TRANSNATIONAL INTEGRATED MANAGEMENT OF WATER RESOURCES IN AGRICULTURE FOR EUROPEAN WATER EMERGENCY CONTROL (EUWATER)

Priority Axis: Protection and Improvement of the Environment
Area of Intervention: A.O.L. 1.2 Improve integrated water management and flood risk prevention
Project Duration: 36 months

Implementation of pilot action in Greece: Application of a DSS to support water-use and eco-friendly decision process in agricultural production planning

WP: WP5 - Pilot Actions

Activity: 5.4 Greece

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Introduction

The pilot action in Greece is an application of a Decision Support System (DSS) to support water-use and eco-friendly decision process in agricultural production planning. The Decision Support System (DSS) is a Computer system which includes models and a set of relational databases. The DSS is an important planning tool enabling the regional authorities to design sustainable agricultural policies for the region. The implementation of a DSS optimizes the farm plan of the pilot area taking into account the available resources (land, labour, capital) and environmental parameters (nitrate reduction, water consumption etc). The DSS is further used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters (e.g. different levels of chemicals or water consumption per crop). DSS also supports spatial development planning process, facilitates the decision-making process and assists farmers and decision makers in choosing the best (economic, social or environmental) alternative solution.

The model that the DSS uses is an Optimization Multicriteria Mathematical Programming model based on Weighting Goal Programming. The methodology model is also based on GIS maps and facilitates and optimizes the decision-making process relating to the problems of land use/water management/environmental protection. In order create these maps and to assess the vulnerability of agricultural land to water and nitrogen losses and the pollution potential of groundwater, the LOS indices were used. The selected area for implementing the pilot action is a part of Sarigkiol basin in Northern Greece.

This report is organized as follows. In the following section, the aim of this report is set and the characteristics of the pilot area are described. In section 2 a definition and a presentation of Decision Support Systems are given. In Section 3 the chosen Methodology is described followed by the model definition in section 4. Section 5 discusses the main results of the model application. Section 6 presents the main characteristics of the EUWater DSS application. The final section concludes.
1. Application of a DSS to support water-use and eco-friendly decision process in agricultural production planning

The pilot action in Greece is an application of a Decision Support System (DSS) to support water-use and eco-friendly decision process in agricultural production planning. The Decision Support System (DSS) is a Computer system which includes models and a set of relational databases. The DSS is an important planning tool enabling the regional authorities to design sustainable agricultural policies for the region. The implementation of a DSS optimizes the farm plan of the pilot area taking into account the available resources (land, labour, capital) and environmental parameters (nitrate reduction, water consumption etc). The DSS is further used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters (e.g. different levels of chemicals or water consumption per crop). The DSS supports spatial development planning process, facilitates the decision-making process and assists farmers and decision makers in choosing the best (economic, social or environmental) alternative solution.

The selected area for implementing the pilot action is a part of Sarigkiol basin in Northern Greece. Sarigkiol basin is located in the Prefecture of Kozani in the Region of Western Macedonia. The part of Sarigkiol basin which was selected for implementing the pilot action; it is constituted from the irrigated agricultural area of two municipalities of Kozani prefecture. The basin selected for its ecologic and natural resources exploitation characteristics influencing agricultural and pollution patterns.

The main problems related to water-saving and nitrate-pollution prevention are:

- Seasonal variation in availability and demand
  - ~70-80% of annual rainfall occurs in wet period (usually dry summers) while agriculture requires increased water supplies in late spring, summer, and early autumn (low water availability)
  - Increased irrigated land (~320 wells and boreholes)
  - overexploitation of the alluvial aquifer
(groundwater discharges from the alluvial aquifer system exceed the recharge)

- Water resources deterioration
  - Mainly due to human activities
  - untreated waste effluent from industrial and livestock units and waste water treatment plant shortage (pollute surface waters)
  - discharge of liquid and solid waste directly into abandoned shallow wells in urban areas or abandoned quarries in rural areas
  - central municipal sewage-treatment systems do not exist in small towns
  - fertilizers and agricultural chemical compounds are being used intensively to maintain the productivity of the soil
  - high nitrate (NO3-) concentrations are locally recorded in basin

1.1 General characteristics of the pilot area

Prefecture of Kozani is an agricultural region. The agriculture constitutes a vital sector of the local economy and is supported mainly in arable crops. The utilized agricultural area (UAA) in Prefecture of Kozani (2009) covers an area of 96084 ha while irrigated area covers only 14,000 ha (~15%). The area is characterized by a semi-arid, Mediterranean climate, with an annual temperature of 12.96 °C and an annual rainfall of 643 mm. In a large part of the area irrigated agriculture is practised. The land is used mainly for cultivation of cereals and cows and sheep graze the area. The major water use is in irrigation for agriculture; 82% of the total consumption. Table 1 presents the distribution of utilized agricultural area and production in Prefecture of Kozani.

The main study area is a part of Sarigkiol basin constituted from the irrigated agricultural area of two municipalities (Municipalities of Ellispontos and Dimitrios Ipsilantis), of Kozani prefecture. 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.
Table 1. Distribution of utilized agricultural area and production in Prefecture of Kozani 2009.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Agricultural Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(ha)</td>
</tr>
<tr>
<td>1 Soft Wheat</td>
<td>19.557</td>
</tr>
<tr>
<td>2 Barley</td>
<td>7.631</td>
</tr>
<tr>
<td>3 Hard Wheat</td>
<td>37.672</td>
</tr>
<tr>
<td>4 Oat</td>
<td>534</td>
</tr>
<tr>
<td>5 Maize</td>
<td>6.669</td>
</tr>
<tr>
<td>6 Tobacco</td>
<td>202</td>
</tr>
<tr>
<td>7 Sugar beet</td>
<td>1.328</td>
</tr>
<tr>
<td>8 Alfaalfa</td>
<td>5.034</td>
</tr>
<tr>
<td>9 Potatoes</td>
<td>724</td>
</tr>
<tr>
<td>10 Rye</td>
<td>1.949</td>
</tr>
<tr>
<td>11 Vegetables</td>
<td>584</td>
</tr>
<tr>
<td>12 Other crops</td>
<td>5220.9</td>
</tr>
<tr>
<td>13 Set Aside</td>
<td>8.979</td>
</tr>
<tr>
<td>Sub Total</td>
<td>96084</td>
</tr>
</tbody>
</table>

