A DSS for Agricultural Land Use, Water Management and Environmental Protection

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Abstract: - A Decision Support System (DSS) to support sustainable development planning processes in the agricultural sector has been developed in the context of the research project entitled WATER MAP (Development and utilization of vulnerability maps for the monitoring and management of groundwater resources in the Archimed area), which is an Interreg - Archimed project. The model is based on vulnerability maps and facilitates and optimizes the decision-making process relating to the problems of land use, water management and environmental protection. The spatial integration of the vulnerability maps in the DSS enables regional authorities to design optimal spatial development policies. The DSS is based on a Multicriteria Mathematical Programming model and can achieve the optimum agricultural production plan in the area combining different criteria to a utility function under a set of constraints concerning different categories of land, labour, available capital, etc. The model is further used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters. In this way we get alternative production plans and agricultural land uses as well as the economic, social and environmental impact of different policies.

Key-Words: - DSS, Sustainable development, Land use, Environmental protection

1. Introduction

Decision Support Systems (DSS) are defined as computerized systems, which include models and databases and they are used in decision-making. They are "tools" that help farmers and everyone who makes decisions, in the procedure of decision-making and in choosing the best (economic, social or environmental) alternative solution [1].
Several scientific disciplines support the development of DSSs and constitute the necessary background for their effective planning. The Science of Informatics has contributed in the planning and the application of Decision Support Systems with the vast supply of tools, materials and software. The disciplines of Operational Research and Management and Business Administration provide the theoretical frame for the analysis of various decisions. The sciences of Behavior, Sociology and the Management of Human Resources, constitute sources of information that concern the way with which humans potentially behave at the treatment of information and the decision-making process [1].
'Support' is the keyword in the conceptual frame of these systems. With the utilization of DSSs the role of the decision maker is limited in the evaluation of the results by the internal mathematic models with which the decision is to be made.
In this paper the DSS presented was developed to support the spatial development planning process. It is based on vulnerability maps and facilitates and optimizes the decision-making process relating to problems of land use, water management and environmental protection. The spatial integration of the vulnerability maps in the decision support system will enable the regional authorities to design optimal spatial development policies.

2. Methodology

A typical Decision Support System, upon Manos and Voros [2] and Manos et al. [3], [4], comprises from the following elements [5], [6] (Fig. 1):
1. The Data Base and the Data Base Management System, (DBMS).
2. The Model Base and the Model Base Management System, (MBMS).
3. The Dialog Generation and Management System, (DGMS).
In our DSS the model base consists of an Optimization Multicriteria Mathematical Programming (OMMP) model that achieves the optimum production plan in the study area combining different criteria to a utility function

under a set of constraints concerning different categories of land, labor, available capital, etc.

