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Development of a Decision Support System (ElmaaDSS) for the integrated water management of Mediterranean phosphate mining areas

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Abstract: The phosphate industry is a major contributor to the economy of many South Mediterranean countries. Large volumes of water are required by the mining industry in areas where water resources are scarce. The integrated management of water in the influence zone of phosphate mines with due respect to other sectors of the economy and populations is a way to further develop these regions. To achieve this objective, the implementation of a Decision Support System constitutes an innovative tool, which offers an integral view of water management in the phosphate mining areas and gives an overview of the interconnections and interactions between the various economic sectors. This paper presents the development of the ElmaaDSS Decision Support System, which was built in the framework of the EU project ELMAA. ElmaaDSS was developed with an integrated approach that takes into account water resources, water consumers and relations between them. It was implemented with Object Oriented Programming Techniques, using Visual Studio.NET. It consists of calculation and optimization routines, an easy to use Graphical User Interface, a Database, and a Knowledge Base. A first application of the ElmaaDSS software in Gafsa mines area, Tunisia, is also presented. This case study demonstrates that ElmaaDSS is a valuable tool for decision-makers to improve the current situation of water scarcity without hampering the development of economical sectors such as mining and agriculture.

***Keywords**:* integrated water management; Decision Support System; phosphate industry; Object Oriented Programming.

1. INTRODUCTION

The phosphate industry is a major contributor to the economy of some Mediterranean countries such as Morocco, Tunisia and Jordan. Mediterranean phosphate mine areas are located in semi-arid regions characterised by water scarcity and pronounced climatic variability. Large volumes of water are required by the mining industry in areas where water resources are scarce or limited. The increasing water demand, due to the development of the mining, agricultural and other socio-economic sectors, threatens groundwater resources. This situation represents a limiting factor to the sustainable development of these regions and it may result in conflicts between the water users. The integrated management of water in the influence zone of phosphate mines with due respect to other sectors of the economy, is an alternative to develop the phosphate industry. To achieve this objective, a Decision Support System (DSS) software tool is developed, offering to the phosphate industry and all the respective water management players an integral view of water management in the phosphate mining areas and an overview of the interconnections and interactions between the various economic sectors (agriculture, mining industry etc).

The concept of a DSS [Adelman, 1992] is extremely broad and its definitions vary depending upon the author's point of view. A DSS can take many different forms and the term can be used in many different ways. On the one hand, Finlay [1994] defines a DSS broadly as "a computer-based system that aids the process of decision-making." This first approach is extended by Turban and Aronson [1995] who define it as "an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision-making. It utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights." It generally involves at least two of the following building blocks [Denzer, 2005]:

- Integrated models able to simulate the behavior of socio-hydrosystems, coming from different fields of science such as water sciences (hydrology, hydrogeology), agronomy (crop needs, irrigation), hydraulic (drinking water supply network), socio-economy (human activities), etc;
- Geographical Information Systems (GIS);
- Database management system (data, information, results);
- Scenario evaluation module (multi-criteria analysis, economical analysis (cost-effectiveness and cost-benefit analysis), etc);
- Convivial Graphical User Interface (GUI).

Some examples of DSS applications are 'WaterWare' [Jamieson and Fedra, 1996], the 'MULINO' DSS [Mysiak et al., 2005], and 'WaterStrategyMan' DSS [Maia and Schumann, 2007].

This paper presents the decision support system (ElmaaDSS) which was built and applied in the European research project Elmaa "Integrated water management of Mediterranean phosphate mining and local agricultural systems" for the integrated water management in Mediterranean phosphate mining areas. ElmaaDSS aims at becoming an assisting tool for the water players at the scale of a phosphate mining district. It is a customized software tool, designed to be used by the actors of water management to explore the impact of various water management strategies combined to climatic scenarios. Its conceptual model comprises distinctive entities that facilitate the efficient description of the tested options.

The ElmaaDSS conceptual model, the calculation and optimization routines, the Graphical User Interface (GUI), the database and the knowledge base are presented in the following paragraphs. As a case study, a preliminary application of the ElmaaDSS software in Gafsa mines area, Tunisia, is also presented. This region is known for its industrial activities related to phosphate (extraction, production of phosphoric acid and fertilizer production) and farming, which both compete for water resources.