Source: National Statistics Service of Greece 2009

1.2 Location and topography of the pilot area

Sarigkiol basin (Fig. 1) is located in the north-eastern part of Kozani Prefecture, Western Macedonia region, Greece, covering an area of 469.2 km².
At the west side there is Askio Mountain, at the east side there is Vermio Mountain, at the south side there is Skopos Mountain. The north border is nowadays the open pit of the south field lignite mines and partly the tectonic horst of Komanos. Important surface waters (e.g. lakes and rivers) are not existed in the study area except Soulou Torrent (non-significant flow and small river bed, is used as a drainage pathway), which intersects the basin and was artificially opened up in 1954. The part of the torrent’s bed which is adjacent to the lignite mines is not stable and is adjusted according to the needs of the Western Macedonia Lignite Center. The land is mainly used for cultivation of cereals and cows and sheep graze the area. In a large part of the area irrigated agriculture is practised. Lignite deposits occurring in the basin 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.

1.3 Land uses and agricultural land

The most important activities in the Sarigkiol basin today, based on their economic and social impact on the wider region, are, in sequence, lignite mining by the mines of PPC, the agricultural exploitation of the lowland region and the livestock-farming on the fringes of the mountain ranges which surround the basin.
The two first and foremost activities occupy land in the central area of the basin. The total extent of the basin amounts to 469.2 km², which are covered by agricultural land (32.7% - 153.3 km²), by forests and semi natural areas (56.9% - 266.8 km²) and by urban or artificial surfaces (10.4% - 49.1 km²) (Fig. 2), which includes coal mines and steam electric power plants that cover 31.7 km² (Corine Land Cover 2000).

1.4 Land use of Utilized Agricultural Area

Arable crops are the main cultivation for the majority of the agricultural holdings. In arable crops are included cereals, alfalfa, oleaginous seeds, potatoes, aromatic crops and industrial crops. The maize presents important increase in the past years because of the increase of irrigated areas and the mechanisation of production, while other sectors present stability. The cultivation of sugar beets, also, was increased the past years for the same reasons that we mentioned above.
Sarigkiol utilized agricultural area, is an area belonging to the municipalities of Ellispontos and Dimitrios Ypsilantis and exhibits three main sectors 1) non irrigated arable land (9318.7 ha), 2) permanently irrigated land (5207.0 ha) and 3) pastures (804.9 ha) (Fig. 3).

Irrigation takes place mainly through private drillings, and in some cases by pumping from the Soulou stream and by the draining channels, in which the waters that drawn from the PPC mines are channeled.
2. Decision Support Systems

The Decision Support Systems (DSS) are defined as computer 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.

Several scientific sectors support the growth and constitute the necessary background for effective planning of Decision Support Systems. The Science of Informatics has contributed in the planning and the application of Decision Support Systems with the supply of tools, material and software. The sciences of Operational Research and Management and Business Administration provide the theoretical frame for the analysis of various decisions. The science of Behavior, the Sociology, the Management of Human Resources, constitute sources of information that concern the manners with which the human potential behaves at the treatment of information and the decisions-making.

“Support” is the keyword in the conceptual frame of these systems. With the utilization of them the role of decision maker is limited in the evaluation of results of mathematic models with which the decision will be made. The accent consequently is given in the benefit of support deciding and no in his replacement.

In a global level there have been developed many DSS applications for agriculture (Manos et al., 2004b). The Agricultural Informatics Laboratory of the School of Agriculture in the Aristotle University of Thessaloniki has developed many such applications that assist the farmers/users to reach the right conclusions. DSS applications include those for the planning of regional agriculture (Papathanasiou et al., 2005), for planning agricultural regions within a context of groundwater rational management (Manos et al., 2010a), for water management and sustainable development (Bournaris et al., 2002; Manos et al., 2004a), for the sustainable development and environmental protection of agricultural areas (Manos et al., 2010b) and for the agricultural land use, water management and agricultural protection (Manos et al., 2007).
2.1 Decision Support Systems Structure

A typical Decision Support System, upon Sprague and Carlson (1982), Manos and Voros (1993) and Manos et al. (2004a), comprises from the following elements:

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)

The Data Base contains all the data that are required for the Decision Support System operation. The total of software that is used for the systematic management of them (storage, briefing, recuperation and maintenance) constitutes the Data Base Management System.

The Model Base contains the models that are used for the data processing of the Data Base, on the analysis of problems and the export of final results. The transformation of data in information - results, which supports the user/decision maker, is provided becomes via the Model Base Management System.

The Dialog Generation and Management System is responsible for the communication of user/deciding with the Decision Support System, for the import of data in it and the presentation of results.

A typical Decision Support System is presented in the following Figure 4.
2.1.1 Data Base and Data Base Management System

The Data Base constitutes essential tool on the organized storage of data and information aiming at the easy renewal, correction and their utilization in every type analysis. The Data Base contains all the data that are required for the Decision Support System operation. The total of software that is used for the systematic management of them (storage, briefing, recuperation and maintenance) constitutes the Data Base Management System. The Data Base of EUWater DSS was developed under Microsoft Access.
2.1.2 The Model Base and the Model Base Management System

The Model Base in a D.S.S. includes mathematics, economically and statistical models, as well as models of Operational Research capable of analyzing problems and to support the process of decision-making. The total of models is run and is checked by the Model Base Management System, (M.B.M.S.). The models that includes can be models that execute specialized operations, models for operational, strategic or tactic decision support. In our case we will use Weighting goal programming for policy analysis models as described above. The Model Base contains the models that are used for the data processing of the Data Base, on the analysis of problems and the export of final results. The model is an Optimization Multicriteria Mathematical Programming model and achieves the optimum production plan in the area combining different criteria to a utility function under a set of constraints concerning different categories of land, labor, available capital, etc. The model is used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters (e.g. different levels of chemicals or water consumption per crop). In this way we will get alternative production plans and agricultural land uses as well as the economic, social and environmental impact of different policies. The transformation of data in information - results, which supports the user/decision maker, is provided becomes via the Model Base Management System. In EUWater DSS the Model Base Management System was developed under Lindo. Lindo is a comprehensive tool designed to make building and solving linear, nonlinear and integer optimization models.

