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Estimating the Potential Impacts of Irrigation Water Pricing Using Multicriteria Decision Making Modelling. An Application to Northern Greece

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Abstract A great challenge of the current European water policy is the implementation of volumetric water pricing in the agricultural sector, especially of Mediterranean countries, where irrigation is a necessary precondition of agricultural production and farmers' income, but also the major consumer of water. The overall aim of the present work is to develop a methodology that will be suitable for the estimation of the potential environmental, economic and social impacts of irrigation water pricing. For this purpose, Multi-Attribute Utility Theory is implemented in order to simulate agricultural decision making at various water pricing scenarios. Water demand functions are then elicited, by means of the best crop and water allocation (farmers' decisions) in each scenario. The European Water Framework Directive recommends that any issue concerning water resources management (including water pricing policies) should be developed at the river basin level. In this framework, a cluster analysis is performed to partition the river basin area (namely, Loudias River Basin, located in Northern Greece) into a small number of homogeneous sub-regions. The differential impact of water pricing in each region is then analyzed, and finally, an average water demand function is formulated for the whole river basin.

Keywords Irrigation water pricing · Multicriteria analysis · Crop-water functions · Optimal resource allocation · Water demand · River basin management

1 Introduction

Irrigated agriculture in Greece is an issue of particular national importance because it constitutes a driving force of both food productivity and agricultural income. As an immediate consequence of the climate and the socio-economic structure, water is an essential input for a profit-making agriculture, but also, for the economic viability and the social coherence of various rural areas. However, arid climate, traditional farming activities

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and farmers' impunity (no penalties for water resources overexploitation or pollution), are the main, among many of the reasons for the current unsustainable and inefficient usage of water resources in agriculture.

The European water policy during the past years has changed in orientation, forsaking the pursuit of an increasing supply and turned to the demand side of water resources. Such demand policies consist, among others, in water pricing, re-allocation of water resources and introduction of water markets. Specifically, the application of water pricing is, according to the Water Framework Directive 2000/60/EC (WFD), a prerequisite in order to provide the right incentives for water use efficiency and sustainable water management. In this framework, agriculture – just like industry and households – should adequately contribute to the recovery of all costs generated by water services, including environmental and resource costs.

The application of water pricing to the agricultural sector should contribute to specific environmental objectives, ensuring at the same time that the economic and social implications would be confined enough. The main effect of a pricing policy is the reduction of farmers' water consumption, according to the negative slope of the demand curve at each price level. A common criticism of this charging system is that it may end up at unsatisfactory levels of water savings, because of the low elasticity of demand for irrigation water. In addition, water pricing can also lead to significant adverse social and economic effects, like the decrease of farmers' income and the reduction in agricultural labour demand (Gomez-Limon and Riesgo 2004).

The present work aims at a thorough examination of the potential implications of irrigation water pricing by determining the water demand function on a representative farm in Northern Greece. The methodology employed in this paper is based on the Multicriteria Decision Making (MCDM). The reason for this selection is that MCDM can handle simultaneously various criteria that farmers take into account when planning their production activities. In fact, current agricultural decision making can be approximated by optimizing a number of objective functions (criteria), broadening thus the classical assumption of rigid profit maximization (usually solved by means of linear programming). The final outcome leads to simulated scenarios that are quite close to farmers' behavior and, consequently, to a better policy-making procedure (Gomez-Limon and Berbel 2000).

Recent literature on the subject includes a number of similar studies regarding the modeling of agricultural decision making in the Mediterranean region. Agricultural production analysis (Berbel and Rodriguez-Ocana 1998; Gomez-Limon et al. 2004), water markets (Arriaza et al. 2002; Gomez-Limon and Martinez 2005) and water demand functions (Gomez-Limon and Berbel 2000; Gomez-Limon and Riesgo 2004) in Spain, as well as, policy impacts on irrigated agriculture in Greece (Manos et al. 2006), have been examined using MCDM techniques.

The present work, however, takes a step forward the previous conceptual framework by using two distinct set of criteria that differ in the risk assessment of farmers. It also attempts to incorporate crop water consumption into the decision variables, in order to get a more complete and insightful analysis of farmers' decisions at higher water prices. Moreover, the methodological approach, outlined in this paper, takes under consideration the WFD's recommendation, according to which, all issues concerning water resources management (including water pricing policies) should be integrated within a common management plan, developed at the river basin level. For this reason, all pricing decisions are supposed to be taken at this level, while the differential impact of each policy to the basin's sub-regions is analyzed in further steps.

2 Description of the Study Area and Cluster Analysis

Loudias River Basin, located in Northern Greece, was selected as the study area because it is a basin where agriculture is the main economic activity and the major water consumer. Loudias River is used mostly as a drainage canal for more than 90,000 ha of agricultural land, which is irrigated with water taken from the rivers Axios and Aliakmon. The main cultivated crops are cotton, rice, fruit-trees, corn and sugar beets that are all high water consuming crops, resulting thus, to an average annual consumption equal to 6,370 m^3/ha. This is a typical consumption of an irrigated area in Southern Europe (EEA 2003). It should be noted that the majority of farmers rely on sprinkler irrigation, which is system of high application efficiency.