2. METHODOLOGY

ElmaaDSS is designed to help decision-makers in improving the current situation of water scarcity without hampering the development of economical sectors such as mining and agriculture. It is a tool which integrates hydrogeological, technical (mining and agricultural) and socio-economic components to have a better overview of the evolution of water resources. The methodology followed for its design includes the description of the conceptual model of the socio-hydrosystem of the studied area, technical studies, hydrogeological modelling, definition of scenarios for water resources and water demands evolution, and definition of water management options.

Indicators and criteria were also defined to allow an efficient exploration of the tested scenarios. Criteria were carefully chosen and constructed to reflect the multiple dimensions (socio-economic and environmental) associated with the water resources management in the Mediterranean phosphate mining areas. Indicators, which are quantified in each case, are related to the criteria.

The implementation of the above methodology was based on the collection of specific data with on-site measurements and surveying, or data from socio-economic and technical studies and literature reviews that were also curried out. Furthermore, ElmaaDSS was designed and developed in close cooperation with the local stakeholders, following a participatory approach, in order to develop a tool corresponding to their needs and their objectives. The involvement of the local stakeholders (phosphate mining industry representatives and state representatives of the drinking water supply, agricultural and sewage sectors) was linked with three main steps:

1. Design of the tool (characteristics, calculations etc.)
2. Determination of water demand evolution scenarios.
3. Selection of water management options. These options aimed at either increasing the available water resources or reducing the water demand.

A detailed description of the methodology followed is provided by Bru et al. [2008].

3. DESCRIPTION OF ElmaaDSS

The development of ElmaaDSS is based on Object Oriented Programming (OOP) techniques, using Visual Studio .NET. The software consists of: calculation and optimization routines, an easy to use Graphical User Interface (GUI), a database containing the input parameters and the results, and a knowledge base containing information on required coefficients and parameters for the execution of the optimization and calculation routines.

3.1 Conceptual Model

Object Oriented Programming (OOP) is a way of thinking about problems using models organized around real world concepts. It is a way to organize software as a collection of discrete objects that incorporate both data structure and system behavior [Simonovic et al., 1997]. Data is organized into discrete, recognizable entities called objects. These objects could be concrete (such as a river reach) or conceptual (such as a policy decision) [Elshorbagy and Ormsbee, 2006].

In ElmaaDSS, the OOP approach is used to design a conceptual model that will allow the simplified but realistic representation of the socio-hydrosystem of the studied area. The conceptual model consists of a set of distinctive entities (Objects) representing the basic water management concepts. These objects are discrete data structures that comprise the data, the methods and the interactions related to each water management concept.

The main entity of ElmaaDSS is a Project. A new Project is created for each analyzed Case Study. Each project consists of:

- A Map, which can be related to the actual map or a schematic representation of the case study area.
- Climate units (Clima), which represent the climatic conditions for different regions for the set of the examined scenarios.
- Scenarios, which represent different sets of parameters describing the evolution of climate conditions, water resources and water demands. Each scenario includes a climate dataset, a set of parameters concerning the evolution of water resources and water demand, and a set of management options.

Each Map contains one or several regions, which are distinctive sub-entities of the case study area. The regions can be independent or linked. Each region contains one or several Water Resources Units (WRU) that are divided in Water Resources (e.g aquifers or surface hydrological units), Water Consumers (e.g. domestic consumption, industry, agriculture, and livestock), Treatment Units. Several types of WRU are described having special attributes, methods and interaction rules. There is also a general consumption and a general source WRU with general attributes and methods to include alternative water sources and other water uses. The WRUs are linked with each other using the appropriate Link Objects, which characterize water flows between these units. An overview of the conceptual model is presented in figure 1. In figure 2, an example of the representation of a socio-hydrosystem conceptual model, using the dedicated objects, in the framework of ElmaaDSS, is illustrated. The symbols representing the various WRUs and the links between them are also presented. In the same figure, the customized window that pops up when the user double clicks each element of the conceptual model in order to modify its properties, is also presented.

