DECISION MAKING PROCEDURES IN THE SUSTAINABLE DEVELOPMENT OF RIVER BASINS

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Introduction

The importance of water for mankind and the dependence of life on it are beyond question. The key issue related to water is that there is often too much or too little, and the existent water amount is either too polluted or too expensive. Typical causes of this include degraded infrastructures, excessive withdrawals of river flows, pollution from industrial and agricultural activities, eutrophication from excessive nutrient loads, infestations of plants and animals, excessive fish harvesting, floodplain and habitat alteration from development activities and changes in water and sediment flow regimes. Moreover, the worldwide water availability and quantity are likely to further deteriorate due to global changes.

Integrated River Basin Management requires that informed decision makers take into account all uses and resources of the basin following an ecosystem approach to ensure that human collectivities will benefit for ever from the basin through the development of harmonious relationships among users and the river (Burton, 1995). The tendency of the European Union to manage water in the Mediterranean Basin as "common property" has resulted in the following necessities: (1) Improved knowledge of water resources, ecosystems and uses, (2) resource demand management and (3) integrated management of water quantity and quality (Manariotis and Yannopoulos, 2004).

After the adoption of the EU Water Framework Directive 2000/60/EC, the formulation and implementation of Integrated River Basin Management (IRBM) strategies consist for all member states more than ever a necessity. Complexity of water resources management does not simply derive from any computational limit in modelling, but also from the multiple interdependent physical, biochemical, ecological, social, legal and political (human) processes that govern the behaviour of water resources systems. These processes are affected by uncertainties and by the unpredictable actions of multiple individuals and institutions affected by the management and operation of such systems. The Decision Support Systems (DSS) for River Basin Management enable for different scenarios the comparison of water strategies based on the effects of multiple objectives. They can be used to support the planning and the implementation of measures, as well as the communication between the stakeholders.

The present paper aims to present the role and the purposes of the Decision Support Systems in River Basin Management, the various decision making procedures, and finally the difficulties and the challenges of the design and the implementation of a DSS for the Mediterranean watersheds taking as a case study the Alfeios River.

Definition and components of Decision Support Systems

Klein and Methlie (1995) define the Decision Support System (DSS) as: "A computer information system that provides information in a given domain of application by means of analytical decision models and access to databases, in order to support a decision maker in making decisions effectively in complex and ill-structured tasks." DSSs are tools assisting the decision making by structuring the processes of: (a) Identification of alternatives and objectives, (b) establishing the linkages between alternatives and objectives, (c) evaluation of the alternatives leading to selection of a given alternative. Its objective is to facilitate the "what if" analysis and not to replace manager's judgment. DSSs have specific simulation and prediction capabilities, but are also used as a vehicle of communication, training and experimentation (Welp M., 2001).

A DSS consists of a database, different coupled hydrodynamic and socio-economic models and is provided with a dedicated interface in order to be directly and more easily accessible by nonspecialists (e.g. policy and decision makers). A Database Management System (DBMS) collects, organizes, and processes data and information. Different coupled hydrodynamic and socio-economic models are integrated in a DSS to perform optimization, forecasting/prediction, statistical functions. The type of models included defines the type of support provided and the area of application of a DSS (i.e. irrigation management, water pollution, etc.). Users' interface assists them in interacting with the system and in analysing the outcome.

Decision making in River Basin Management

Decision making is a common activity of everyday life. The key component in decision making is the decision maker (person, organisation, government, etc.), who is committed to take decisions and actions. For any decision there may be numerous plans, analyses and various advice-seeking and consulting activities. In some cases the decision makers could choose not to act. The reason for this decision is the uncertainty of the decision outcomes in combination with the fact that in some countries non-action is more acceptable than failure. Analysis of such problems starts with three questions: (1) What do we want, (2) how can we achieve it, and (3) how much do we know about the problem. Providing answers to these questions will lead to the structured formulation of a decision making problem leading to analysis and solution.
The first question involves the definition of objectives or performance criteria (Figure 1), which are usually expressed in terms of minimising or maximising certain outcomes (i.e. minimising water pollution). In structured formulation of the decision making problem the performance criteria should be quantified. This is accomplished through the criteria variables, which define the valuation framework. In cases when the performance criteria cannot be quantified, surrogate quantification is used. The differences in the valuation frameworks between decision makers introduce complexities in this process.