Central water administration is under the responsibility of a General Land Reclamation Board, which is assigned with the water management of a broader area of 206,600 ha. This central authority is subdivided into several Local Land Reclamation Boards that are liable for water charging. Up until now, water charges are determined by means of an area pricing method, with the sole objective to recover the operation and maintenance costs of local irrigation systems. It is worth mentioning that there is a great variation of annual water charges among the sub-regions of Loudias Basin, ranging from 70 up to 180 €/ha. However, the spatial distribution of prices was found totally uncorrelated to the actual water consumption (Latinopoulos and Mylopoulos 2004). This inference underlines the inefficiency of the current charging system and highlights the necessity of a new pricing policy-harmonized to the WFD–that will make use of the volumetric pricing mechanism.

By simulating farmers' decision making, it would be feasible to predict the potential environmental and economic impacts of volumetric pricing in the study area. Nevertheless, the examination of the whole river basin, as a uniform and homogeneous area, may introduce significant aggregation bias. This bias is usually due to substantial variations in soil, climate and market conditions. According to Berbel and Rodriguez-Ocana (1998), MCDM should be applied in areas that are large enough in order to contain a significant number of farmers, but not as large as to introduce the aforementioned sources of variation. For this reason, the river basin was divided into several clusters according to the characteristics of the average farm in each region. Crop mix vectors (i.e. percentage share of cultivated area for each crop in the average farm) were selected as classification variables for the spatial cluster analysis, because they directly depict farmers' agricultural decisions. The "Ward method" and the hierarchical classification based on the square Euclidean distance were used by means of a combine use of statistical (SPSS v10.0) and Geographical Information Systems (MapInfo v.7.0) software. The final outcome of this procedure was seven clusters (regions) with a satisfactory degree of homogeneity in cropping patterns (Fig. 1). The main characteristics of each cluster are presented in Table 1.

The necessary data that refer to the 6-year period (1998–2003) were gathered from: (a) agricultural authorities and municipalities that are located in the reference area, (b) the Prefecture of Central Macedonia, (c) the Statistical Service of Greece, (d) the statistical database of FAO, (e) the Ministry of Rural Development and Food, (f) the Central Land Reclamation Board of Thessaloniki, and (g) the National Meteorological Service. It should be also mentioned that a sample of 20 farms in the reference area was also analysed in order to make more reliable estimates of the local crop coefficients (technical and economical).

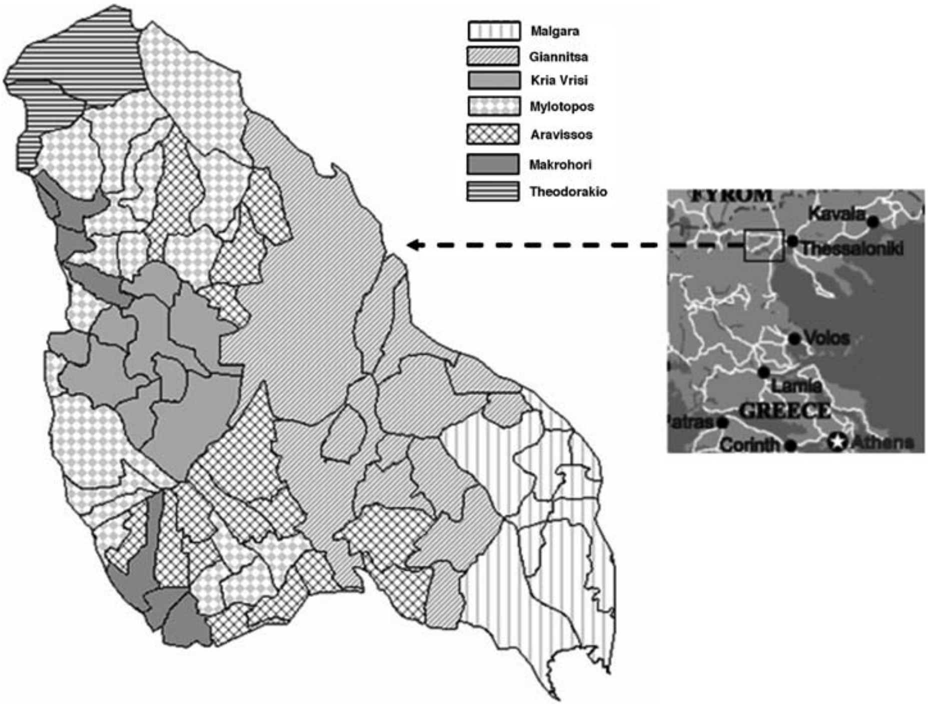


Fig. 1 Study area and clusters of spatial analysis

Table 1 General features of the reference areas (clusters)