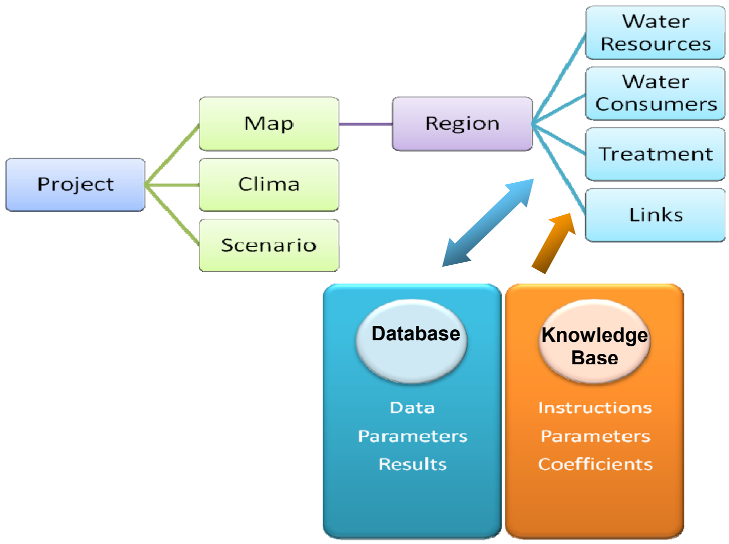

Figure 1: Graphical representation the ElmaaDSS Conceptual Model

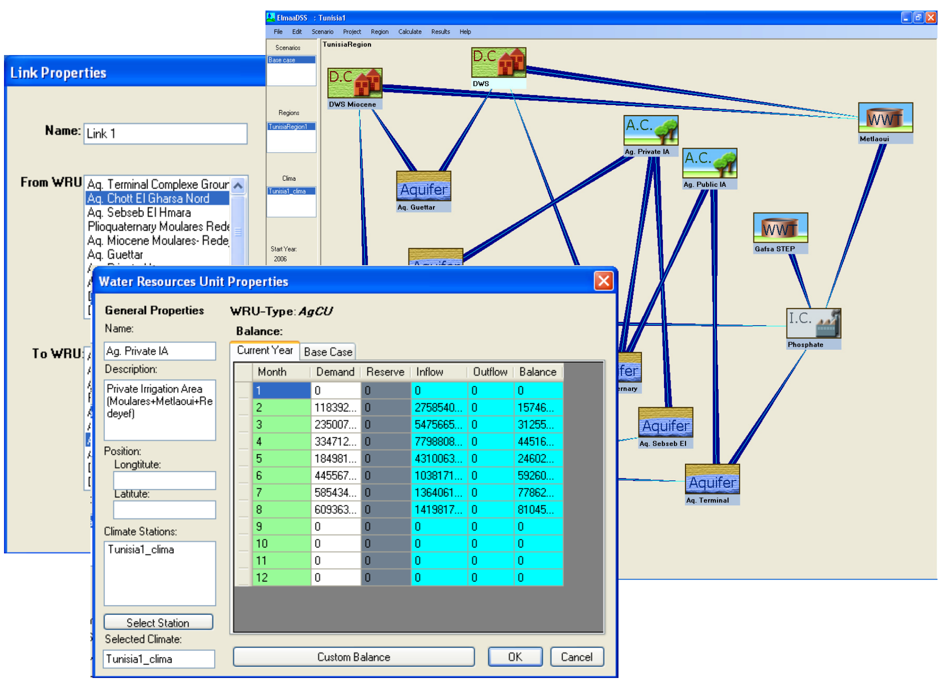

Figure 2: Example of the representation of a socio-hydrosystem conceptual model, using the dedicated objects, in the framework of ElmaaDSS, and of the customized properties window (Gafsa, Tunisia).

3.2 Data Base and Knowledge Base

Elmaa DSS is linked with a database in which input data and results are stored and processed, and a knowledge base which contains the necessary coefficients and parameters for the accomplishment of calculations. Elmaa DSS is interfaced with the database, which is used for information storage and organization of the various data. For each water management unit and for each selected scenario, the corresponding information is defined and stored in the database. The calculations of the various modules of the DSS (e.g. agricultural water needs, groundwater resources, etc) are also implemented in this environment. The stored information is linked with each object and it is accessible by the user at any point of the implementation.
The knowledge base contains information on coefficients, parameters and details of the required inputs of the calculation and optimization routines of the DSS, which estimate the needs for each water management unit (e.g. agriculture, domestic consumption, industry, etc). The existence of a knowledge base behind the DSS assists the user to define the input parameters and coefficients for some units and thus calculate the water needs. The knowledge base was designed as an additional, supporting tool, which contains predefined values of particular parameters in order to efficiently confront any lack in data or metadata. For example, the knowledge base consists of information needed to estimate the agricultural water needs such as the crop coefficients, the length of the growing stages for many plants, the plant date, etc [Allen *et al*., 1998].
The socio-economic and consumption parameters (e.g. inhabitants' consumption rate, visitors' consumption rate, efficiency, etc) were also defined after constant consultation with the local stakeholders. With the predefined input parameters, the user can customize the water balance for agricultural and domestic consumption (Figure 3).

