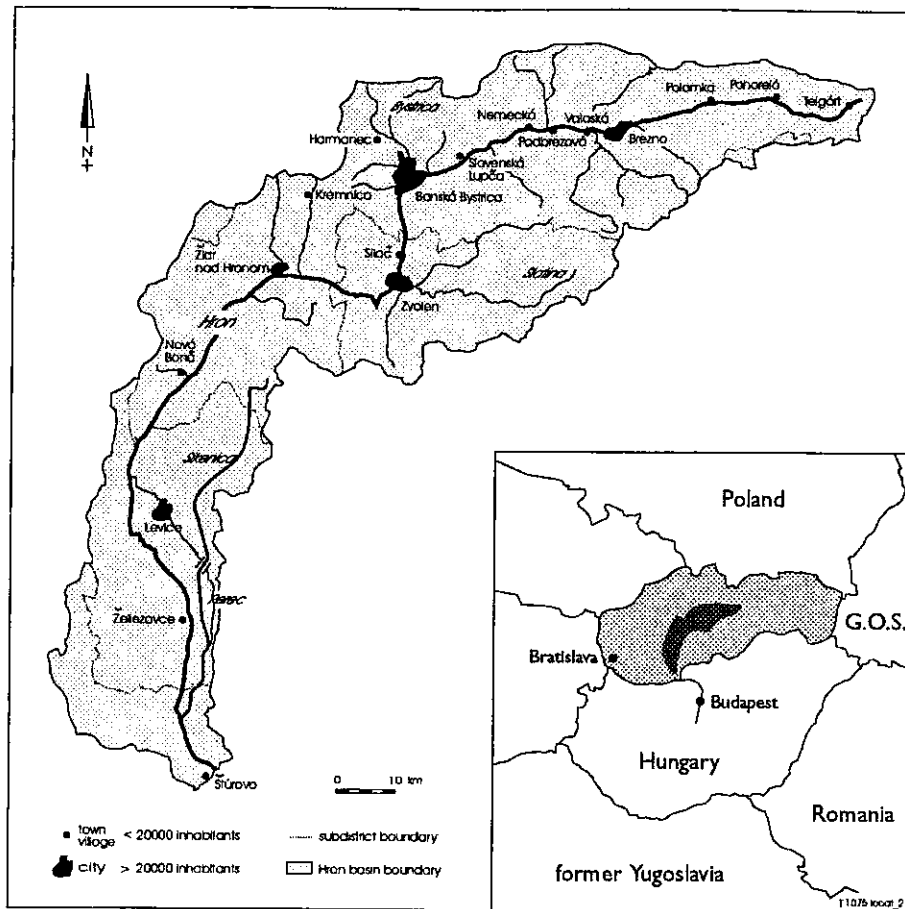


Figure 2: The Hron river basin in Slovakia

In the past, mining activities took place in the upper part of the catchment. Most mining activities have been abolished but in some places mining was replaced by processing of ore, such as in Špania Dolina (copper), Kremnicka (coins), and Banská Stiaavnica. The activities in present and past still are important for the water quality of the small mountain streams feeding the Hron, due to ongoing activities as well as leaching of old tailings. For this reason, the situation in the smaller tributaries to the Hron is generally less favourable than in the Hron itself.

Despite heavy bacterial pollution of the Hron river basin and high amounts of contaminants at selected locations, it can be stated that the Hron river basin presently is in a reasonable state regarding environmental conditions. Nevertheless, the river basin clearly has sufficient ecological value, both terrestrial and aquatic, to justify an increased effort for sustained environmental protection. The floodplains and the riverbanks are well provided with forest, and after the bad river quality conditions of about 10 years ago fish has returned again in the Hron river and some of its tributaries. Conservation measures and pollution reduction, however, will remain necessary in order not to deteriorate the environmental conditions again. Particularly pollution with heavy metals and micro pollutants, presently not getting sufficient attention from an environmental viewpoint, is a major threat for the Hron basin. Another threat is the potential future pollution by leaching of the existing waste dumps and chemical storage sites.