Features	CL1 Malgara	CL2 Giannitsa	CL3 Aravissos	CL4 Mylotopos	CL5 Makrohori	CL6 Theodorakio	CL7 Kria Vrissi
Agricultural area (ha)	13,255	34,256	18,202	16,766	4,304	717	11,917
Irrigated area (ha)	12,850	29,772	16,927	15,229	4,187	255	11,085
Main crops	Rice, cotton	Cotton	Cotton, peaches, sugar beets	Peaches, corn	Peaches	Wheat	Corn, asparagus
Average farm size (ha)	8.15	6.16	4.60	3.35	2.70	3.64	3.89
Percentage of land ownership	50.9%	51.9%	61.1%	75.1%	82.9%	60.3%	64.0%
Number of farmers	3,560	8,510	7,090	7,545	3,430	350	5,070
Average gross margin (€/ha/year)	996	1,100	1,738	2,517	3,243	673	2,184
Average rainfall (mm)	465	540	550	554	560	492	569
Water consumption (m^3/ha/year)	7,900	5,435	6,422	6,455	7,190	3,380	6,415

3 Conceptual Framework

3.1 Overall Description

The basic stages of the analytical procedure, followed in this paper, are displayed in Fig. 2. All stages are occurring on a spatial level (cluster), where farmers are reacting (i.e. selecting their crop mix and water consumption) rather similarly to any new agricultural or water policy. These clusters are already determined and presented in the previous section. Therefore, the next step of the proposed methodology is to set the decision variables, the objective functions and the set of constraints that outline farmers' behavior within each reference area. Special attention is paid in selecting the objective functions, in order to represent the actual situation, but also the short and mid-term future agricultural decision making. Then, all these elements are introduced into a complex multicriteria model, which is based on the Multi-Attribute Utility Theory (MAUT). The outcome of the MAUT model is the assessment of utility functions for every group of farmers. Utility functions are next validated, so as to check the quality of the results. Trial and errors techniques are also applied in cases when the results do not simulating well the existing farmers' decisions.

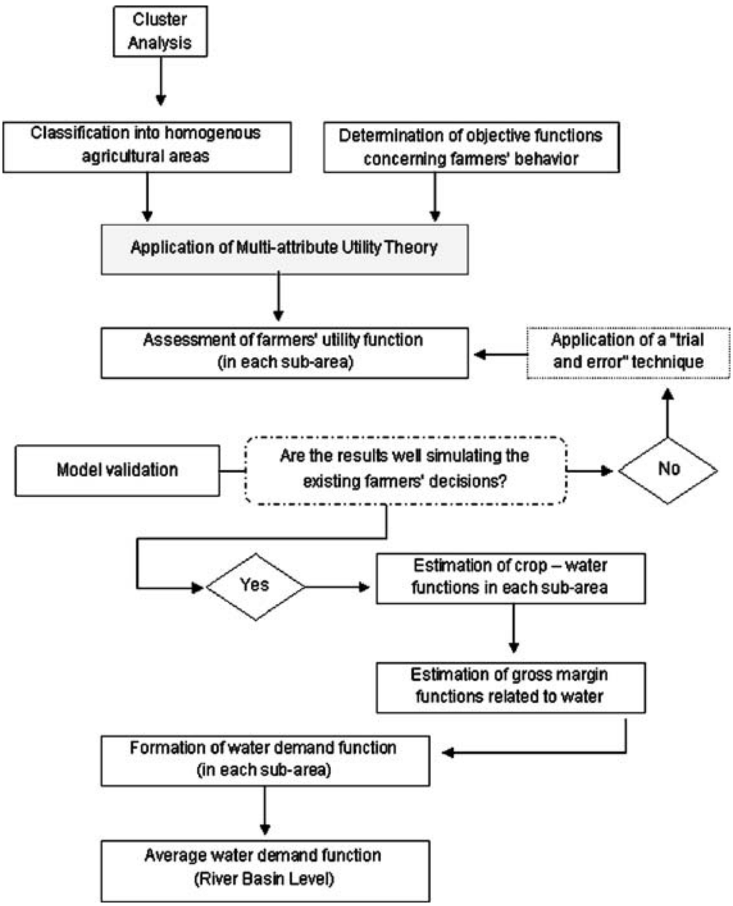


Fig. 2 Conceptual framework

The next stage of the analysis comprises the maximization of utility functions, under a set of different water pricing scenarios. Non-linear models are used in order to best allocate crops to the specific area and water consumption to the selected crops. Hence, crop-water response functions are first estimated for each irrigated crop in the reference areas. Through these functions the corresponding gross margin–water consumption functions are also calculated and incorporated into the maximization model. Water demand curves are then elicited by means of the best crop and water allocation in each pricing scenario. The economic (farmers' income), environmental (water consumption) and social (farmers' labour) attributes of water pricing are further assessed. Finally, an average water demand function is formulated for the whole study area (i.e. river basin).