2.1.3 The Dialog Generation and Management System

The Dialog Generation and Management System, (D.G.M.S.) determines the interaction between the user/decision maker and the D.S.S., influencing in important degree the output, the flexibility and manageability of the D.S.S. The Dialog Generation and Management System is responsible for the communication of user/deciding with the Decision Support System, for the import of data in it and the presentation of results. EUWater DSS was developed under Visual Basic.
3. Models Methodology

The chosen model for the DSS is an Optimization Multicriteria Mathematical Programming model based on Weighting Goal Programming. The methodology model is also based on GIS maps (sensitivity vulnerability maps) and facilitates and optimizes the decision-making process relating to the problems of land use/water management/environmental protection.

The model achieves the optimum production plan in the area combining different criteria to a utility function under a set of constraints concerning different categories of land, labor, available capital, etc. The model is further used to simulate different scenarios and policies due to changes on different 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.

3.1 Weighting goal programming

Both Sumpsi et al. (1997) and Amador et al. (1998) have recently developed methodologies for the analysis and simulation of agricultural systems based upon multicriteria techniques applied to irrigated agriculture. 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 (Berbel and Gomez-Limon, 2000; Gomez-Limon and Riesgo, 2004; Manos et al., 2006).

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. This surrogate utility function is then used to estimate the value of water demand in irrigated crop production, using utility-derived demand functions.

Briefly, the methodology can be summarised as follows:

1. Tentatively 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. Using this matrix estimate a set of weights that optimally reflect farmers' preferences.

The first step in our analysis thus consists of defining a tentative set of objectives \( f_1(X) \ldots f_i(X) \ldots f_n(X) \) which seeks to represent the real objectives of the farmers (e.g. profit maximisation, risk minimisation, nitrogen balance etc.).

Once these objectives have been defined, the second step is the calculation of the pay-off matrix, which has the following formulation:

<table>
<thead>
<tr>
<th>Objectives attributes</th>
<th>( f_1(X) )</th>
<th>( f_2(X) )</th>
<th>( \ldots )</th>
<th>( f_n(X) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_1(X) )</td>
<td>( f_1^* )</td>
<td>( f_{12} )</td>
<td>( \ldots )</td>
<td>( f_{1n} )</td>
</tr>
<tr>
<td>( f_2(X) )</td>
<td>( f_{21} )</td>
<td>( f_2^* )</td>
<td>( \ldots )</td>
<td>( f_{2n} )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( f_n(X) )</td>
<td>( f_{n1} )</td>
<td>( f_{n2} )</td>
<td>( \ldots )</td>
<td>( f_n^* )</td>
</tr>
</tbody>
</table>

The elements of the matrix need to be calculated by optimising one objective in each row. Thus, \( f_{ij} \) is the value of the \( i \) attribute when the \( j \)th objective is optimised. Once the pay-off matrix has been obtained, we can try to solve the following system of \( q \) (number of objectives) equations:

\[
\sum_{j=1}^{q} w_j f_{ij} = f_i, \, i = 1, 2, \ldots q; \, \text{and} \sum_{j=1}^{q} w_j = 1,
\]

where \( w_j \) are the weights attached of each objective that reproduce the actual behavior of the farmer, \( f_{ij} \) are the elements of pay-off matrix and \( f_i \) is the value achieved for the \( i \)th objective according to the observed crop distribution.

Normally, the above system does not result in a set of \( w \) and it is therefore necessary to search for the best possible solution by minimizing the sum of deviational variables that find the closest set of weights. For this purpose a weighted goal
program with percentage deviational variables can be formulated (Romero, 1991). This solution will be obtained by resolving the following LP Model:

\[
\text{Min } \sum_{i=1}^{q} \frac{n_i + p_i}{f_i}
\]

subject to:

\[
\sum_{j=1}^{q} w_j f_{ij} + n_i - p_i = f_i, i = 1, 2, ..., q \text{ and } \sum_{j=1}^{q} w_j = 1
\]

where \(p_i\) is the positive deviational variable (i.e. the measurement of the over-achievement of the \(i\)th objective respect to a given target), and \(n_i\) is a negative deviational variable that measures the difference between real value and model solution for the \(i\)th objective.

In some cases certain objectives are closely correlated, which means that maximising one objective implies the simultaneous achievement of the rest. In such cases it may be advisable to be very selective regarding the number of objectives modelled, avoiding those that are closely related (in agricultural production, for example, sales are closely related to gross margin). The pay-off matrix, shows the degree of conflict among criteria, and in the hypothetical case that all objectives are closely related (maximisation of an objective implies almost optimal values for the rest); we conclude that there is no need to represent the multicriteria problem.

### 3.1 Data acquisition

#### 3.1.1 Crops

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 water 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. Crops available for the farmers' decision-making process vary in each area as a function of farming and physical conditions as defined by the parameters shown in.

3.1.2 Yields
In order to give the system as much freedom as possible regarding land use and water allocation, each activity (crop) was allocated a range of different intensities of water usage (deficit watering), giving farmers the opportunity to choose between different levels of water supply.

3.1.3 Prices
Prices applied to crops are averages for the area obtained from official statistics.

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

3.1.5 Income
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.

3.1.6 Variable costs
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.
We calculated the variable costs for Sarigkiol basin main crops. These are presented in the following Table 2.

3.1.7 Gross margin
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 use this parameter as the best estimator of short-run profit and thus as the function to be considered as an objective for the model.