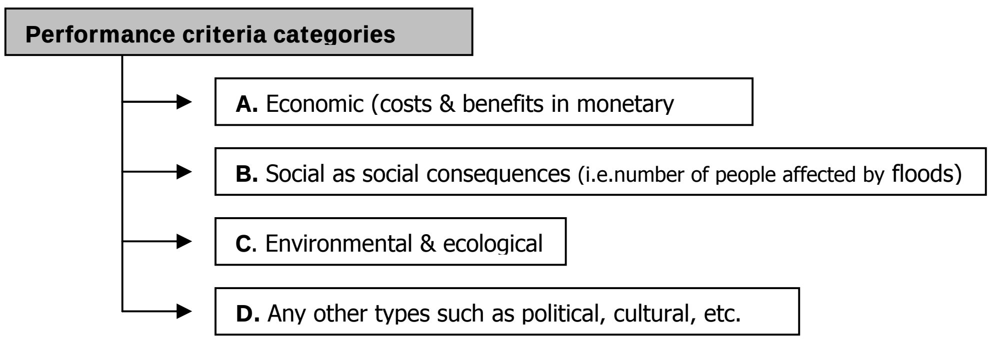

Figure 1 Categories of performance criteria

The second question introduces alternatives, options or strategies. The set of all possible alternatives of a decision making problem define the decision space. In many cases, the alternatives could be quantified through the use of the decision variables. The combination of values of the decision variables is linked to an alternative. Alternatives could be also defined without making use explicitly of the decision variables.
A decision making problem could be simply described as shown in Figure 2. Defining a certain number of alternatives, the best alternative should be selected with the best outcome corresponding to the performance criteria. Supplementary information is needed for the detailed structure of the decision making problem. Firstly, the linking between alternatives and objectives should be specified. Functional relations, process-based models, historical data (statistical models, data-driven models), past experience from "if-then" rules and intuition could be used for this purpose. In any case, the uncertainty of the specification of this linkage should not be overlooked. Secondly, the links among different objectives should be defined. This information could be obtained by interviewing decision makers, past experience, comparison with similar previous decision making settings, use of rational decision making theories, common sense, etc. The

different prioritisation of objectives from different stakeholders according to their interests (mainly conflicting) is one of the main difficulties.
In order to deal with uncertainty, the use of scenarios is common in decision making. Scenarios define sets of external conditions, which we cannot influence or control, such as population growth, socio-economic development and climate change. The scenario analysis process includes the analysis of a structured decision making problem with specified alternatives and objectives under different scenarios. The selected alternative or set of alternatives (strategy) is the one performing well under different scenarios (the most robust alternative).