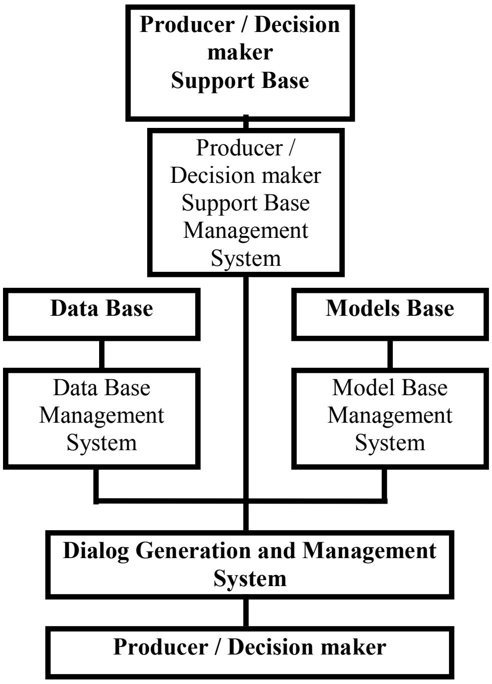

Fig 1. Decision Support System

The OMMP model is used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters (e.g. different levels of fertilizers or water consumption per crop).
In this way we get alternative production plans and agricultural land uses as well as the economic, social and environmental impact of different policies.
Sumpsi et al. [7] and Amador et al. [8] have developed methodologies for the analysis and simulation of agricultural systems based upon multicriteria techniques. These authors propose weighted goal programming as a methodology for the analysis of decision making. This methodology has been successfully implemented on real agricultural systems [9], [10], [11].
We employ this methodology to estimate a surrogate utility function in order to simulate farmers' decision-making processes, broadening in this way the traditional profit-maximising assumption.
Briefly, the methodology can be summarised as follows:
1. Establish a set of objectives that may be supposed to be most important for farmers.
2. Determine the pay-off matrix for the above objectives.
3. Use this matrix to estimate a set of weights that optimally reflect farmers' preferences.

3. Area of study

Sarigkiol basin extends to the north-eastern region of the Kozani Prefecture, Western Macedonia, covering an area of 407 km^2 (Fig. 2). A part of Sarigkiol basin, constituted from the irrigated agricultural area of two municipalities of the Kozani prefecture, is used for the spatial model/decision support system (DSS). Technical and economic data concerning the agricultural land use and other socio-economic and environmental information gathered from this area are necessary for the spatial model/DSS.
The area is characterized by a semi-arid, Mediterranean climate, with an annual average temperature of 13 °C and an annual rainfall of 643 mm. In a large part of the area irrigated agriculture is practiced. The major water use is for irrigation purposes in agriculture; 82% of the total consumption.
>From a geological point of view, carbonate rocks are mostly distributed on the highlands and Neogene and Quaternary sediments cover the lowlands (Fig. 3). Lignite deposits occurring in the Plio-Pleistocene sediments and are one of the most rich energy resources in the Balkans. A large amount of 65% of country's total electric power is produced in this area.
The main aquifer systems are developed in Quaternary deposits (alluvial aquifer) and carbonate rocks (karst aquifer). The water needs of the basin are predominantly being covered by the exploitation of the aforementioned aquifers, through a large number of boreholes.

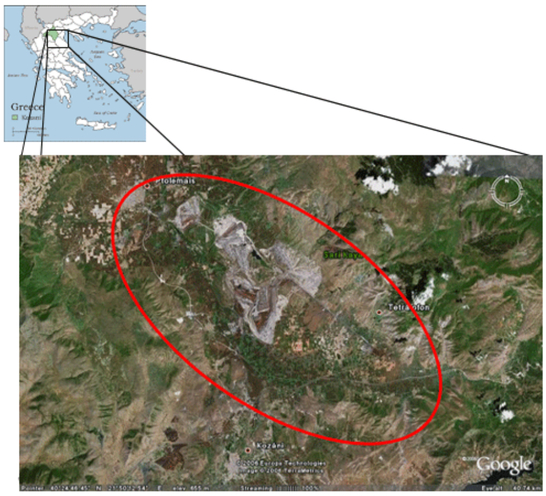

Fig. 2 Topographic map of the study area

The alluvial aquifer is recharged by direct infiltration during rainfall and seepage through the torrent beds, lateral subsurface inflows and recharge from irrigation returns. The aquifer recharge presents significant fluctuations, depending on the annual rainfall depth. The depth to water table in the study area ranges from 7 to 75 m [12].