### 3.1.8 Fertiliser use

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

**Table 2. Variable costs for Sarigkiol basin main crops.**

<table>
<thead>
<tr>
<th></th>
<th>Soft Wheat</th>
<th>Barley</th>
<th>Hard Wheat</th>
<th>Maize</th>
<th>Sugar beets</th>
<th>Oat</th>
<th>Potatoes</th>
<th>Alfalfa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeds</td>
<td>65</td>
<td>53</td>
<td>76</td>
<td>146</td>
<td>92</td>
<td>36</td>
<td>1385</td>
<td></td>
</tr>
<tr>
<td>Fertilisers</td>
<td>113</td>
<td>97</td>
<td>113</td>
<td>194</td>
<td>148</td>
<td>81</td>
<td>215</td>
<td>260.6</td>
</tr>
<tr>
<td>Chemicals</td>
<td>39</td>
<td>32</td>
<td>37</td>
<td>65</td>
<td>277</td>
<td></td>
<td>205</td>
<td>25.5</td>
</tr>
<tr>
<td>Machinery</td>
<td>63</td>
<td>58.8</td>
<td>48.72</td>
<td>180</td>
<td>198</td>
<td>57.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of water</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>178</td>
<td>185</td>
<td>5</td>
<td>330</td>
<td>136.2</td>
</tr>
<tr>
<td>Marketing cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1035</td>
<td></td>
</tr>
<tr>
<td>Labour cost</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>720</td>
<td>1080</td>
<td>108</td>
<td>1470</td>
<td>750</td>
</tr>
<tr>
<td>Total Variable Cost</td>
<td>393</td>
<td>353.8</td>
<td>387.72</td>
<td>1483</td>
<td>1980</td>
<td>287.6</td>
<td>4640</td>
<td>1172.3</td>
</tr>
</tbody>
</table>

### 3.2 Data for Sarigkiol basin

As described before Sarigkiol utilized agricultural area, is an area belonging to the municipalities of Ellispontos and Dimitrios Ypsilantis and exhibits three main sectors 1) non irrigated arable land (9318.7 ha), 2) permanently irrigated land (5207.0 ha) and 3) pastures (804.9 ha). Irrigation takes place mainly through private drillings, and in some cases by pumping from the Soulou stream and by the draining channels, in which the waters that drawn from the PPC mines are channelled.

The crop distribution 59.4% hard wheat, 6.3% soft wheat, 6.1% barley, 9.6% sugar beet, 8.7% maize, 1.2% potatoes, 0.4% oat, 3.3 alfalfa and 5.1% pastures (Table 3). The maize and sugar beet present important increase in the past years because of
the increase of irrigated areas and the mechanization of production, while other sectors present stability. The percentage of the total extent of Sarigkiol basin, which is occupied by xeric (dry) crops (wintry cereals) is a dependence of the generally applied rural policy, as well as the particular policy of PPC for reestablishment and output in the cultivation of grounds which are today occupied by the mines. It should be noted that the mines occupy a central section of the basin and should any section be subject to cultivation, at a first level, it will be irrigated either by private drilling or by draining waters of the PPC mines (even defectively) and consequently dynamic – instead of dry – crops will be preferred. Accordingly, the land that is cultivated with wintry cereals is expected to remain constant, with a percent proportion of wintry cereals decreasing or increasing, depending on the land which the PPC will provide or bind. Next table presents the distribution of utilized agricultural area of Sarigkiol basin.

Table 3. Main crops cultivated in Sarigiol basin.

<table>
<thead>
<tr>
<th>No</th>
<th>Crops</th>
<th>(ha)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soft Wheat</td>
<td>971.9</td>
<td>6.3</td>
</tr>
<tr>
<td>2</td>
<td>Barley</td>
<td>931.5</td>
<td>6.1</td>
</tr>
<tr>
<td>3</td>
<td>Hard Wheat</td>
<td>9110.2</td>
<td>59.4</td>
</tr>
<tr>
<td>4</td>
<td>Maize</td>
<td>1327.8</td>
<td>8.7</td>
</tr>
<tr>
<td>5</td>
<td>Sugar beet</td>
<td>1465.9</td>
<td>9.6</td>
</tr>
<tr>
<td>6</td>
<td>Oat</td>
<td>55.8</td>
<td>0.4</td>
</tr>
<tr>
<td>7</td>
<td>Potatoes</td>
<td>185.0</td>
<td>1.2</td>
</tr>
<tr>
<td>8</td>
<td>Alfalfa</td>
<td>503.6</td>
<td>3.3</td>
</tr>
<tr>
<td>9</td>
<td>Set Aside</td>
<td>778.5</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15,330</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The technical and economic coefficients of crops resulted from the agricultural indicators from the Regional Government of West Macedonia. The data are referred to the main of period 2005-2009 (5 years) for the Sarigkiol basin.

We also used additional data provided by the Department of Agricultural Economics of Aristotle University for the fertilizers use of each crop.
Table 4. Technical and economic coefficients of crops during 2005-2009 in the region of West Macedonia.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soft Wheat</th>
<th>Barley</th>
<th>Hard Wheat</th>
<th>Maize</th>
<th>Sugar beets</th>
<th>Oat</th>
<th>Potatoes</th>
<th>Alfalfa</th>
<th>Set Aside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prices (Euro/kg)</td>
<td>0.15</td>
<td>0.14</td>
<td>0.14</td>
<td>0.15</td>
<td>0.04</td>
<td>0.16</td>
<td>0.23</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Yield (kg/ha)</td>
<td>3,500</td>
<td>3,500</td>
<td>2,900</td>
<td>12,000</td>
<td>55,000</td>
<td>3,000</td>
<td>45,000</td>
<td>109,000</td>
<td></td>
</tr>
<tr>
<td>Subsidies (Euro/ha)</td>
<td>155.6</td>
<td>155.6</td>
<td>435.5</td>
<td>495.6</td>
<td></td>
<td></td>
<td>155.6</td>
<td></td>
<td>221.1</td>
</tr>
<tr>
<td>Income (Euro/ha)</td>
<td>681</td>
<td>646</td>
<td>842</td>
<td>2,296</td>
<td>2,200</td>
<td>636</td>
<td>10,350</td>
<td>2,180</td>
<td>221</td>
</tr>
<tr>
<td>Variable Costs (Euro/ha)</td>
<td>393</td>
<td>354</td>
<td>388</td>
<td>1,483</td>
<td>1,980</td>
<td>288</td>
<td>4,640</td>
<td>1,172</td>
<td>0</td>
</tr>
<tr>
<td>Gross Margin (Euro/ha)</td>
<td>288</td>
<td>292</td>
<td>454</td>
<td>813</td>
<td>220</td>
<td>348</td>
<td>5,710</td>
<td>1,008</td>
<td>221</td>
</tr>
<tr>
<td>Labour (Hours/ha)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>240</td>
<td>360</td>
<td>36</td>
<td>490</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Fertilizers (kg/ha)</td>
<td>500</td>
<td>430</td>
<td>500</td>
<td>850</td>
<td>1,350</td>
<td>350</td>
<td>950</td>
<td>320</td>
<td></td>
</tr>
</tbody>
</table>
4. 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.