### THE SPECIFIC COMPUTATIONAL FRAMEWORK FOR THE HRON

The models of the computational framework are strongly related. The output of a model serves as input for one or more other models. The river basin oriented computational framework (CF), supplied including a case management tool (CMT), includes the following main models:

- The water quantity model (HYDSIM) to simulate the surface water balance and to allocate surface water flows in the network representation of the river basins;
- The waste load model (WLM) to calculate waste loads from domestic, industrial, non-point (agricultural) and livestock sources;
- The water quality model (DELWAQ) to calculate the time variable transport of pollutants including all relevant water quality processes to which they are subdued;
- The cost model (COIN) to evaluate and assess the overall yearly costs of water quality measures, in particular the measures to reduce the waste water discharges from point sources of pollution in the entire or in specific hot-spots of the Hron river basin;
- The risk assessment module (QRIUS) to compare the results with the standards for water quality.

## DATA REQUIREMENTS FOR THE DECISION SUPPORT SYSTEM

It may be clear that a successful application of any DSS strongly depends on the availability and reliability of monitoring information. At the (upstream) boundaries the computational framework has to be supplied with hydrological and water quality information, while a vast amount of information will be required to adequately describe the waste load situation in the river basin under consideration. Furthermore, in the calibration and validation phase of the development, the computational framework requires data to tune the relevant models and relations. Finally, the system requires information to simulate the proposed strategies and measures and to subsequently supply the water manager with information that can be used for future water management.

## WATER QUALITY SUBSTANCES AND PROCESSES

The list of substances that has been selected for simulation with the water quality model DELWAQ has been based on the availability of waste load data, the availability of water quality monitoring data and the extent of their threat to the environment. Water quality monitoring data for the river Hron and its tributaries are available for the years 1988-1992, for most of the substances on a monthly basis. Data for heavy metals and organic micro-pollutants and also phosphate are rather scarce, however. The following list of substances have been selected for simulation:

- |                                                |                                   |
|------------------------------------------------|-----------------------------------|
| - chloride (Cl)                                | - dissolved oxygen (DO)           |
| - biological oxygen demand (BOD <sub>5</sub> ) | - ammonium (NH <sub>4</sub> )     |
| - nitrate (NO <sub>3</sub> )                   | - total phosphorus (Tot_P)        |
| - suspended solids (SS)                        | - total coliform bacteria (TColi) |
| - arsenic (As)                                 | - cadmium (Cd)                    |
| - mercury (Hg)                                 | - lead (Pb)                       |
| - zinc (Zn)                                    | - lindane (γ-HCH)                 |

The residence time of the water in the Hron river is rather short: based on the hydrology for 1990 it ranges from 2-6 days for the main river from Brezno until the mouth at Kamenín. This means that in general there is limited time available for water quality processes to cause significant changes in the concentrations of substances. For this reason, waste load discharges and their transport through the river are the dominating factors for concentration gradients in the Hron river. However water quality processes cannot be neglected. In the Hron system, still a significant part of especially the BOD and coliform load will be decomposed. Therefore, and for demonstration purposes, processes such as nitrification of ammonium, denitrification of nitrate in water and sediment, decomposition of organic material, reaeration, decomposition and sedimentation of BOD, sedimentation of suspended solids, decay of coliform bacteria, adsorption and sedimentation of arsenic, cadmium, mercury, lead, zinc, and lindane have been incorporated. Of course it is possible to consider additional or more complicated processes, such as for instance

algae growth or sediment chemistry. Considering the residence time of the river, the availability of data and the purpose of the study, the above list of processes is regarded to be adequate.

## WATER RESOURCES AND WATER QUALITY ANALYSIS

The computational framework has been used to analyze the present and future water resources management in terms of water quantity, water quality and waste loads. The basic steps in such an integrated analysis, of which some are of limited importance for the situation in the Hron river basin, are:

- effects of demand increase and identification of quantity problems;
- identification and screening of water quantity measures;
- effects of waste load increase, identification of quality problems;
- identification and screening of water quality measures;
- analysis and evaluation of integrated measures and strategies.

The preparation of an integrated analysis involves the specification of analysis conditions, hydrologic scenarios and the definition of cases. A case is defined as a combination of a projection year, a hydrologic scenario and a measure or strategy.

## CHARACTERISTIC RESULTS

The DSS has been calibrated with data from the calendar year 1990, using the measured discharges in the Hron as a starting point. The schematization for both the water quantity and the water quality simulation comprises 26 segments covering the entire basin of the Hron river and tributaries such as the Slatina.