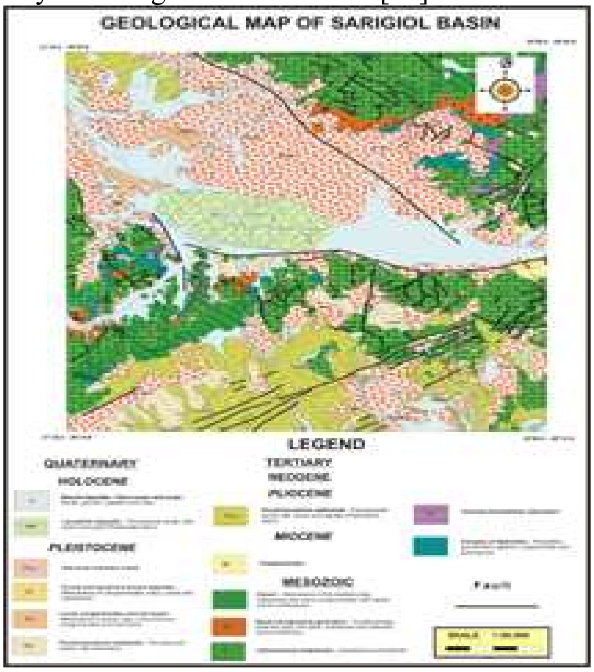

Fig. 3 Geological map of the study area [12]

Groundwater is the main source of water supply in the area and is taken from a numerous boreholes. The irrigation in the area relies on groundwater from the Sarigkiol alluvial aquifer. The irrigated land increased greatly in last decades, as indicated by the number of boreholes. The most important limiting factor in the Sarigkiol basin is the seasonal variation of water availability and demand. Agricultural activities require increased supplies in late spring, summer, and early autumn, when the water availability is low.

Table 1. Distribution of utilized agricultural area.

No	Crops	Total (Sarigkiol)	
		(ha)	(%)
1	*Soft Wheat*	1,324	6.5%
2	*Hard Wheat*	12,411	61.1%
3	*Barley*	1,269	6.3%
4	*Maize*	1,809	8.9%
5	*Sugarbeet*	1,997	9.8%
6	*Oat*	76	0.4%
7	*Potatoes*	252	1.2%
8	*Set Aside*	1,164	5.7%
	Total	20,302	100.0

The groundwater resources in Sarigkiol basin are under many pressures, e.g. quality deterioration and overexploitation. Fertilizers and agricultural chemical compounds are being intensively applied to maintain the productivity of the soil. Agricultural impact on groundwater quality has been mostly associated with nitrate pollution. Based on hydrogeological data [12], the alluvial aquifer shows groundwater level decline due to overexploitation during the last decades. Estimated water balance shows that the groundwater abstractions from the alluvial aquifer system exceed the recharge, indicating that the aquifer is overexploited through numerous boreholes (approximately 320).

Arable crops are the main cultivation for the majority of the agricultural holdings. Arable crops include cereals, alfalfa, potatoes and industrial crops.

The Sarigkiol basin utilized agricultural area is covered by arable crops especially hard wheat (61.1%), soft wheat (6.5%), barley (6.3%), sugar beet (9.8%), maize (8.9%), potatoes (1.2%) and oat (0.4%) (Table 1).

4. Data acquisition

We focus on the annual herbaceous crops that represent the largest proportion of irrigated production in the area of study. As herbaceous crops are the most common system of production in the area, they can be good indicators of the short-term behaviour of farmers when policy is being changed.

The European Common Agricultural Policy (CAP) obliges farmers who are devoted to growing these crops to set aside land if they wish to receive subsidies for agricultural production.

Yields of the crops and their prizes are both averages for the area obtained from official statistics.

Subsidies depend upon the European Union's CAP, and were therefore obtained from official publications.

Income is an important attribute of the system as it defines total agricultural output. Income is computed by the simple combination of yields and prices, plus subsidies where applicable.

We consider six categories to describe inputs and variable costs: 1. seeds; 2. fertilisers; 3. chemicals; 4. machinery; 5. labour; and 6. cost of water.

Data already obtained (prices, yields, subsidies and variable costs) enabled us to compute gross margins by simple calculations. Gross margin is defined as total income less total variable costs.

We estimate fertiliser use (nitrogen) because it is regarded by the producers as a cost and not as a decision variable. Nevertheless, this criterion is relevant for policy analysis, as it may represent an environmental impact (pollution caused by nitrogen fertilisation).

The technical and economic coefficients of crops resulted from the agricultural indicators of the Regional Government of West Macedonia. The data are referred to the main of period 2001-2005 (5 years) for the Sarigkiol basin.