4.1 Variables

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

4.2 Objectives

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

4.2.1 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:
4.2.2 Fertiliser minimisation

Fertiliser minimisation it is a public objective. For this reason it is not considered in the decision process by farmers (Zekri and Romero, 1993). 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 surplusses 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:

\[ \Sigma TFI \times XI = TF. \]

4.2.3 Minimization of labor

The minimization of labor 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 behavior 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:

\[ \Sigma TL_i \times X_i = TL \]
4.3 Constraints

4.3.1 Total cultivation area
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.

4.3.2 CAP Constraints (Set Aside, Rights, Quotas, Crop Rotation)
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):

\[ \sum X_i + SA = 100 \]

CAP Production Rights are the sum of production rights (PR) according to CAP for crops (Xi) following CAP regulations.

\[ PR = \sum PR_i \times Xi \]

CAP Quotas are the sum of Quotas according (QP) to CAP for all crops (Xi) following CAP regulations.

\[ QP = \sum QP_i \times Xi \]

CAP Crop rotations
There are also constraints for crop rotation according to the obligations of participating in CAP RDP agri-environmental measures.

4.3.3 Market and other constraints
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 alfalfa 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.
4.3.4 Rotational and agronomic considerations

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.

4.3.5 Irrigation Constraints

Land Irrigated is the sum of irrigable available land for irrigated crops (Xi)

4.3.6 LOS Indices agricultural land Constraints

According to the LOS Indices developed for EU-Water three different types of agricultural land constraints were used.

1. \( \text{LOSW-PR} \) is the sum of total losses of water

\[
(\text{LOSW-PR}) = (\text{LOSW-P}) + (\text{LOSW-R})
\]

where \( \text{LOSW-P} \): are the annual losses due to deep percolation beneath the root zone of the 30 cm (mm year\(^{-1}\)), \( \text{LOSW-R} \): are the annual losses due to surface runoff (mm year\(^{-1}\))

In our model 3 different types of LOSW-PR constraints were used according to the following agricultural land zones:

- High (415-522 mm year\(^{-1}\))
- Medium (310-415 mm year\(^{-1}\)) and
- Low (255-310 mm year\(^{-1}\)) WATER losses
The land zones developed according to the findings of the related GIS Maps for the agricultural land of Sarigkiol basin.

2. LOSN-PRN is the sum of total losses of nitrogen

\[ \text{LOSN-PRN} = \text{LOSN-PN} + \text{LOSN-RN} \]

Where \( \text{LOSN-PN} \): are the annual nitrogen losses due to deep percolation beneath the root zone of the 30 cm (kg ha\(^{-1}\) year\(^{-1}\)), \( \text{LOSN-RN} \): are the annual nitrogen losses due to surface runoff (kg ha\(^{-1}\) year\(^{-1}\)),

In our model 3 different types of LOSN-PRN constraints were used according to the following agricultural land zones:

- High (24.5 – 28.3 kg ha\(^{-1}\) year\(^{-1}\))
- Medium (20.8-24.5 kg ha\(^{-1}\) year\(^{-1}\)) and
- Low (17.0 – 20.8 kg ha\(^{-1}\) year\(^{-1}\)) NITROGEN losses

The land zones developed according to the findings of the related GIS Maps for the agricultural land of Sarigkiol basin.
Figure 6. LOSN-PRN index for the agricultural land of Sarigkiol basin in kg N ha⁻¹ year⁻¹.

3. **Relative Transit Time.** The relative transit time is a measure of groundwater vulnerability. The less the transit time, the greater the chances of the pollutant to be transported to the groundwater surface (high vulnerability). It is pointed out that, the deeper the water levels are, the longer the pollutant takes to reach the groundwater table (low vulnerability).

In our model 3 different types of Relative Transit Time constraints were used according to the following agricultural land zones:

- **High** (21-263 Days)
- **Medium** (263-586 Days) and
- **Low** (586-829 Days) **TRANSIT TIME**

The land zones developed according to the findings of the related GIS Maps for the agricultural land of Sarigkiol basin.
All this information has been included in the model that forms the basis for the MCDM simulation. We also include some attributes that are to be analysed later in the study, but that are not taken into consideration in the farmers’ decision-making process.

4.4 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 main environmental impact of irrigated agriculture is water consumption itself, with the creation of a mosaic landscape and a rise in crop diversity and humid areas. The projected consumption of water measured in m³/ha, is the variable that policy makers wish to control as a consequence of changes in water management policy.
2. Nitrogen balance in groundwater: fertilisers and chemicals 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 kilograms of nitrogen added per hectare (N/ha). This is the main form for calculating the surpluses of nitrogen potentially dangerous for the environment. It is also 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.
5. Results of multicriteria model

5.1 Pay-off Matrix

We applied the weighted goal programming algorithm, described above, for Sarigkiol basin.

The 3 objectives in each case 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 5.

<table>
<thead>
<tr>
<th>VALUES</th>
<th>Optimum</th>
<th>Real</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GM</td>
<td>FER</td>
</tr>
<tr>
<td>GM</td>
<td>58,260</td>
<td>48,391</td>
</tr>
<tr>
<td>FER</td>
<td>50,566</td>
<td>50,465</td>
</tr>
<tr>
<td>TL</td>
<td>8,238</td>
<td>8,238</td>
</tr>
</tbody>
</table>

The last column shows real data (observed) for 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 (2009) is from any single optimum (column). This may induce us to try a combination of objectives as a better simulation of farmers' behaviour. Besides, this is the basis for the multicriteria theory and for the methodology described.

With the values of table 5 we obtain the set of weights that best reflects farmers' preferences. These are:

\[ W1 \text{ (max GM)} = 0.281 \]
\[ W2 \text{ (min FER)} = 0.719 \]
The set of weights for Sarigkiol basin is compatible with a type of behaviour that combines fertiliser minimization which presents a very high weight (71.9%) and gross margin maximisation (28.1%). 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 particular agricultural system.