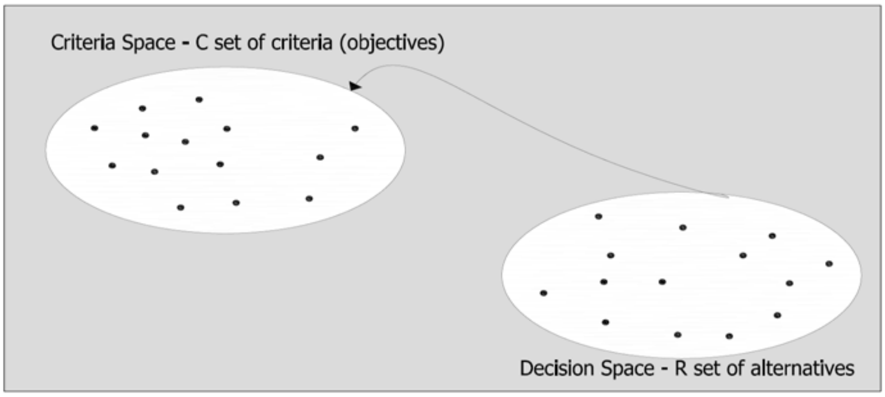

Figure 2 Definition of a decision making problem

Decision support procedures

The types of decision support problems and the corresponding solution methods are presented in Figure 3. Simulation addresses "*what if*" questions: What is likely to happen over time and at one or more specific places, if a particular design and/or operating policy is implemented? The procedure involves testing all alternatives (one by one) with respect to the chosen objective. The link between alternatives and objectives should be known. In river basin management this relation is very complex due to the complexity of the physical, socio-economic and administrative-institutional systems involved. For this reason models are being used, which can incorporate this complexity and specify the system responses. Models are, therefore, seen as simplified representations of the system, which consist of sets of inputs, outputs, parameters and transformation functions. The inputs to simulation models can be long time series of hydrological, economic and environmental data, such as rainfall or flows, water supply demands, pollutant loadings and so on.

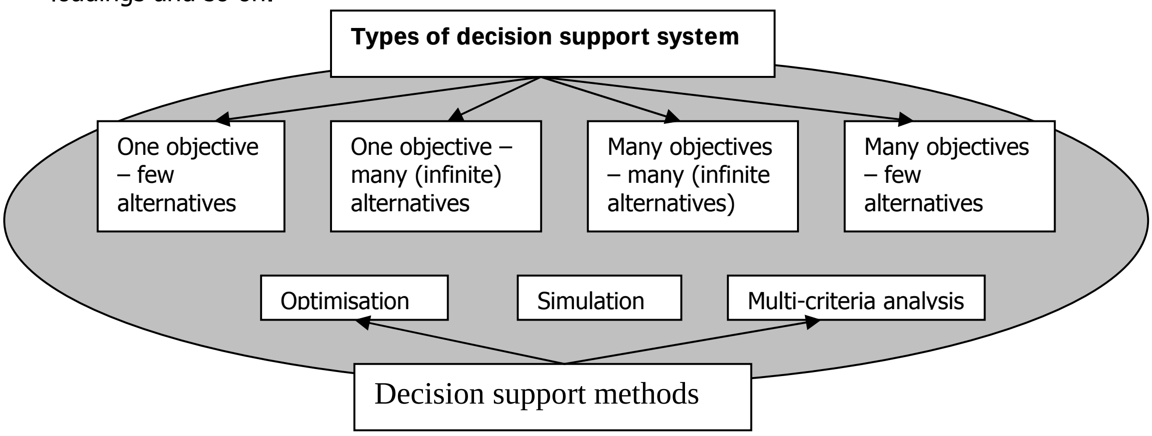

Figure 3 Types and methods of decision support systems

The resulting outputs can identify in detail the variations of multiple system performance indicator values. Simulating multiple sets of values for many variables can take very long time. In reality there could be an infinite combination of feasible values for each of the decision-variables. The trial and error process of simulation can be in this case time consuming. Simulation works, when there are only a relatively few alternatives to be evaluated, not when there is a large number of them.

Optimization on the other hand is used when there are many alternatives, since it is an automated procedure finding the best alternative. Having a clear relation between objectives and alternatives still remains a key issue also in this case. The only difference is that this link is achieved through simpler functions. The optimization problem could be either discrete or continuous. It has usually constraints or limitations, which limit the decision space only in a feasible region comprising all the alternatives satisfying these constraints. The steps of the optimization procedure include the identification and quantification of objectives through the development of the objective function. Then the alternatives are defined through the decision variables. The constraints are specified in terms of the decision variables, and optimization methods are applied in order to find the optimal solution. According to the type of the objective functions and the constraints, one of the following optimization methods could be used: (a) calculus-based for known and differentiable objective function, (b) linear programming for linear objective function and constraints, (c) dynamic programming, when the problem could be formulated in stages, states and decisions and (d) global optimization, for multiple-extreme functions or for analytically not known functions.