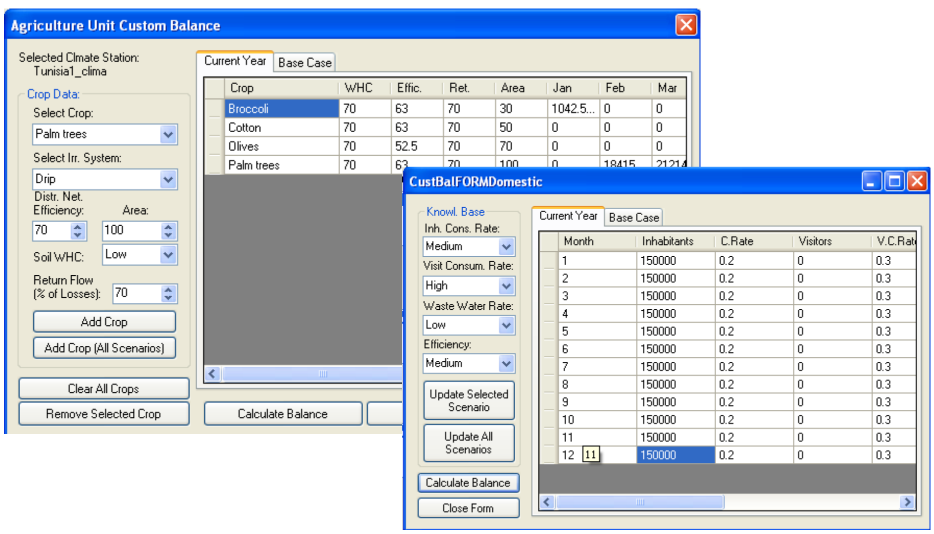

Figure 3: Implementation of optimization and calculation routines with the use of the knowledge base

3.3 Graphical User Interface (GUI)

The Graphical User Interface (GUI) of Elmaa DSS is designed with the aim of transforming the DSS in an easy to use tool, which will be valuable for decision making. Since 'user-friendliness' of a user interface depends a great deal on the experience of the user, graphical user interfaces hailed by one group of users may be condemned by a different group of users [Coffman, 1992]. The GUI implemented in ElmaaDSS provides an easy to use environment even for less experienced users.
In particular, the schematic visualization of the conceptual model for each case study can easily give overall information about the studied area. Moreover, the knowledge base incorporated in the DSS can provide the user with accurate information about coefficients and parameters such as consumption rates which otherwise may not be readily available. The GUI facilitates the selection and set up of the simulated scenarios (Figures 3 and 4),

and provides different forms of results' presentation, including tables, graphs, etc. By evaluating different ways to optimise the water consumption and its re-use and by measuring the potential impact of changes in the mining and agricultural practices related to technological innovations or evolutions in the institutional or regulatory framework, this DSS helps water managers to adopt plans to improve water availability, its conservation and its sharing between the different users in the influence area of phosphate mines.