3.2 Multicriteria Decision Making Approach

In regions, where water is currently provided for free or under uniform per-area charging, water demand functions can only be estimated by using hypothetical scenarios of farmers' behavior to some potential volumetric water charges. Profit maximization with traditional mathematical programming would be a rather simplistic approach to tackle this issue. For this reason, several criteria are further taken under consideration, by means of a multicriteria decision making model. In particular, MAUT is applied in order to specify a surrogate utility function that will evaluate farmers' aggregate utility, resulting from their agricultural decisions. The relative methodology, which is based upon weighted goal programming, was initially developed by Sumpsi et al. (1997) and further extended by Amador et al. (1998). The main reason for selecting this technique is that it can overcome the limitations of the single-attribute utility function. Furthermore, the MAUT is a methodology that usually avoids the necessity of interacting directly with farmers, and in which, the utility functions are elicited on the basis of revealed preferences regarding the real values of decision variables (Gomez-Limon and Riesgo 2004).

In this paper, an additive utility function was used, according to which: a) all objectives should be mutually utility-independent and b) the aggregated utility is a linear function of all the individual utilities. The basic steps of MAUT application are the following:

- Selecting the objective functions

The first step of this procedure consists of finding a set of q objectives that affect, or even determine, agricultural decisions (e.g. profit maximization, labor minimization). Each objective should be mathematically expressed as a function of the decision variables: $f_1(x)\ldots f_i(x)\ldots f_q(x)$. Since water consumption is currently free of charge, only the crop mix vectors are initially used as decision variables.

- Determining the pay-off matrices for the objectives

After the definition of the objective functions, the pay-off matrices in each reference area should be calculated. On this account, a number of q mathematical programming models are applied, so as to optimize separately each objective. The general form of a pay-off matrix is the following:

$$\begin{bmatrix} f_1^* \cdots f_{12} \cdots f_{1i} \cdots f_{1q} \\ f_{i1} \cdots f_{i2} \cdots f_1^* \cdots f_{iq} \\ f_{q1} \cdots f_{q2} \cdots f_{qi} \cdots f_q^* \end{bmatrix} \tag{1}$$

where f_i^* is the ideal value for the i-th objective and f_{ig} is the value of the g-th attribute when the i-th objective is maximized.

- Elicitation of Farmers' Preferences

Once the pay-off matrix is formed, the following system of q equations can be solved in order to estimate the different weights that farmers attach to each objective:

$$\begin{bmatrix} f_1^* \ldots f_{12} \ldots f_{1i} \ldots f_{1q} \\ f_{i1} \ldots f_{i2} \ldots f_1^* \ldots f_{iq} \\ f_{q1} \ldots f_{q2} \ldots f_{qi} \ldots f_q^* \end{bmatrix} \begin{bmatrix} w_1 \\ w_i \\ w_q \end{bmatrix} = \begin{bmatrix} f_1 \\ f_i \\ f_q \end{bmatrix}$$
$$w_1 + \ldots + w_i + \ldots + w_q = 1 \tag{2}$$

where w_i is the weight of i-th objective, f_{ig} is the element of the pay-off matrix and f_i is the current value (according to the existing farmers' decisions) for the i-th objective.

If the above system results in a non-negative solution (i.e. a set of weights, w_i), then this solution corresponds to the original weights that farmers attribute to their objectives, and it can be further used in order to simulate the agricultural decision making process. However, in most cases this solution does not exist (Sumpsi et al. 1997) making necessary to solve a weighted goal programming model, with percentage deviational variables (Romero 1991) as follows:

$$\mathrm{Min} \sum_{i=1}^{q} \frac{d_i^+ + d_i^-}{f_i}$$

subject to:

$$\sum_{i=1}^{q} w_i f_{ig} - d_i^+ + d_i^- = f_i \quad , \quad \mathrm{i} = 1, 2, \ldots, q \quad \sum_{i=1}^{q} w_i = 1 \tag{3}$$

where d_i^+ is the positive deviation variable from the goal target (in this case from the existing value) and d_i^- is the negative deviation variable from the goal target.

- Model validation and trial and error procedure

The term "validation" refers to a process that assess the divergence between real and simulated (for the current scenario) decision making, by observing the deviations in both objectives (percentage deviation) and decision variables (divergence index). In cases where current decisions differ significantly from the simulated ones, a trial and error technique is further performed, so as to better adjust the weights of the surrogate function: higher weights should be given to objective functions with negative deviations and vice-versa. Model validation can also be applied in order to compare the various utility functions coming from different models, as well as, to test the quality of their results.

As soon as the best approximation of current decision making is obtained by the trial and error procedure, the multi-attribute utility functions (MAUF) for different groups of farmers can be assessed. The general expression of a separable and additive MAUF should be, according to Gomez-Limon and Riesgo (2004), the following:

$$U = \sum_{i=1}^{n} w_i \frac{f_i(x) - f_{i^*}}{f_i * - f_{i^*}} \tag{4}$$

where f_{i^*} is the minimum (nadir) value for criterion i in the pay-off matrix.