Many decision support problems in river basin management have several objectives that should be satisfied simultaneously. These objectives are in most cases conflicting and the reaching of a solution involves compromise. This problem is called multi-criteria or multi-objective. Here the multi-criteria analysis is used, which is further classified in (a) the Multiple Objectives Decision Methods (MODM) and (b) the Multiple Attribute Decision Methods (MADM). These two classes overlap and their concepts are very similar. The first type of multi-criteria analysis includes alternatives with continuous decision variables, thus infinite. Objectives are usually specified by the objective function. This procedure is mainly an extension of the continuous optimization method for multiple objectives. In the criteria space a frontier, the Pareto frontier, could be found which defines those points (sets of values of the criteria) being the best solutions. These solutions are equally good and moving along this frontier may improve one criterion, but always in expense of the others. Therefore, in order to select one solution, some rule is needed determining the relative importance of each criterion/objective. This is the preference structure of the decision maker. The second type of multi-criteria analysis refers to finite and discrete alternatives, which should be evaluated. Objectives are determined from a hierarchical structure in terms of diverse (quantitative and qualitative) attributes. Starting from the general objectives, sub-objectives are defined, and the sub-objectives are further described by attributes or performance indicators. The number of possible alternatives increases moving downwards, but they become more specific. After formulating objectives and alternatives, the general decision matrix (Table 1) is used, in which each entry (y_{ij}) represents the performance of a given alternative (A_i) with respect to attribute (X_j). The simple additive weighting, the TOPSIS (using distances from the ideal solutions) and other methods could be used to solve the problem.

The three aforementioned decision support methods are usually nowadays combined, mainly simulation with optimization and/or multi-criteria analysis. With optimization many alternatives could be tested and evaluated, but the simplified models introduce uncertainty and a limited number of objectives can be addressed. In many cases a combined use of simulation and optimization is selected for solving decision support problems. In this case, the role of optimization methods is to reduce the number of alternatives (screening) for simulation analyses.

Table 1 General decision matrix used in the Multiple Attribute Decision Method

Alternatives	Attributes			
	X_1	X_2	...	X_m
A_1	y_{11}	y_{12}	...	y1n
A_2	y_{21}			
...				
A_n				y_{mn}

Through the use of optimization we do not select one best alternative, but we try to eliminate a large number of bad alternatives. After selecting few good alternatives, complex simulation models may be used to evaluate their performance. However, if only one method of analysis is to be used to evaluate a complex water resources system, simulation together with human judgment is often the chosen method.

Optimization can be also combined with modeling simulation in a coupled way. Decision making problems are formulated as optimization problems and the simulation models results are included in the optimization algorithms. The only disadvantage is that the optimization methods may require large number of model run to find the best solution. Alternatively, the results of model run could be included into the decision matrix in the Multiple Attribute Decision Method. The combination of simulation with this multi-criteria method could result in diverse outputs.

All these methods and their combination could be used by a single decision maker or by a group. Group decision method has two classes. The join decision making, where more than one decision makers work jointly towards a resolution of a given decision making problem making compromises and taking into consideration trade-offs among objectives. This involves cooperation. The second class is the game theory-based method, where more than one decision makers (player) are confronted with a decision making problem in which each player wants to obtain a best outcome for himself. In this case the involved parties are competing. These two different aspects are very important, since the stakeholders involvement in the decision making process for water resources management is a necessity.

Levels of decision making

DSSs are developed for three different levels of decision making as presented in Figure 4. The content and the form of the incorporated in DSSs knowledge at each level correspond to the various kinds of users and objectives. Despite this wide variety, the generic structure and the corresponding functional components of DSSs at all levels are similar. The only difference is the importance and the level of sophistication of components at each level. Loucks and van Beek (2006) have given the details of a generic structure of DSSs.

The DSSs at operational level are characterised by simple user interfaces covering the available expertise, and fast responses. The decision support is based on operational rules and procedures and the reliability and the detail level of data plays a significant role. At this level only the operators (not the stakeholders) are involved.