Based on the available data, both the water distribution in the system and the residence time for the Hron have been calculated, resulting in a residence time for the main part of the Hron ranging from 2 days during high flow situations and 6 days in low flow periods (1990). Furthermore, the origin of the surface water at Kamenín has been analyzed, as is indicated in the Figure 3. In the same way, various water quality substances have been simulated (calibrated) with the DSS, ranging from oxygen budget parameters, nutrients, heavy metals to organic micro-pollutants (Figure 4).

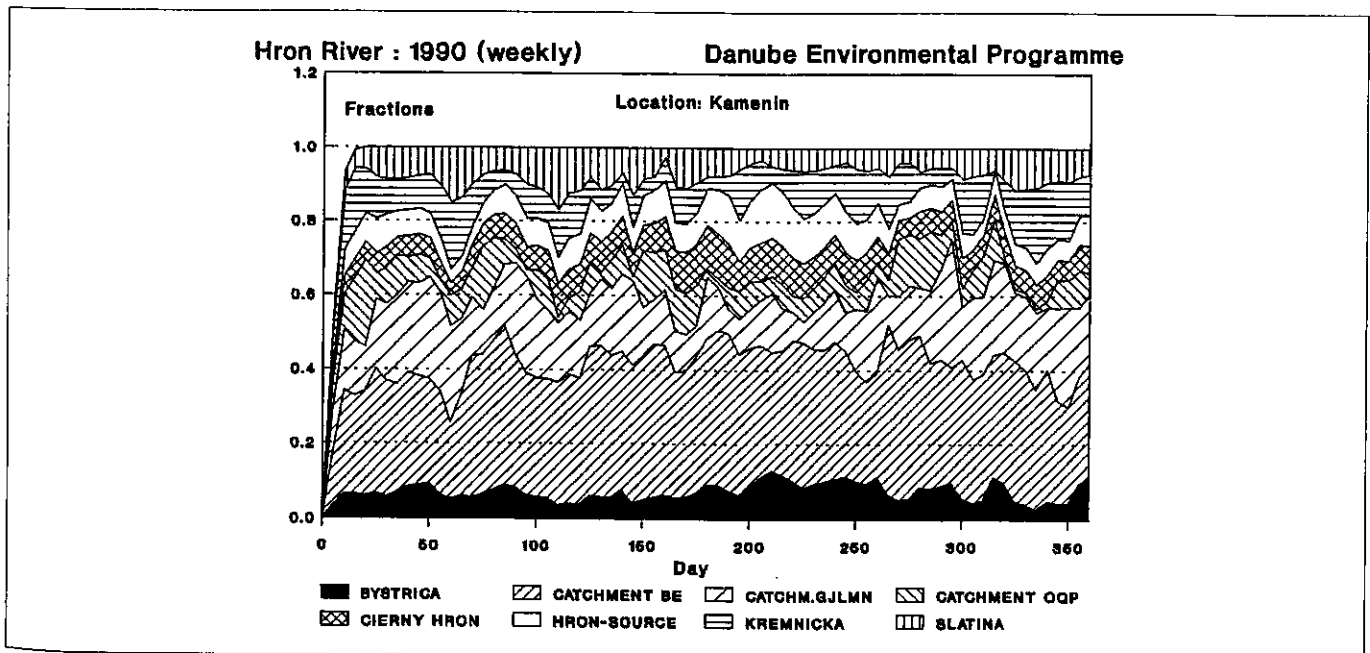


Figure 3: Origin of water in the Hron river at Kamenín (1990)