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 EU Water scenarios, we use the weightings given above in order to represent the farmers’ utility function. For Sarigkiol basin the utility function will be as follows:

\[ U = 28.1\% \text{ GM} - 71.9\% \text{ TL} \]

5.2 Real values vs simulated (validation)

It is essential to compare the real (observed) situation with the situation predicted with the help of the estimated utility function.

Table 6 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 in Sarigkiol basin, the MCDM model gives a production plan that achieves gross margin 13.9% more than the existent plan. As regards the total fertilizer use the OMMP model achieves a decrease -13.0%.

The new production plan that OMMP model suggests includes a decrease in cultivated hectares for wheat (-100.0%) and sugar beets (86.7%). It also suggests an increase in cultivated hectares for barley (76.2%), maize (50.0%), oat (51.7%), potatoes (49.6%) and set aside (63.7%).
Table 6. Model validation for the Sarigkiol basin

<table>
<thead>
<tr>
<th></th>
<th>Observed values</th>
<th>OMMP model</th>
<th>% deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mod. values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM</td>
<td>51,169</td>
<td>58,260</td>
<td>13.9%</td>
</tr>
<tr>
<td>FER</td>
<td>58,091</td>
<td>50,566</td>
<td>-13.0%</td>
</tr>
<tr>
<td>TL</td>
<td>9,532</td>
<td>8,238</td>
<td>-13.6%</td>
</tr>
<tr>
<td>WATER</td>
<td>116,140</td>
<td>115,526</td>
<td>-4.0%</td>
</tr>
<tr>
<td>Wheat</td>
<td>6.3</td>
<td>0</td>
<td>-100%</td>
</tr>
<tr>
<td>Barley</td>
<td>6.1</td>
<td>10.7</td>
<td>76.2%</td>
</tr>
<tr>
<td>Hard wheat</td>
<td>59.4</td>
<td>59.4</td>
<td>0.0%</td>
</tr>
<tr>
<td>Maize</td>
<td>8.7</td>
<td>13.0</td>
<td>50.0%</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>9.6</td>
<td>1.3</td>
<td>-86.7%</td>
</tr>
<tr>
<td>Oat</td>
<td>0.4</td>
<td>0.5</td>
<td>51.8%</td>
</tr>
<tr>
<td>Potatoes</td>
<td>1.2</td>
<td>1.8</td>
<td>49.6%</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>3.3</td>
<td>4.9</td>
<td>50.2%</td>
</tr>
<tr>
<td>SA</td>
<td>5.1</td>
<td>8.3</td>
<td>63.7%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.0</td>
<td>100.0</td>
<td>32%</td>
</tr>
</tbody>
</table>
5.3 Scenarios

The model is further used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters (e.g. different levels of chemicals or water consumption per crop). In order to define the different scenarios we used the LOS Indices developed for EU-Water.

According to the LOS Indices developed for EU-Water three different types of constraints were used, as described in a previous section:

1. **LOSW-PR** is the sum of total losses of water
2. **LOSN-PRN** is the sum of total losses of nitrogen
3. **Relative Transit Time.** The relative transit time is a measure of groundwater vulnerability. The less the transit time, the greater the chances of the pollutant to be transported to the groundwater surface (high vulnerability).

We used 4 different Scenarios using these indices.

- **Optimum Scenario** gives the optimum production plan (without LOS Indices constraints)
- **Vulnerability Scenario** uses as constraints the data from the Relative Transit Time (TT)
- **Water Losses Scenario** uses as constraints the data from Total Losses of Water (LOS-W-PR)
- **Nitrate Losses Scenario** uses as constraints the data from Total Losses of Nitrogen (LOS-N-PR)

The results show that all the scenarios used, achieve the three main goals set by the model definition.

**Table 7. Alternative Production Plans of EU Water DSS Scenarios**

<table>
<thead>
<tr>
<th></th>
<th>Observed values</th>
<th>Nitrate Losses Scenario</th>
<th>Water Losses Scenario</th>
<th>Vulnerability Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>values</td>
<td>values</td>
<td>values</td>
<td>values</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>GM</td>
<td>51,169</td>
<td>58260.19</td>
<td>3.08</td>
<td>58260.19</td>
</tr>
<tr>
<td>FER</td>
<td>58,091</td>
<td>50492.59</td>
<td>-13.08</td>
<td>52275.78</td>
</tr>
<tr>
<td>WATER</td>
<td>116,140</td>
<td>111526.6</td>
<td>-3.97</td>
<td>109417.28</td>
</tr>
</tbody>
</table>

|       | Wheat           | 6.3                     | 31.93                  | 403.64                 | 8.75                   | 37.99                  | 13.04                  | 105.71                 |
|       | Barley          | 6.1                     | 12.15                  | 99.87                  | 12.15                  | 99.87                  | 12.15                  | 99.87                  |
|       | Hard wheat      | 59.4                    | 26.3                   | -55.75                 | 49.24                  | -17.15                 | 44.95                  | -24.37                 |
|       | Maize           | 8.7                     | 12.99                  | 50.02                  | 12.99                  | 50.02                  | 12.99                  | 50.02                  |
|       | Sugar beets     | 9.6                     | 1.27                   | -86.71                 | 3.03                   | -68.33                 | 1.29                   | -86.5                  |
|       | Oat             | 0.4                     | 0.28                   | -21.51                 | 0.55                   | 51.67                  | 0.55                   | 51.67                  |
|       | Potatoes        | 1.2                     | 1.81                   | 49.61                  | 1.81                   | 49.61                  | 1.79                   | 47.93                  |
|       | Alfalfa         | 3.3                     | 4.93                   | 50.23                  | 3.17                   | -3.36                  | 4.93                   | 50.23                  |
|       | SA              | 5.1                     | 8.34                   | 64.12                  | 8.31                   | 63.65                  | 8.31                   | 63.65                  |
| TOTAL |                 | 100.0                   | 100.0                  | 100.0                  | 100.0                  | 100.0                  | 100.0                  | 100.0                  |

The alternative production plans resulted from the scenario analysis are different in each scenario. The cultivations of Barley (12.15%), Maize (12.99%), Potatoes (1.81%) and Set Aside (8.31%) remain stable in all the alternative crop plans. The main
changes in the scenarios production plans are due to changes in the cultivations of Wheat (from 8.75% to 31.93%), Hard Wheat (from 26.3% to 49.24%) and Sugar beets (from 1.27% to 3.03%). The cultivations of oats and alfalfa have small changes in each scenario (Table 7).