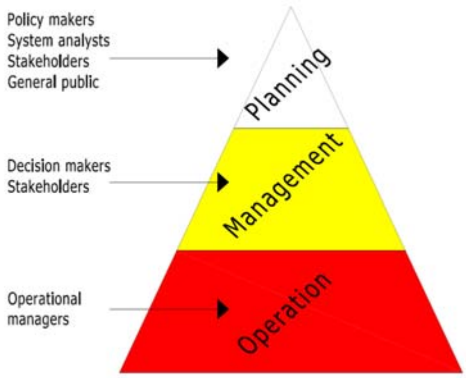

Figure 4 Level of development for the DSSs

The DSSs at management level are characterised by more complicated user interfaces enabling the exchange of information among different kinds of stakeholders. The decision support is based on the evaluation of design and management alternatives, known as multi-criteria decision support. Models with detailed representation of physical and socio-economic system are needed at this level. In this category flood-related design and management projects are very common.

Finally, the DSSs at planning/policy level are characterised by very complex user interfaces in order to satisfy the highly diverse knowledge needs arising from the involvement of different kinds of stakeholders such as policy makers, system analysts and general public. The decision support is based on the evaluation of long-term planning options involving usually sets of alternatives. In this case aggregating models capable of generating results from combined outputs, the so called integrated models, are used. A characteristic example at this level is the development of long-term flood risk management strategies.

The development of one single DSS satisfying the requirements for all levels of decision making is extremely difficult and too complex. Therefore, it has been attempted to combine two of the three levels in some DSSs (i.e. the planning and the management level). These attempts include aggregation or/and disaggregation of models, "nesting of models".

The DSSs models for planning and management should be capable of analysing, evaluating and assisting the selection of alternatives, which could change the physical system or the social – institutional arrangements. They should permit the involvement of different stakeholders in the planning and management process. These are physically-based models, which through deliberate human interventions aim at improving the future state of the water system.

On the other hand, the DSSs models for operational management should enable the use of real time data from the measuring stations, accurately forecast future state of the water system and incorporate the results of the forecast into an operational management system. These are simpler models which deal with reactive human interventions to extreme natural events. They use optimisation methods with a high running speed in order to take the optimal short-term operational step, which have incorporated the multi-criteria analysis.

Challenges in modelling technologies

The challenges of the future DSSs are the incorporation of techniques for meeting the increased demand for involvement of all different stakeholders as well as of public participation. The decision making process should additionally take into consideration negotiations and trade-offs among participants in decision making problems. The use of Internet could play a significant role in stakeholder involvement. Besides the well-known potentials of Internet (speed, accessible to everybody, etc.), it enables the exchange, transfer and delivery of knowledge at extreme points of a given socio-technical network, facilitating the address of immediate concern of public. An attempt to meet some of the pre-mentioned challenges of the DSSs is the concept of Network Distributed Decision Support Systems. It includes three functional components: (a) The fact engine, which is a knowledge centre, (b) the judgment engine, which consists of the users' periphery and (c) the platform for negotiation and collaboration distributed both in the knowledge centre and the users' periphery. The fact engines could include all kind of models (i.e. hydraulic, hydrologic, ecological, economic), databases, optimisation methods, measuring utilities, etc. It is worth mentioning that the main concern in this case is the software interoperability. The judgment engine deals with the mapping of beliefs, according to given facts, attitudes, judgements, decisions and actions. The main challenge of this component is the content customisation and adaptation of user transformations. The platform for negotiation and collaboration should collect mappings from the judgment engines and then aggregate the judgments.

Another challenge is to create sufficiently useful, attractive, transparent and understandable model-building environments for various stakeholders. One approach for achieving these environments is to develop interactive modelling "shells" for environmental issues. Modelling shells are defined as data-driven programs, in which by entering sufficient data their final form is developed. Interactive shells allow the definition of models and their input data interactively and in an adaptive way. The highly sophisticated development of computer technology has led to the development of an impressive wide range of such generic simulation modelling shells for water resources systems enabling interaction and communication between the analysts or modellers and their clients. Some of the most widely used river basin management DSSs worldwide are AQUATOOL (Andreu et al., 1991), RIBASIM (Delft Hydraulics, 2004), MIKE-BASIN (Danish Hydraulic Institute, 1997) and WEAP (Raskin et al., 2001). These computer software systems include interactive river–aquifer simulation shells representing the system as a network of nodes and links. The required data of each node and link depend on what that node or link represents, as well as on the users interests. Obviously, the more different types of information desired or the greater spatial or temporal resolution desired in the model output, the more input data required.