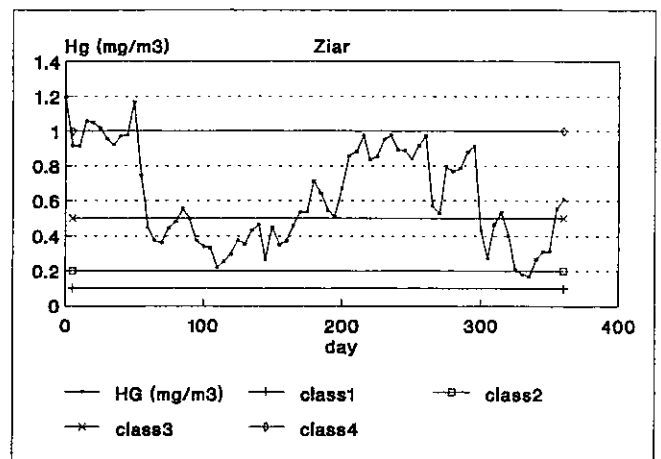
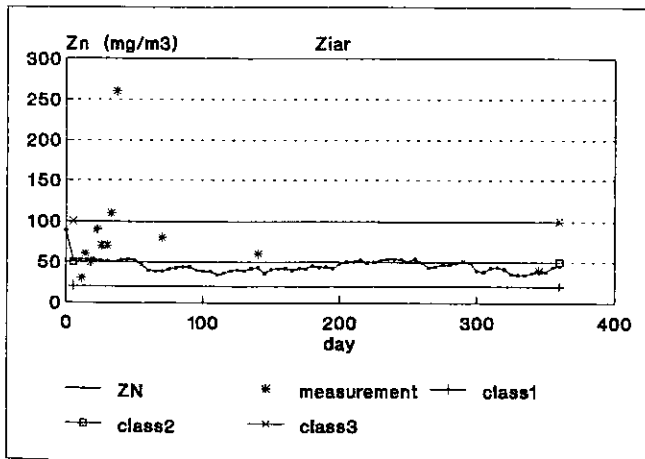
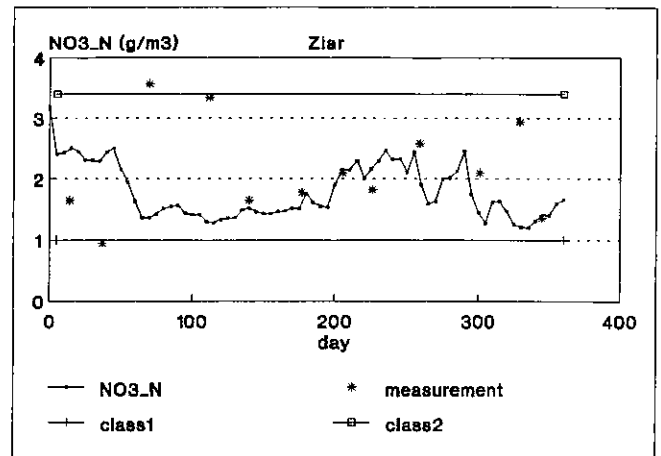
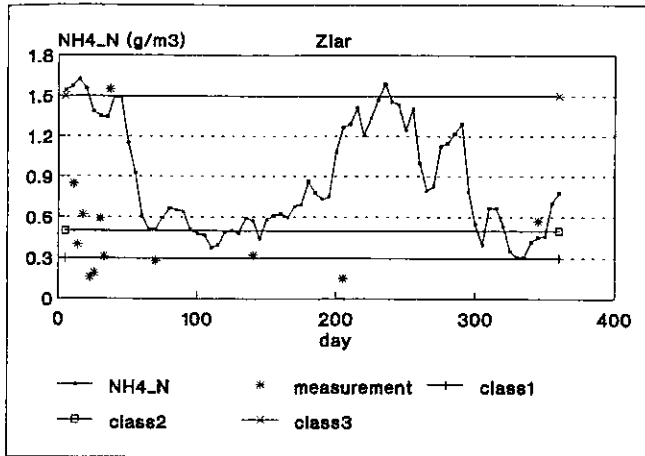
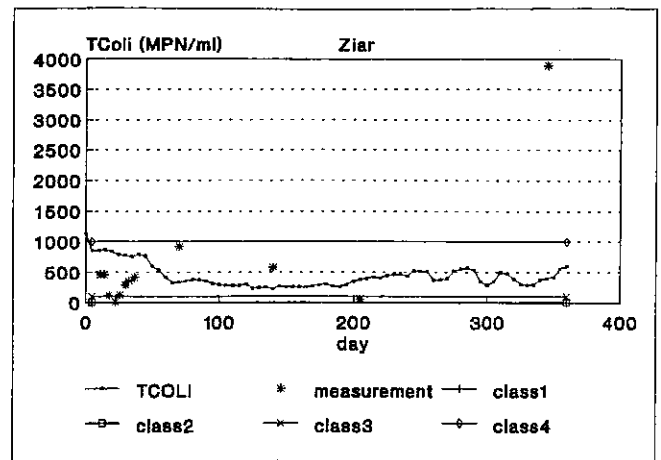
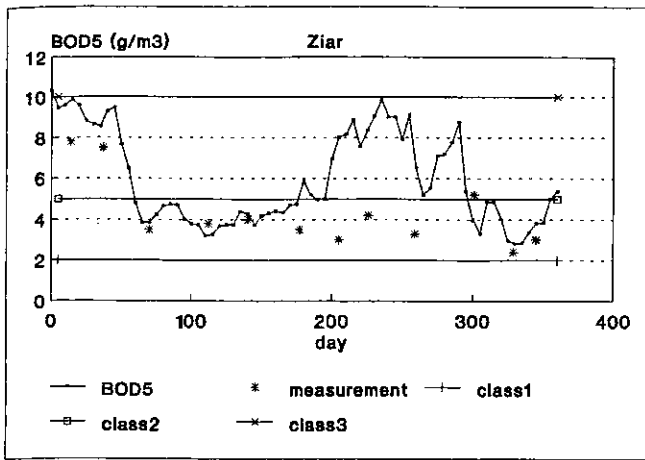