5. Multicriteria model definition

We define a system via a mathematical simplification of the variables and relationships between them in order to understand the effect of any modifications of the initial conditions that characterise the system. Every system has variables that control the processes involved and that belong to the decision-making process as `decision variables'; e.g. the farmer can decide the crop distribution or the level of use of water.
The crop plan selected will determine changes in certain attributes of the system. Attributes are relevant functions deduced from the decision variables, but as we have mentioned above, not all attributes are relevant to the decision makers. Fertiliser consumption, for example, may be an attribute of interest to policy makers but irrelevant for producers.
Attributes to which decision makers assign a desired direction of improvement are considered objective functions. In this study we will analyse not only the farmers' objectives but also attributes that are relevant to policy makers, as we explain in the following section.

5.1 Variables

Each farmer has a set of variables Xi (crops), as described in the previous section. These are the decision variables that can assume any value belonging to the feasible set.

5.2 Objectives

This model will optimize at the same time different criteria as profit maximization, fertilizer minimization etc. Three objectives must be regarded as belonging to the farmer's decision-making process.

Profit maximisation
Farmers wish to maximise profits, but calculation of profit requires the computation of some relatively difficult factors such as depreciation. Therefore, for convenience it is assumed that gross margin (GM) is a good estimator of profit, and maximisation of profit is equivalent in the short run to maximisation of gross margin.
The objective function included in the model is defined as follows:

$$Max\ \text{GM} = \Sigma\ \text{GM}i \times \text{X}i \qquad (1)$$

Fertiliser minimisation
Fertiliser minimisation is a public objective. For this reason it is not considered in the decision process by farmers. The most obvious indicators are those related to the consumption of water and use of pesticides that are directly related to the pollution of water resources and appear more directly quantifiable at farm level. They are, nevertheless, not obviously subject to aggregation at higher level and their effects on the environment can be evaluated only after some elaboration of prediction models based on diffusion functions.
Fertiliser Minimisation is the main form for calculating the surpluses of nitrogen potentially dangerous for the environment. It would also be the main indicator of the impact of farming on the environment as groundwater quality is concerned.
In this way, all nitrogen reaching the cultivated soil is included as input. Similar indicators can be designed for other nutrients, such as phosphorus and potassium. For this reason, fertiliser is computed as the sum of fertilisers used for all crops (TF), and its objective function will be as follows:

$$\Sigma \text{TF}i \times \text{X}i = \text{TF} \qquad (2)$$

Minimization of labor
The minimization of labour implies not only a reduction of input cost, but also an increase of leisure time and reduction of administration and management processes. The farmers usually show an aversion to hiring labor. An explanation of this behaviour is that this parameter is connected with the complexity of crops because the hired labor adds a degree of complexity to family farming. For this reason, labor is calculated as the sum of labor for all farm activities (TL), therefore the objective function will be:

$$\Sigma \text{TLi} \times \text{Xi} = \text{TL} \qquad (3)$$

5.3 Constraints

All crops (Xi) must add up to 100. This constraint is only introduced in order to obtain the outcome of the model (decision variables Xi) as percentages.
A large proportion of agricultural income depends upon CAP subsidies, and farmers cannot afford to ignore CAP regulations that affect most of the crops available for cultivation. For this reason, in accordance with CAP rules, we need to include set-aside activity (SA) related to the subsidised crops (which are the majority):

$$\Sigma\ \text{X}i + \text{SA} = 100 \qquad (4)$$

Some of the crops are not subject to CAP rules but

marketing channels put an upper limit on short-term variations. In our model we put some market constraints for hard wheat, oat and maize in order to express the market demand of these products in the area, according to the historical quotas of the last 5 years (2001-2005) in Sarigkiol.
Agronomically it is regarded as sound policy not to cultivate a crop such as a cereal if, during the previous year, the same plot has grown another cereal. This is called a rotational constraint. A rotational constraint limits the cultivated area for a crop to a maximum number of the total available area, and applies to all cereals.
All this information has been included in the model that forms the basis for the OMMP simulation.
We also include some attributes that are to be analysed in the study, but that are not taken into consideration in the farmers' decision-making process.