Moving a step forward in shared vision modelling is to use open modelling systems. These are environments, which allow to all stakeholders to introduce their own models in the overall system description. A characteristic example is in the trans-boundary water resources systems, where each country would like to use its own hydrodynamic model for its reaches. The implementation of Water Framework Directive in Europe has initiated the development of the European Open Modelling Interface and Environment (OpenMI). OpenMI will simplify the linking of water-related models that will be used in the strategic planning required by the Water Framework Directive (Gijsbers et al., 2002).

Project planning and analysis for Decision Support

The first step in the project planning and analysis of the decision making process is the identification of the water resources system (Figure 5).

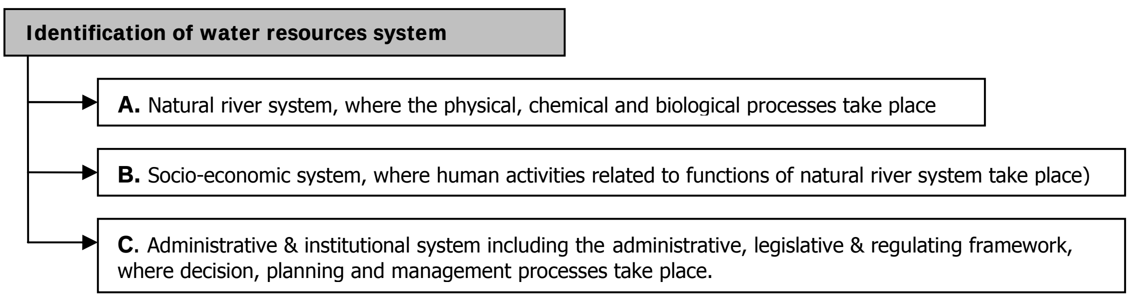

Figure 5 Identification of the water resources system

The next step involves the specification of the diverse functions of the water resources system. This includes (a) subsidence functions, such as water supply, irrigation, fishing, (b) commercial

functions including consumptive and non-consumptive functions, (c) environmental and ecological functions and (d) other functions, such as aesthetic, religion values, etc. The formulation of objectives is based on the defined system functions.
Afterwards, the system components are analytically analysed including the boundaries, the elements/components (inputs and parameters) and the control (decision) variables of the system. The definition of a project can be done in any of the three pre-mentioned systems previously identified. For the natural system the system boundaries are determined from the natural/physical boundaries of the river basin. From hydrological aspects watersheds or river basins are usually considered logical basin units for the analysis of water resources planning and management. But, they may be inadequate, if particular water resources problems are affected or strongly interconnected to events outside the physical basin boundaries. In this case the system boundaries are determined by an administrative unit. The boundaries of the socio-economic system are very difficult to define, since they could be influenced from wider national or even international economies. The socio-economic decision variables could include legislative and regulatory measure, taxes, water prices, etc. The boundaries of the administrative-institutional system are specified by the administrative boundaries. The decision variables of this system are quite unclear and involve measures toward better institutional arrangements. Before selecting and developing a quantitative simulation model, it is often useful to develop a conceptual model, which defines the overall system structure non-quantitatively and without its element and functional relationships. Then this conceptual model is expressed in mathematical terms forming the mathematical model.
The modelling project process could include the selection of an existing model for a particular project, depending on the processes needed to be modelled, the data available and the data required by the model. In this step it is important to know what data are available, if they are complete and what to do about missing data. The identification and the testing of the assumptions of the model are required. A plan should be selected in order to test and evaluate the model i.e. under extreme conditions. Then, if the test-phase is satisfactory the calibration of the model takes place. To find out if a calibrated model could be considered as "good", the processes of validation and verification take place. The criterion for this is whether the model is capable of providing results comparable to field measurements not used in the calibration-phase. If a model is used to predict situations within the range of conditions used for validation, we could be more confident concerning the reliability of the predictions. Although the use of models should not include extrapolation for predictions and scenario analyses, this is exactly the reason for modelling.
The next step includes the running of the model. The inputs, the simulation time period and the expected quality of the results are some of the points, which should be clear before using the model. At the end the model results should be interpreted. This could be done by comparing them with the results of other similar studies. The presentation of the results in a comprehensive, clear, unambiguous and synoptic way is meaningful. The uncertainties and the restrictions in the results should be also presented.