Figure 4: Monitoring and calibration results for BOD<sub>5</sub>, Coliform bacteria, ammonium, nitrate, zinc and mercury compared to Slovak standards at Žiar (1990)

Water quality and water quantity cannot be separated. Integrated strategies have to be considered to achieve the desired objective at minimum cost. However, for the Hron river basin, it must be concluded that options for water quantity measures to improve the water quality situation in the Hron basin are quite limited. As is clear from the available data for the Hron river basin, the loads mainly originate from domestic and industrial sources. In different strategies, the domestic and industrial loads can be adapted to the projected loads for different future waste water discharges (Figure 5). Measures such as the construction of additional reservoirs or change of operational management of the existing barrage and

reservoirs in order to increase the dilution in critical periods are considered not sufficient (and desired) to improve the water quality in the basin. Instead, solutions have to be found in the field of more and better treatment of municipal and industrial waste water, a change in the production processes at factory level, and the increase of sewage collection.

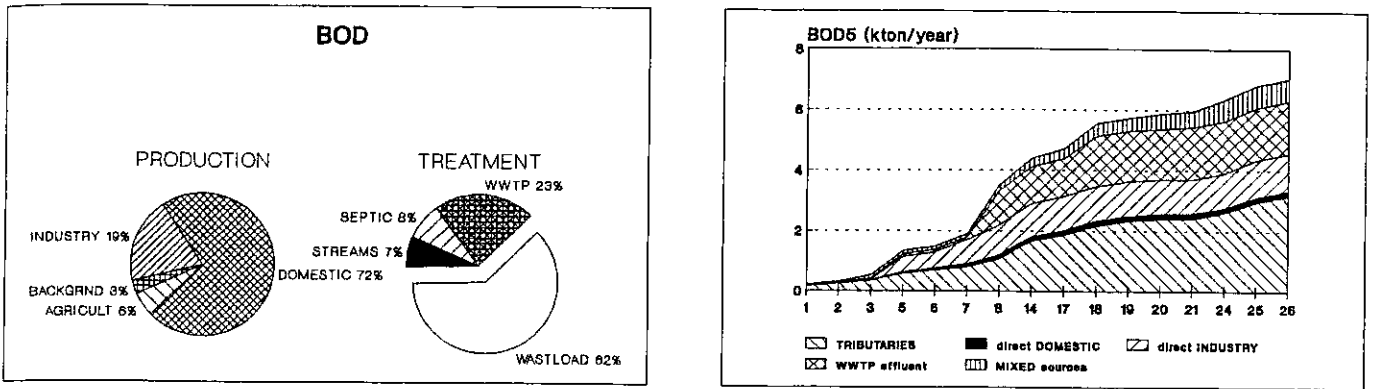


Figure 5: Relative contribution of various sources of BOD waste loads (production) and purification (treatment) in the Hron river basin (left) and cumulative waste load profile of actual load (right).