3.3 Using Water Consumption as a Decision Variable

So far, most of the studies focusing on the derivation of irrigation water demand functions consider water consumption as fixed to a certain level that maximizes crop productivity, according to the local climatic, weather and soil conditions. Therefore, in those studies, there are two farmers' alternatives in facing higher water charges: (a) the substitution of water-intensive crops by other less intensive ones or (b) the cessation of irrigated agriculture and the introduction of rain-fed cultivations. In other words, the relationship between water consumption and farmers' profit is taken as linear and indirect (based on changes of crop mix). According to this practice, farmers are able to maximize the yield per unit cropped area, but not necessarily their total profit (Haouari and Azaiez 2001). This argument is illustrated in Fig. 3, where farmers' profit (gross margin), crop productivity, crop water consumption and water prices are all interconnected. As depicted in this figure, in the short-time period higher water prices may induce reductions of water consumption to the already cultivated irrigated crops. These reductions are actually reflecting a water deficit irrigation, which, in turn, affects negatively crop productivity and farmers' profit. Consequently, at higher water charges farmers have another alternative: to reduce water consumption without altering their cropping patterns.

Hence, it seems to be essential to analyze first the relationship between crop water requirements and crop yields. Then, all the possible water deficit strategies, as well as, their implications to farmers' profits, should be examined. Finally, it is necessary to incorporate all these results to the MAUF, in order to derive the water demand functions in each reference area.

3.3.1 Analysis of Water Effect on Crop Productivity

The first step aiming to incorporate water consumption to the decision variables of the multicriteria model is to define the water–yield relationship for every potential crop in the cropping pattern. A water–yield function, frequently used and recommended by FAO (Doorenbos and Kassam 1979), is the following:

$$\frac{Y_\mathrm{a}}{Y_\mathrm{m}} = \prod_{n=1}^{r}\left[1 - k_{y_n}\left(1 - \frac{\mathrm{ET}_{\mathrm{a}_n}}{\mathrm{ET}_{\mathrm{c}_n}}\right)\right] \tag{5}$$

where the ratio of actual (Y_a) to the maximum crop yield (Y_m) depends on the ratio of the actual (ET_a) to the maximum evapotranspiration (ET_c), as well as, to the yield response factor (k_y) of each crop, for every growth period n (n=1,r). Water–yield functions have, in general, flat peaks so that a small reduction of water consumption will not have dramatic effects on crop productivity. This low elasticity of the irrigation water production function was often the core argument for not taking into account water stressing in water demand studies (Ogg and Gollehon 1989). However, this low elasticity can also be interpreted as a profitable reallocation of water away from the point of maximum yield. For example, in the same study area it has been shown that at higher water charges it is possible to save up to 15% of the current crop water consumption (Latinopoulos 2006).

It is worth noting that the water–yield functions, as estimated through Eq. 5, are not taken for granted and they are being adjusted in advance, according to the characteristics of each reference area, in order to associate water consumption with crop productivity. Local climate, soil and crop characteristics as well as irrigation network efficiency data are