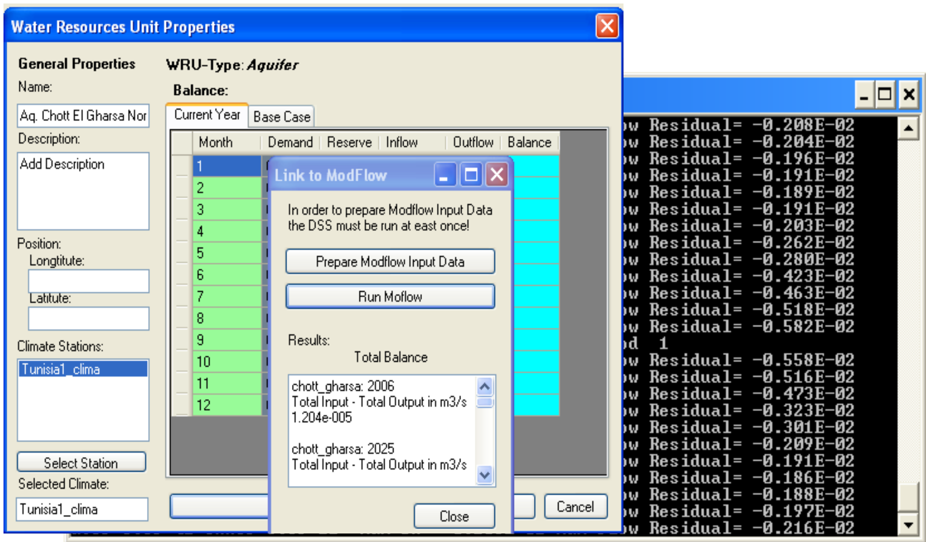

Figure 4: Example of the Graphical User Interface of ElmaaDSS, illustrating the Aquifer properties window.

4. APPLICATION EXAMPLE

As an example of the ElmaaDSS software application, a preliminary case study in the Gafsa mines area, Tunisia, is presented (Figure 5). The Gafsa mines influence area is situated 350 km south of Tunis near the north-eastern part of the desert. This region is known for its industrial activities related to phosphate (extraction, production of phosphoric acid and fertilizer production) and farming, which both compete for water resources. The influence area has a population of 323.709 inhabitants, including 73% living in urban zones and 27% in rural zones. Gafsa region, which is classified in the bioclimatic arid level, has a dry subtropical climate characterized by very cold winter, dry hot summers and low and irregular precipitation. The continuous increase in water demand combined with these unfavourable climatic factors result in depletion and degradation of the water resources. Indeed, water demand is increasing due to the population growth, the extension of irrigated areas and the fast-growing mining exploitation. Currently, the phreatic aquifers, which are mainly allocated to agriculture, are overexploited with an exploitation rate of

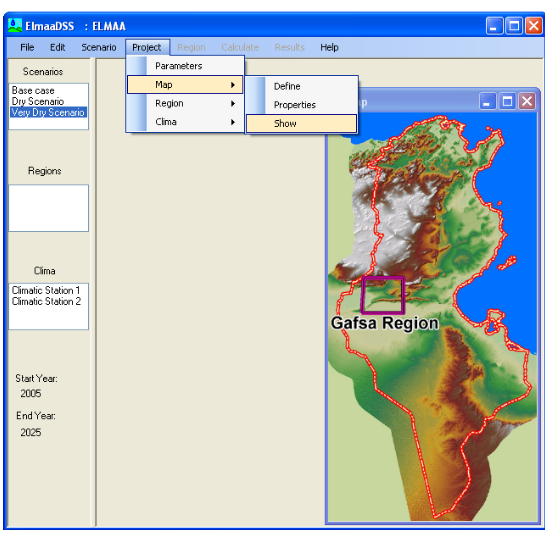

Figure 5: Gafsa study area in Tunisia

113%, while the exploitation rate of the deeper aquifers reaches 80%. The withdrawals in deep aquifers are mainly used by industry (76%), the rest being divided between agriculture (13%) and drinking water (11%). [DGRE, 2001a; DGRE, 2001b; DGRE, 2005a; DGRE, 2005b; Bru et al., 2008].

The objectives of the DSS developed for the Gafsa mines influence area are to allow a better allocation of the water resources between all the water users and to improve water management, e.g. by proposing technological innovations for water savings. The implementation of ElmaaDSS for the Tunisian case study includes the following steps: building of the conceptual model, definition of the parameters and the coefficients for water demand scenarios, description of the water management options and presentation of the results.

The conceptual model (Figure 2) derived from the analysis of the Tunisian studied area reveals the complexity of the hydrology of the region. Parameters influencing the water demand in Gafsa area were defined during workshops with the stakeholders. For each parameter, two or three values were fixed: a "low value" corresponding to a decrease in water consumption, a "tendency value" (following the Business As Usual) and a "high value" corresponding to an increase in water consumption. Combination of all parameters fixed at the "tendency value" defines the baseline scenario. Furthermore, the investigated scenarios comprise the following management options:

- Drip Irrigation, utilization of treated wastewater for the phosphate industry and use of a press filter in the mines.
- Utilization of treated wastewater for irrigation of particular cultivars (for example leafy vegetables and other cultivars for direct human consumption were excluded), utilization of treated wastewater for the phosphate industry and use of a press filter in the mines.
- Drip Irrigation, utilization of treated wastewater for the phosphate industry, installation of systems to reduce households' water consumption, groundwater desalination for drinking water.

In this preliminary application, changes in climate conditions were not considered.