### EFFECT OF MEASURES

After calibration with the available data, the computational framework can and has been used to analyze different measures and strategies. A number of scenarios have been identified for analysis with the DSS. The scenarios mainly include the construction of various waste water treatment plans at specific locations, i.e. major cities along the Hron river, connection of the Levitex factory to the WWTP in Levice, extension of the sewer system and prevention of direct discharge in Banská Bystrica, connection of the Bučiná wood factory to the WWTP in Zvolen, and finalization of the bentonite wall at the aluminum factory in Žiar to prevent pollution via the groundwater to the Hron surface water system.

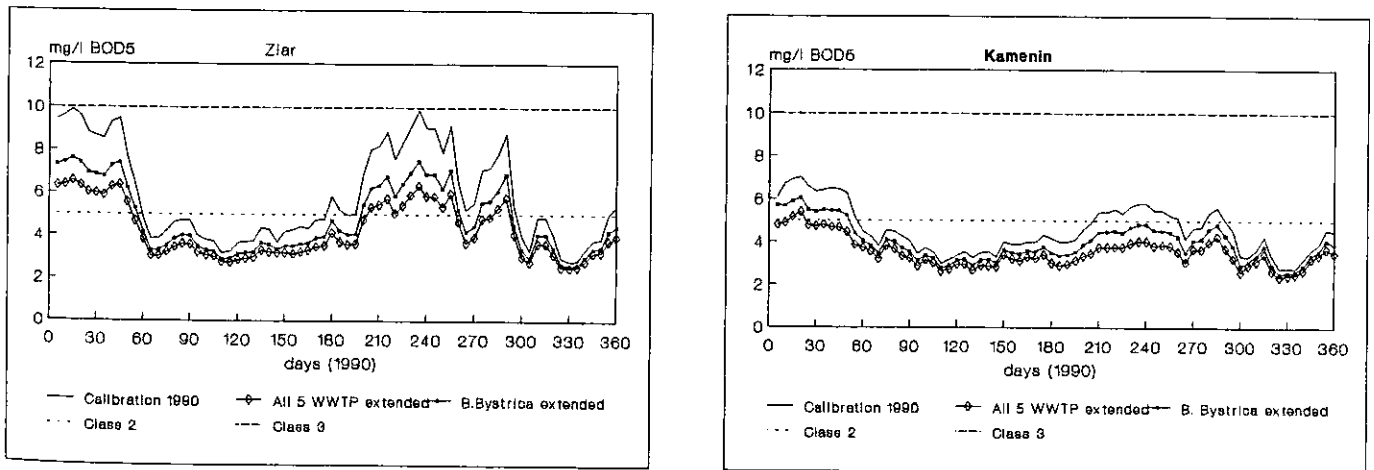


Figure 6: Effect of proposed measures on the BOD<sub>5</sub> concentration at Žiar and Kamenín (Danube)

Major conclusions that could be drawn from the DSS application for the Hron river basin are:

- The DSS in general and the Waste Load model in particular gives a good overview of inputs for various substances at the different locations within the Hron river basin;
- The simulated results generally compare reasonably well to the monitoring data available;
- The present water quality situation in the Hron system varies from moderately till severely polluted on most substances: BOD<sub>5</sub>, bacteria, nutrients, micro-pollutants and heavy metals;
- Due to the relative low residence time of the water in the Hron river the self-purification capacity of the Hron is small;
- As is indicated in Figure 6, a significant decrease of BOD<sub>5</sub> (20%) and coliform bacteria (20%) can be achieved with the construction of WWTP's in selected cities. Locally the reduction can be substantially higher, particularly in low flow situations. Reduction of nutrients and heavy metals is hardly effectuated by such measures;
- Reduction of micro-pollutants and heavy metals should be implemented at the (point) source of origin, i.e. end-of-pipe or in process technology at factory level;
- The pollution of diffuse sources, such as agriculture, atmospheric deposition, traffic, mining, etc. should also be tackled at source level as hardly any reduction of concentrations takes place by water quality processes in the river system.

#### CONCLUDING REMARKS

Analysis of the oxygen budget, nutrient budget and coliform related water quality problems is only a first step in controlling water quality problems. After fulfilment of the intended water quality measures such as the construction of sewage treatment plants for the domestic or industrial waste loads and a reduction of industrial waste loads obtained by a shift to more efficient production processes, some water quality standards may still be violated. The computational framework can be used to assess the environmental impacts and costs related to measures or specific human activities.