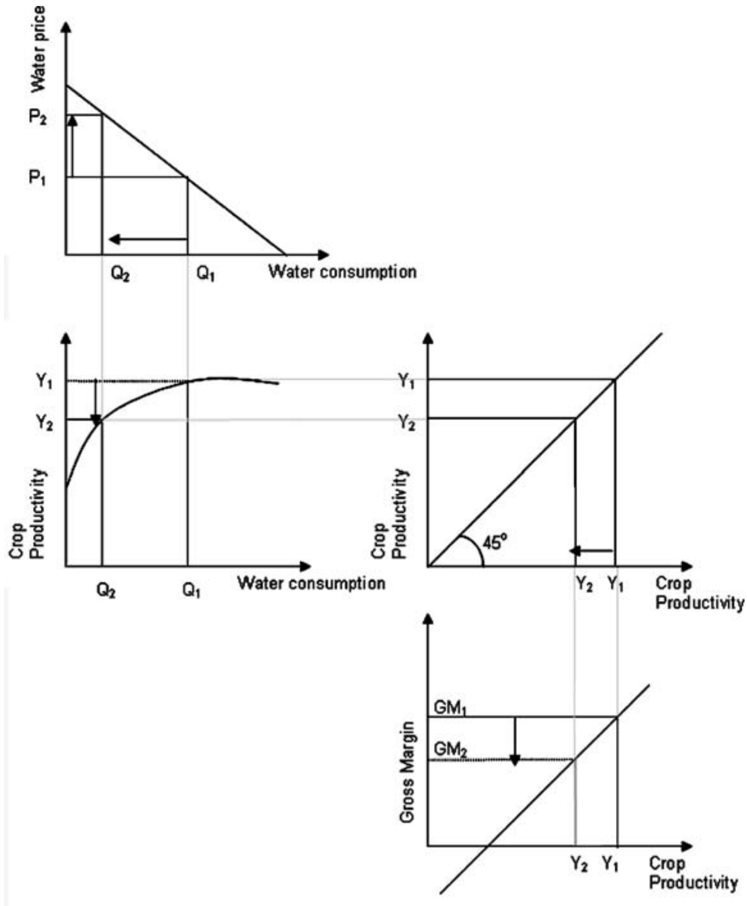


Fig. 3 Water consumption, crop production and farmers' profit

collected in each reference area from various sources, namely: the Ministry of Rural Development and Food, the Central Land Reclamation Board of Thessaloniki, the National Meteorological Service of Greece and the Greek Geological Institute. These data are analyzed by means of a specific computer software, called CROPWAT (Smith 1992). The implementation of CROPWAT results to different values of the actual crop yield, Y_α, for various levels of irrigation water consumption, $\mathrm{VIR_j}$. A regression analysis is then performed on the crop responses of sequential water consumption reductions, in order to obtain the corresponding water–yield functions (Latinopoulos 2005). Concave functions were used in the regression analysis, as they approximate the empirical water–yield functions much better than the linear ones. The final form of water–yield functions, expressed for any type of crop, is thus the following:

$$Y_{\alpha,j} = -a_j + b_{1j}\mathrm{VIR}_j - b_{2j}\mathrm{VIR}_j^2 \tag{6}$$

where $Y_{\alpha,j}$ is the actual yield of crop j, related to the variable level of irrigation water consumption, VIR_j.

3.3.2 Incorporating Water Stressing to the Multicriteria Model

Once the water–yield functions are estimated, the next step is to examine the potential economic impact of water stressing. Farmers' profit is, by definition, a linear function of crop productivity, so that–according to Eq. 6–it turns out to be a second-degree polynomial function of the varying irrigation water consumption, VIR_j. Hence, it is necessary to express the economic output of each crop as a function of water availability in all reference areas. Thereafter, farmers' behaviour to any potential (volumetric) water pricing scheme can be determined by a set of alternative choices related to both crop mix and water consumption. It should be noted, though, that this inference presupposes that farmers are fully informed about the relative importance of water application to their final economic outcome.

Turning back to the multicriteria model, the final step of the current analysis consists of the maximisation of the MAUF in each reference area. Conventional linear programming techniques can not be applied in this case because MAUF is no more a linear function (i.e. farmers' profit maximisation is for certain a decisive objective, while it is also a second-degree function of water consumption in all future pricing scenarios). Therefore, a computer program, called "What's Best" solving linear and non-linear optimisation problems is utilised. Specifically, successive linear programming techniques (SLP) at the outset of the solution process are applied, in order to approximate the non-linear model with a linear one. It should be mentioned that this technique is actually looking through values that are in proximity to the initial values used to set up the SLP model. As a consequence, this is a technique that is prone to locate local, instead of global, optima. To cope with this drawback, trial and error techniques are carrying out for different starting points of the adjustable (control) variables and a relatively high number of iterations is performed (Latinopoulos 2005).

4 Model Application in the Study Area

4.1 Multicriteria Modelling

4.1.1 Decision Variables

Farmers' actual preferences are revealed by means of their decisions, concerning the allocation of their agricultural land. For this reason, the decision variables in this model, X_j, represent the hectares covered by the j-th crop, in each reference area.

4.1.2 Objective Functions

Objectives should not only reflect current farmers' behavior, but they must also determine agricultural decision making in the near future. In other words, it is quite significant to be properly selected in order to constitute optimization targets to any policy scenario that is going to be implemented in modeling agricultural activities. Within this framework, and having also in mind the main characteristics of agriculture in Greece, three objectives were considered as the most crucial in agricultural decision making:

1. Gross margin maximization

Gross margin can be considered as a good approximation of the farmers' profit in the short-run. Within this sense, the respective decision variable, GM, is defined as the total income minus the variable costs of production and is expressed as a monetary variable per unit area. The data required for calculating GM is the following: (a) prices of agricultural products (obtained from local agricultural authorities and adjusted for inflation), (b) yields of different crops (determined by empirical findings and regional statistics), (c) subsidies (obtained from official publications) and d) variable costs, including seeds, fertilizers, chemicals, human labour and current water charges (determined by empirical findings and regional authorities). Average gross margin for each crop (in each reference area) was estimated from a 6-year period (1998–2003) time series of the above mentioned data. The objective function of GM that is included in the model is defined as follows:

$$\max \sum_j \mathrm{GM}_j \cdot X_j \tag{7}$$

2. Minimization of human labour

Farmers are usually displaying an aversion to work themselves for long times but, at the same time, they are rather reluctant to hire other people to do the fieldwork. The reason is that extra human labour entails higher costs of production (in case of hired labor), less time for leisure (in case of own labor) and less managerial involvement (in both cases). Human labour is estimated as the sum of all farming activities in each reference area, LB, expressed in terms of labour time per unit area. The necessary data were gathered from regional statistics, as well as, from a sample of farmers in the study area. The relative objective function is the following:

$$\min \sum_j \mathrm{LB}_j \cdot X_j \tag{8}$$

3. Minimization of risk

Annual variations in prices and yields induce uncertainty to farmers' income. This uncertainty stimulates a risk-aversion behavior and affects farmers' decision making. It should be noted that, in most studies, risk is measured as the variance of total gross margin. Thus, the first way to incorporate farmers' risk into their utility function is through the minimization of this variance, VAR, that is:

$$\min \mathrm{VAR} = \min \overline{X}'_j [\mathrm{Cov}] \overline{X}_j \tag{9}$$

where [Cov] is the variance-covariance matrix of the crop gross margin, for the 6-year period. In Manos et al. (2006) this classical risk approach resulted in a MAUF without the risk parameter (risk weight was found equal to zero). Similar findings came up in most of the reference areas of the present study. Therefore, the measure of risk is alternatively expressed by another parameter, SB, which is the share of income that corresponds to subsidies and relates to income security. The rationale is that according to empirical findings from practicing agriculture in Greece, subsidized crops are always the first choice of farmers, as they generate more income and they are less prone to risk factors. The objective function of income security that is included in the multicriteria model is defined as follows:

$$\max \sum_j \mathrm{SB}_j \cdot X_j \tag{10}$$

Another drawback of using the variance as a measure of risk is that it assumes that the negative semivariance is equal to the positive semivariance, a condition that in many practical situations is not satisfied. Therefore, a third way to measure income variability attached to different crops is to employ the negative semivariance, SVR, of gross margin (Romero 2000).

$$\mathrm{SVR}_j = \frac{\sum_k^m \left(\mathrm{GM}_{jk} - \overline{\mathrm{GM}_j}\right)^2}{m} \text{ when } \mathrm{GM}_{jk} \leq \overline{\mathrm{GM}_j} \tag{11}$$

In Eq. 11, k=1,m is the number of observations (m=6 years in the present application), GM_{jk} is the gross margin for crop j and observation k and $\overline{\mathrm{GM}_j}$ is the average gross margin for crop j. This measure of risk is introduced into the multicriteria model in the form of the following objective function:

$$\min \sum_j \mathrm{SVR}_j \cdot X_j \tag{12}$$

Finally, in order to avoid the case of crops with a great individual variability throughout the years, the maximum negative individual semivariance, MV, was used as a fourth form of farmers' risk. The relative objective function is a minmax function, which reads as:

$$\min \mathrm{MV} = \min \max\left(\mathrm{SVR}_j \cdot X_j\right) \quad , \quad \forall j \tag{13}$$

Optimizing all four risk functions would certainly result to a certain degree of conflict. Besides, significant correlations were depicted in the corresponding pay-off matrix between VAR and SVR, as well as, between SB and MV. Therefore, two separate models are analyzed in the following: (a) The GM-LB-VAR-SB model and the (b) GM-LB-SVR- MV model.

4.1.3 Constraints

The whole set of constraints that complements the multicriteria model, which is based on the previously defined group of decision variables, can be classified into the following four categories:

1. *Total cultivation area constraint*: all crops must add up to 100 ha, which is chosen to be the size of the representative farm in each reference area. This constraint is introduced in order to obtain the final resolution (decision variables X_j) as the percentage distribution of crops in each reference area.
2. *Agricultural policy and CAP constraints*: constraints concerning historical quotas as well as the minimum area for the set aside activity.
3. *Markets constraints:* upper or lower limits are set to ensure the well functioning of the marketing channels and the supply of local (processing) industry.
4. *Rotational constraints:* upper limits are set to all crops in order to alternate the cultivation of all plots, during the years (applied to all crops except of tree cultivations).

This set of constraints is prevalent in the relevant studies (e.g. Berbel and Rodriguez-Ocana 1998; Gomez-Limon and Berbel 2000; Gomez-Limon and Martinez 2005) as it corresponds to all the necessary restrictions concerning the agricultural activities.

Table 2 Pay-off matrices in Malgara region (CL1; 1st model)

Objectives	Optimum values				Existing values
	GM	LB	VAR	SB	
Z_1: Max profit (GM)	14,709	8,388	8,798	9,411	9,701
Z_2: Min labor (LB)	3,209	1,714	2,293	2,470	2,444
Z_{31}: Min Risk (VAR)	2,541	1,446	906	2,247	2,065
Z_{32}: Max income insurance (SB)	6,869	5,000	3,397	8,007	6,888

4.2 Multi-Attribute Utility Theory Application

Once the objective functions and decision variables are selected and the feasible set of decisions is defined, the next step is to obtain the pay-off matrix by successively optimising each individual objective. Pay-off matrices are created for both models in each reference area (cluster). These matrices provide a reliable test of the degree of conflict among the selected objectives. Specifically, if the maximization of one objective implies almost optimal values for any other objective, then it becomes clear that there is a certain degree of utility dependence between these objectives. As it was more or less expected, a slight compatibility was distinguished between gross margin and subsidies as well as between SVR and MV. However, there is no sign of significant conflict between these objectives and therefore the assumption of mutually utility-independent objectives can not be rejected.