5.4 Attributes

Attributes are values of interest for the analysts that are deduced as functions of decision variables. In this sense we have considered several attributes that are relevant to policy makers. The model used in this study has been developed in order to estimate the values of these attributes (not relevant to the decision maker) at the same time as the decision variables. The analysed attributes are:
1. Water consumption: the projected consumption of water measured in m^3/ha, is the variable that policy makers wish to control as a consequence of changes in water management policy.
2. Environmental impact: the main environmental impact of irrigated agriculture is water consumption, with the creation of a mosaic landscape and a rise in crop diversity and humid areas. In addition to this positive impact, however, comes an increase in the use of fertilisers and chemicals that are the main source of non-point source pollution in agriculture. We use the demand for fertilisers as an indicator of the environmental impact of irrigated agriculture, measured in kg of nitrogen added per hectare (N/ha).
3. Nitrogen balance in groundwater: Physical difference (surplus/deficit) between nitrogen inputs and outputs from an agricultural system, per hectare of agricultural land. This is the main form for calculating the surpluses of nitrogen potentially dangerous for the environment. It would also be the main indicator of the impact of farming on the environment as groundwater quality is concerned.
In this way, all nitrogen reaching the cultivated soil is included as input and the nitrogen in groundwater is considered as output. The difference is the net amount of nitrogen that, over one year, is released in the environment.

6. Results

We applied the OMMP model to Sarigkiol basin.
The 3 objectives were:

1. Max Gross Margin (GM)
2. Min Fertilizers Use (FER)
3. Min Total Labour (TL)

The pay off matrix for the Sarigkiol basin is shown in table 2.

Table 2. Pay off matrix.

VALUES	Optimum			Real (Observed)
	GM	FER	TL	
GM	68,103	47,388	47,029	49,330
FER	51,201	50,589	51,268	58,678
TL	7,846	6,742	6,661	8,962

The last column shows real data (observed) for the Sarigkiol basin. These values show the actual crop distribution (considering a theoretical 100 ha farm) and the relation among different crops and the objectives considered (GM, FER and TL). We can see how far the real situation (2005) is from any single optimum (column). This may induce us to try a combination of objectives as a better simulation of farmers' behaviour. With the values of table 2 we obtain the set of weights that best reflects farmers' preferences. These are:

W1 (max GM) = 0.109
W2 (min FER) = 0.000
W3 (min TL) = 0.891

The set of weights for Sarigkiol basin is compatible with a type of behaviour that combines labor minimisation which presents a very high weight (89.1%) and profit maximisation avoidance (10.9% weight). It is important to note that although we proposed fertilizers use as an objective taken into account by farmers, the results have shown us that this hypothesis was wrong and actually is not considered as a relevant criterion in this area.
The estimation of these weights is based on the current situation. In this sense, it is important to note that we assume that this set of weights can be considered as a structural factor. As these weights correspond to the producers' psychological attitudes, it is reasonable to assume that they will be kept at the same level at short and medium run, and this is in fact the key assumption in our simulation.
In order to simulate fertilizers use scenarios, we will use the weightings given above in order to represent the farmers' utility function. For Sarigkiol basin the utility function will be as follows:

$$U = 10.9\%\ GM - 89.1\ \%TL \qquad (5)$$

In order to include this utility function (5) in our decision model, we must use the «normalised weightings» according to Sumpsi et al. [12]. Thus function (5) results in the following transformed utility function:

$$U = 5.181 \times 10^{-6} GM - 7.519 \times 10^{-4} LAB \qquad (6)$$

This expression that the model will attempt to maximise is employed in the subsequent simulation. It is essential to compare the real (observed) situation with the situation predicted with the help of the estimated utility function.