After the implementation of ElmaaDSS and the evaluation of a preliminary set of scenarios, it was indicated that the best combination of water management units in terms of both cost reduction and water conservation, involves drip irrigation in agriculture, utilization of treated wastewater in phosphate industry, and use of a press filter in the mines.

5. SUMMARY AND CONCLUSIONS

The ElmaaDSS software presented in this paper is a general tool which integrates several kinds of information to explore the impact of various water management strategies. ElmaaDSS, in its current state of development, provides a user friendly interface which facilitates its use even by a less experienced user. Moreover, the customized subroutines which are incorporated into the DSS for the industry water needs, the agricultural water needs and the domestic consumption of water, make ElmaaDSS into a tool that can be easily adapted to each case study selected, regardless of the country or the region examined. Furthermore, the knowledge base which is also incorporated into the DSS, facilitates the selection of the correct input parameters and reduces the possibility of false entries for the input parameters. Finally, the use of object oriented techniques, gives the opportunity of a future development of the tool and its enhancement with other subroutines according to the users' needs, while it ensures the future connection of the DSS with other applications.

ElmaaDSS, gives valuable information to help the actors of water management to explore the impact of various water management strategies in the influence zone of the phosphate mining regions. It facilitates the study of the interactions between the various sectors of economic development (e.g. mines, agriculture, domestic and industry) and the available water resources. Concluding, ElmaaDSS, upon its completion, will provide the regional stakeholders with an integrated tool for the water resources management in the areas of phosphate mining, adjusted according to their particular needs and capabilities.

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REFERENCES

Adelman, L., *Evaluating Decision Support and Expert Systems*, John Wiley and Sons, 248 pp., New York, 1992

Allen, R. G., Pereira L. S., Raes D. and Smith M., *Crop evapotranspiration - Guidelines for computing crop water requirements* - FAO Irrigation and drainage paper 56, 328 pp, 1998.

Bru, K., Guézennec A.G., Lanini S., Graveline N., Soulis K., and Karaouli F., Model development for integrated water management in the influence area of phosphate mines, *International Congress on Environmental Modelling and Software Integrating Sciences and Information, Technology for Environmental Assessment and Decision Making, 4th Biennial Meeting (iEMSs),Barcelona, Spain*, 2008.

Coffman, E.G., *Computing (Handbooks in Operations Research and Management Science)*, 692 pp, Elsevier Science Ltd, 1992.

Denzer, R., Generic integration of environmental decision support systems - state of the art, *Environmental Modelling & Software*, 20(10), 1217-1223, 2005.

DGRE : *Direction Générale des Ressources en Eau, Situation de l'exploitation des nappes profondes de Tunisie*, Publication DGRE, 2001a.

DGRE : *Direction Générale des Ressources en Eau, Situation de l'exploitation des nappes phréatiques profondes de Tunisie*, Publication DGRE, 2001b.

DGRE : *Direction Générale des Ressources en Eau, Situation de l'exploitation des nappes profondes de Tunisie*, Publication DGRE, 2005a.

DGRE : *Direction Générale des Ressources en Eau, Situation de l'exploitation des nappes phréatiques profondes de Tunisie*, Publication DGRE, 2005b.

Elshorbagy A., Ormsbee L, Object-oriented modeling approach to surface water quality management, Environmental Modelling & Software 21 (2006) 689-698

Finlay, P.N., *Introducing decision support systems*, NCC Blackwell; Blackwell Publishers, 274 pp, Oxford, UK; 1994.

Jamieson, D.G. and K. Fedra, The "WaterWare" decision-support system for river-basin planning. 1. Conceptual design, *Journal of Hydrology*, 177(3-4), 163-175, 1996.

Maia, R. and Schumann, A.H., DSS Application to the Development of Water Management Strategies in Ribeiras do Algarve River Basin, *Water Resources Management*, 21(5), 897-907, 2007.

Mysiak, J., Giupponi, C. and Rosato, P., Towards the development of a decision support system for water resource management, *Environmental Modelling & Software*, 20(2), 203-214, 2005.

Simonovic, S.P., Fahmy, H., Elshorbagy, A., The use of object oriented modeling for water resources planning in Egypt. *Water Resources Management* 11 (4), 243-261. 1997

Turban, E. and Aronson, J.E, *Decision support and expert systems: management support systems*, Prentice Hall, 960 pp, Englewood Cliffs, NJ, 1995.