As regards gross margin maximization there is an increase from 3.08% in the Nitrate Losses Scenario to 13.86% in Optimum Scenario. On the other hand the reduction in fertilizers use starts from -10.01% in Nitrate Losses Scenario to -13.11% in Optimum Scenario. There is also reduction in irrigation water consumption from 3.91% in Vulnerability Scenario to -5.79% in Water Losses Scenario. Finally, the minimization of labour use goal achieves decrease from -11.55% to -13.60%. The results of the implementation of these scenarios are given in the next figure.

Figure 9. Gross Margin, Fertilisers Use, Water Use and Labour Use in Sarigkiol Basin.

As we described before in the methodology section, the model can be further used to simulate different scenarios and policies due to changes on different environmental parameters.
6. The EUWater DSS

EUWater DSS is a simple step by step software which is based on the related GIS Maps created using LOS Indices developed for EU-Water project. EUWater DSS supports production planning and water and fertilization management, and facilitates and optimizes the decision-making process relating to the problems of land use, water management and environmental protection. It uses the methodology described in the former section and it aims to assist the producers during the production planning process. It can be used also for the planning of agricultural holdings and for the planning of agricultural areas.

![EUWater Decision Support System Desktop](image)

The application was programmed in Visual Basic and runs in a Windows XP, Vista or 7 environments. Keeping in mind the need for simplicity and user friendliness, a step-by-step approach was used.

6.1 Using EUWater DSS Software

The first step on using the application is the creation of the Database. All the data needed for the implementation of the methodology are stored in this database. When user creates the new database Main Menu options appear in the Desktop.
User has to move step by step between the main menu options. There are 8 options in the main menu according to the model methodology described before:

1. Crops and Data Entry
2. Matrix
3. Pay off Matrix
4. Utility Function
5. Optimal Plan
6. LOS Indices Maps
7. LOS Indices Data
8. Scenario Analysis

In the first step, the user can choose the ‘Crops and Data entry’ button and enter through another form that appears the data regarding the hectares allocated to the various existing crops in the area under study. Thus, the existent production plan for this specific area is created. Data Entry is also about the input of all the technical and economic data required as input by the procedure.

**Figure 11. EU Water DSS “Crops and Data entry” Option**

The technical and economic coefficients include among others the price for each product in €/kg, the mean production in kg/ha, the subsidies in €/ha where applicable, the variable cost in €/ha and the fertilizers use in kg/ha (Figure 11).
6.1.1 Matrix and Pay off Matrix

The most important part is most probably the input of the constraints for the linear programming matrix, as the user must have some basic knowledge of mathematical programming in order to input to the system the proper constraints. Those constraints are about the available soil, labour and capital plus the agricultural policy practiced, the market constraints, the fertilisers’ used and other agricultural regulations (Figure 12).

After this step, it is possible to solve the multicriteria problem with the weighted multicriteria goal programming technique described in an earlier section and integrated into the DSS. In this step you can have a full view of the pay off matrix, the optimum Gross Margin, Fertilizers and Labour values and we can see how far the real situation is from any single optimum. We applied the weighted goal programming algorithm, described above, for Sarigkiol basin (Fugure 13).

The 3 objectives in each case were: 1) Max Gross Margin (GM), 2) Min Fertilizers Use (FER) and 3) Min Total Labour (TL). In the next image step you can have a view of the Utility Function
6.1.2 Optimum Plan

In this step you can have a view of the Optimum Plan and compare the real (observed) situation with the situation predicted with the help of the estimated utility function. The differences among the existent situation and the optimal one produced by the system can also be seen (Figure 14).
6.1.3 LOS Indices Maps and Data

In this step user has to insert the GIS maps created using the LOS Indices methodology. From the results of these maps user can create the land zones of the study area. The land zones are developed according to the findings of the related GIS Maps for the agricultural land for Total Losses of Water (LOSW-PR Map) Total Losses of Nitrogen (LOS-PRN Map) and Related Transit Time (TT Map).

Land Zones also define the LOS Indices data constraints which are feed the database for the Scenario Analysis. According to the LOS Indices developed for EU-Water three different types of constraints were used, as described in a previous section.
6.1.4 Scenario Analysis

In the scenario analysis EUWater DSS gives the alternative production plan for the 3 LOS Indices Scenarios.

In the next figures the optimum production plans according to LOS Indices Scenarios are shown.
### Figure 16. Optimum Plan for LOSN-PRN Scenario

<table>
<thead>
<tr>
<th>Crop name</th>
<th>Percentage</th>
<th>Gross margin (Euro)</th>
<th>Fertilizers use (kg)</th>
<th>Total labour use (h)</th>
<th>Water (cbm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Wheat</td>
<td>6.34</td>
<td>51168.81</td>
<td>58091.44</td>
<td>9531.85</td>
<td>118140.00</td>
</tr>
<tr>
<td>Barley</td>
<td>6.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard Wheat</td>
<td>59.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>8.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>9.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oat</td>
<td>3.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>1.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>5.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Aside</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Figure 17. Optimum Plan for LOSW-PR Scenario

<table>
<thead>
<tr>
<th>Crop name</th>
<th>Percentage</th>
<th>Gross margin (Euro)</th>
<th>Fertilizers use (kg)</th>
<th>Total labour use (h)</th>
<th>Water (cbm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Wheat</td>
<td>8.75</td>
<td>58260.19</td>
<td>50492.59</td>
<td>8236.92</td>
<td>109417.28</td>
</tr>
<tr>
<td>Barley</td>
<td>12.15</td>
<td></td>
<td>98.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard Wheat</td>
<td>49.24</td>
<td></td>
<td>-17.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>12.99</td>
<td></td>
<td>50.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>3.03</td>
<td></td>
<td>-68.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oat</td>
<td>55</td>
<td></td>
<td>51.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>1.81</td>
<td></td>
<td>49.61</td>
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<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>3.17</td>
<td></td>
<td>-3.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Aside</td>
<td>8.31</td>
<td></td>
<td>63.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the final steps the final solution is shown with a 2 dimension bar chart view (and print if required) of Gross Margin, Fertilizers Use, Water Use and Total Labour Use.