Challenges in development and implementation of DSS

For strategic planning and policy making, most attempts for developing DSS tools have involved up to now specific case studies for particular problems and river basins. The challenges of formulating a more generic and comprehensive tool for integrated river basin management are enormous. The first obstacle is the lack of data and theories to fully describe the complex processes of the river basin system and their interactions with the socio-economic and administrative-institutional system. Few efforts to take into account the socio-economic processes include only a limited number of aspects.
Besides all aforementioned challenges for the development of a DSS, current peculiarities of the Greek status and of the Mediterranean countries in general should be considered. This involves the great diffusion of water management in several authorities with unclear and overlapping areas of responsibilities. Moreover, there are multiple stakeholder conflicts without

comprehensive prioritisation or limitations of water uses. Irregular and inadequate pollution monitoring programs and low financial resources pose more difficulties. There is great lack of environmental education and of citizen motivation for active participation in environmental issues. Some attempts towards integrated river basin management practices – such as control of gravel extraction or changes in agriculture management – were hampered by the lack of monitoring systems, of actual and continuous verification of the water bodies' status, of criteria/plan to measure and evaluate progress and of proper practical support.

The design and implementation of a DSS will be applied to the Alfeios River basin in Peloponnesus (Greece). River basins in Greece have been used more intensively in the last decades, with man-imposed pressures often exceeding the sustainable resource limits. The Alfeios River Basin has experienced stresses and environmental problems. The Alfeios River is the greatest in length and river flow rate in Peloponnesus and constitutes an important water resource and ecosystem of Western Greece. A number of infrastructure works and human activities have been constructed and are operating in Alfeios River Basin, while in the past extensive gravel extraction had been taken place. The impacts of infrastructure works and gravel extraction in the lower Alfeios Basin on the hydro-morphological river characteristics have been examined (Manariotis and Yannopoulos, 2001 & 2004) and the results show that gravel extraction and infrastructure works, in conjunction with the reduced sediment transport rates, cause diachronically adverse effects on riverbed erosion as well as the water level. Besides that, lignite mining and wastewater disposal; threatened water bodies; synergistic effects; water quality issues; development pressures; habitat protection; wetland restoration and creation; source water protection are some additional problems. Some of the preliminary goals that might be developed for the Alfeios basin include: Meet water quality standards for dissolved oxygen and temperature; restore aquatic habitat to meet designated uses for fishing; protect drinking water from excessive eutrophication; manage future growth; restore wetlands to maintain healthy wildlife community; protect river banks and bottom from erosion; restore the groundwater level and infrastructure works safety; protect open space. From this short description of the stresses exerted on Alfeios river basin, it is obvious that simple approaches and efforts are inadequate to simulate such complicated systems. It is thus necessary to develop and implement a decision support system.

Conclusions

The implementation of integrated and sustainable river basin management is a huge challenge. This result from one side from the complexity and the uncertainty related to the natural water systems and its interconnections with the social and economic system, and from the other side from the competing and changing objectives and priorities of different interest groups. The role of the decision support systems is to assist in defining and evaluating various alternatives corresponding to different possible compromises and tradeoffs among conflicting groups and management objectives. Despite the fact that models cannot define the best objectives or set of assumptions, they can help identify the decisions that best meet any particular objective and assumption. A Decision Support System model considering the special conditions (climatic conditions, the threat of the global climatic change, complexity of authority responsibilities, stakeholder conflicts) observed in the Mediterranean watersheds could be a precious informative tool for an effective decision-making of the administration bodies of river basins.

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