Table 3 shows that the adopted methodology produces a better approximation to observed values at the present. Trying to combine the two objectives of profit maximisation and labour minimisation, the OMMP model gives a production plan that achieves gross margin 9.2% more than the existent plan. As regards the total fertilizer use the OMMP model achieves a decrease -4.8%.

Table 3. Existent and optimum plans for the Sarigkiol basin

	Observed values	OMMP model	
		Mod. values	% deviation
GM	49,330	53,903	9.2
FER	58,678	55,856	-4.8
TL	8,962	8,962	0.0
Wheat	6.5	0.0	-100.0
Barley	6.3	4.9	-22.2
Hard wheat	61.1	61.1	0.0
Maize	8.9	17.8	100.0
Sugar beet	9.8	4.6	-53.0
Oat	0.4	2.0	400.0
Potatoes	1.2	1.2	0.0
SA	5.7	8.4	1900
TOTAL	100.0	100.0	

References:

[1] Manos, B., A. Ciani, Th. Bournaris, I. Vassiliadou, J. Papathanasiou, A Taxonomy Survey of Decision Support Systems in Agriculture, *Agricultural Economics Review*, Vol. 5, No 2, 2004.

[2] Manos, B., M. Voros, A Decision Support System for Poultry Producers, *Proceedings of 9th World Farm Management Congress*, Invited paper, Budapest 1993.

[3] Manos, B., Th. Bournaris, N. Silleos, V. Antonopoulos, J. Papathanasiou, A Decision Support System Approach for Rivers Monitoring and Sustainable Management, *Environmental Monitoring and Assessment*, Vol. 96, Issue: 1-3, 2004, pp. 85-98.

[4] Papathanasiou, J., B. Manos, M. Vlachopoulou, I. Vassiliadou, A Decision Support System for Farm Regional Planning, *Yugoslav Journal of Operations Research*, Vol. 15, No 1, 2005, pp. 109-124

[5] Georgakakos, A.P., Decision Support System for Integrated Water Resources Management with an Application to the Nile Basin, in *Proceedings, International Federation for Automatic Control Workshop on Modelling and Control for Participatory Planning and Managing Water Systems*, Venice, Italy, Sep. 29 B Oct. 1, Elsevier, New York 2004.

[6] Pereira, A.G., Quintana, S.C., Funtowicz, S., GOUVERNe: new trend in decision support for groundwater governance issues, in *Environmental Modelling & Software*, vol. 20, no. 2, 2005, pp. 111-118.

[7] Sumpsi M.J., F. Amador, C. Romero, On Farmers' Objectives: a Multi-criteria Approach. *European Journal of Operational Research* Vol. 96, 1997, pp. 64-71.

[8] Amador, F., M.J. Sumpsi, C. Romero, A Non-Interactive Methodology to Assess Farmers' Utility Functions: An Application to Large Farms in Andalusia, Spain. *European Review of Agricultural Economics*, 25, 1998, pp. 95-109.

[9] Berbel, J. and J.A. Gómez-Limón, The Impact of Water-Pricing Policy in Spain, An Analysis of Three Irrigated Areas. *Agricultural Water Management*, Vol. 43 No 2, 2000, pp. 219-238.

[10] Berbel J. and A.O. Rodriguez, An MCDM Approach to Production Analysis: An Application to Irrigated Farms in Southern Spain. *European Journal of Operational Research* 107, 1998, pp. 108-118.

[11] Manos, B., Th. Bournaris, M. Kamruzzaman, A.A. Begum and J. Papathanasiou, The Regional Impact of Irrigation Water Pricing in Greece Under Alternative Scenarios of European Policy: A Multicriteria Analysis, *Regional Studies*, Vol. 39, No 9, 2006

[12] Voudouris, K., E. Patsios, DRASTIC Method to Assess Groundwater Vulnerability. Experiences from its Application in Greek Test Sites. *Meeting in the frame of INTERREG III B project*, Bari, Italy, 2007.