**Figure 18. Optimum Plan for RTT Scenario**

**Figure 19. Optimum Plans vs LOS Indices Scenarios**
7. Conclusions

A Decision Support System (DSS) to support water-use and eco-friendly decision process in agricultural production has been developed in the context of the research project entitled EU Water. The DSS uses an Optimization Multicriteria Mathematical Programming model and is based on GIS maps and facilitates and optimizes the decision-making process relating to the problems of land use, water management and environmental protection. In order create these maps and to assess the vulnerability of agricultural land to water and nitrogen losses and the pollution potential of groundwater, the LOS indices were used. The DSS aims to achieve optimum crop combining different criteria to a utility function under a set of constraints concerning different categories of land, labour, available capital, etc. and taking in account the GIS maps which have been developed for the area. According to the LOS indices 4 different Scenarios were used (Optimum Scenario, Vulnerability Scenario, Water Losses Scenario and Nitrates Losses Scenario).

The results show that the DSS achieves the three main goals set by the model definition. An increase in Gross Margin achieved (from 3.08% to 13.86%) depending on the scenario, a reduction of fertilizers use (from -10% to -13.1%) depending on the scenario, a reduction of water use (from -3.79% to -5.79%) depending on the scenario and finally a reduction in labour use (from -11.55% to -13.60%) depending on the scenarios. The DSS is further used to simulate different scenarios and policies due to changes on different social, economic and environmental parameters (e.g. different levels of chemicals or water consumption per crop).

The main conclusions are that the DSS is an important planning tool enabling the regional authorities to design optimal spatial development policies and protect the groundwater from the agricultural land use. It also supports production planning and water and fertilization management. From the results we can summarise that the DSS achieves to decrease both fertilizers use (nitrates) and irrigation water consumption. With the use of EU Water DSS we can achieve optimum crops plans in the pilot area combining different criteria taking in account the EU Water GIS maps of the pilot area. The EU Water DSS can be further used to simulate different scenarios and policies due to changes on different social, economic and
environmental parameters (e.g. different levels of chemicals or water consumption per crop). In this way we will be able to get alternative production plans and agricultural land uses as well as the economic, social and environmental impact of different policies.
8. References


APPENDIX

EU-Water DSS user instructions

The EU-Water DSS is programmed in Visual Basic and uses the LINDO v6.1 solver; in order to run it must be installed in a Windows XP, Vista or 7 environment. When the program is installed, in the installation folder the user can find the 3 maps and the database of the pilot study in the Sarigkiol Basin; also an application icon is installed in the user desktop and another in the start folder. When the user double-clicks on the icon the splash screen shown in figure 1 appears with the project title and logo; the user can click on it or wait for 8 seconds in order for the main application to begin (figure 2). The EU-Water DSS is based on a MDI (Multiple Document Interface) environment, typical for such systems and is designed with the ‘ease of use’ aspect as a priority.

Figure 1
The user can create a new MS Access database or load an existing one from the ‘New case’ window in the center of the main screen or choose from the menu ‘File’ (figure 3).
The ‘Crops data’ window appears then (figure 4), where the user can enter, delete and modify the data as he sees fit. The columns shaded in grey are calculated automatically when the user presses the ‘Update table’ button. When the user finishes with entering the data he must press the ‘Update table’ button and then the ‘Save and continue’ button. If the user comes back to this window from another one, the user must remember to press the ‘Update table’ button before continuing in order for the changes to be applied. The ‘Send data to MS Excel’ does exactly what its title says, it sends all the data in the window in an MS excel table; in all windows that this button appears it has the same function. The ‘Add crop’ button adds a new line for data input and the ‘Delete crops’ deletes a line. The ‘Print data’ button prints all the data, provided a printer is installed and connected; in all windows that this button appears it also has the same function.

After the ‘Crops data’ window the ‘Matrix’ window follows (figure 5) where the user enters the model. The first lines are not editable as the system computes these constraints automatically. The user can enter, delete or modify the lines titled ‘Constraint’ and a number in the far most left column. The model is solved by pressing the ‘Solve’ button and if a feasible solution exists the ‘Go to pay off matrix’ button is enabled. If a feasible solution does not exist a message appears that the solution is infeasible or unbounded and the user must check his data and the constraints in order to continue.

The payoff matrix is in figure 6, all the values in the cells are automatically computed and the user can compare the real vs the optimum values of the gross margin, the fertilizers and the labour. None of these cells are editable.
When the user presses the ‘Utility function’ button the window in figure 7 appears picturing the utility function as calculated by the system. These textboxes are not editable. Pressing the ‘Go to optimum plan’ button loads the ‘Optimum plan’ window where the user can compare the values of the existent plan and the optimum one produced by the EU-Water DSS (figure 8). A column with the deviations between the 2 plans is also presented for the user’s reference.

![Figure 7](image1)

![Figure 8](image2)
When the user presses the ‘Go to scenario analysis’ button, the window in figure 9 is loaded. Pressing on the three large form areas with the relevant label will allow the loading of the maps for the three scenarios for the region. In figure 9 two maps are loaded and another is left blank for demonstration purposes. The map file formats can be jpg, bmp or png and when the user presses the ‘Go to scenario analysis; button this window is not unloaded but minimized and figure 10 is presented.

Figure 9

Figure 10
When button ‘LOSN-PRN constraints’ is pressed the window in figure 11 appears where the user can enter the additional constrains for this scenario. Then he must press the ‘Save and solve’ button and if a feasible solution exists then the new optimum plan appears in figure 12. In the same manner, the user can enter the constraints for the LOSW-PR and the RTT scenarios. It is important to note that the user must enter the constraints for all the three scenarios in order to continue, else a warning message appears, depending on the scenario not calculated (figure 13). The final window (‘Scenario analysis results’, figure 14) appears when the user has input all constraints and presses the ‘Final solution’ button in figure 10. The diagram presents the final solution to the problem, and the user can go back and change the data and the constraints if he wishes to, in order to check different approaches. Finally, he can save or print the image, begin a new case or end the application.

![Figure 11](image-url)
Figure 12

Figure 13
Figure 14

Figure 15