Given the practical inability of exhibiting the results for all clusters, only some typical ones will be presented hereafter. Tables 2 and 3 shows an example of a pay-off matrix for both models in cluster 1 (Malgara region). The divergence between the real situation and all single optima (first four columns in Tables 2 and 3) denotes the necessity to apply the MAUT, aiming to find a combination of weights that will come as close as possible to the actual farmers' behavior.

Weighted goal programming (see Eq. 3), as proposed by Sumpsi et al. (1997), is next applied. The purpose of applying this technique is to estimate the weights assigned from farmers (i.e. to simulate the weights of the "average" farmer), of each reference area, to the selected objectives. However, in order to obtain the utility functions, all weights have to be non-dimensional. It should be also mentioned that, in some cases, the final outcome (farmers' behaviour simulation) was further improved by means of a trial and error procedure.

Table 3 Pay-off matrices in Malgara region (CL1; 2nd model)

Objectives	Optimum values				Existing values
	GM	LB	SVR	MV	
Z_1: Max profit (GM)	14,709	8,388	8,190	9,606	9,701
Z_2: Min labor (LB)	3,209	1,714	2,567	2,805	2,444
Z_{33}: Min Risk (SVR)	501	197	166	95	298
Z_{34}: Min Max (MV)	409	147	95	88	190

The utility functions of three reference areas (Malgara, Giannitsa and Aravissos regions) are next analysed. The selection of these areas was made on the basis of: (a) their current water consumption status (i.e. cluster 1 is the region with the most water-intensive cropping patterns), and (b) their total pressure on water resources (clusters 2 and 3 are the regions with the higher overall demand for irrigation water). Their utility functions (MAUF) are:

$$\mathit{Cluster}\ 1 : (\mathit{Malgara}) \quad \begin{array}{c} \text{First model} : U = 0.12\text{GM} - 1.383\text{LB} + 2.612\text{SB} \\ \text{Second model} : U = 0.33\text{GM} - 1.438\text{LB} - 6.702\text{MV} \end{array} \tag{14}$$

$$\mathit{Cluster}\ 2 : (\mathit{Giannitsa}) \quad \begin{array}{c} \text{First model} : U = 0.45\text{GM} - 2.923\text{LB} + 0.077\text{SB} \\ \text{Second model} : U = 0.51\text{GM} - 2.595\text{LB} - 0.627\text{MV} \end{array} \tag{15}$$

$$\mathit{Cluster}\ 3 : (\mathit{Aravissos}) \quad \begin{array}{l} \text{First model} : U = 0.62\text{GM} - 1.026\text{LB} + 0.685\text{SB} - 0.056\text{VAR} \\ \text{Second model} : U = 0.84\text{GM} - 0.982\text{LB} \end{array} \tag{16}$$

According to these utility functions, profit maximisation (gross margin) and human labour minimisation seems to be always present into farmers' decision making. Overall, profit maximisation was found as the most important objective in Loudias River Basin. On the other hand, risk factors, such as SVR and VAR turn out to be not relevant criteria in these reference areas (with the exception of VAR in cluster 3).

In order to validate these models, their utility functions are maximized under the current pricing system (non-volumetric price and charges based on the total irrigated area) and farming constraints. Then, the values accrued from the simulated model, in each reference area, are compared with the corresponding current (real) values. Two different validation procedures were used on this account: (a) the deviation in objectives (percentage deviation of objectives values from the current values), and (b) the deviation in decision variables (sum of all absolute deviations in the crop mix between the observed and the predicted crop allocation), which is also referred as divergence index (Arriaza and Gomez-Limon 2003).

The results of both procedures in each cluster of analysis are illustrated in Table 4. According to this table the predicted values are close enough to the current ones (i.e. the deviation is less than 25% in all objective functions and less than 30% in all divergence indices). It is therefore possible to deduce that both models are a good approximation to the

Table 4 Model validation

Deviation of the objective functions	1st model			2nd model		
	Cluster 1 (%)	Cluster 2 (%)	Cluster 3 (%)	Cluster 1 (%)	Cluster 2 (%)	Cluster 3 (%)
GM	−8.8	−11.4	−14.9	+4.2	−16.7	−16.8
LB	+19.9	+15.8	−13.8	+14.2	+12.8	−2.4
SB	+12.1	+3.1	−12.1			
VAR	+22.1	+24.8	−6.2			
MV				−11.4	−0.4	+0.6
Divergence index	9.6	22.1	19.7	11.5	27.2	22.8

farmers' own decision-making. However, it is difficult to compare the individual reliability of those models because the first one simulates better the decision variables (i.e. cropping patterns are closer to the actual crop mix), while the second one results to smaller deviations in the objectives. Therefore, both models are introduced to the next stage of the analysis, which is the derivation of irrigation water demand functions.

In the next stage, the surrogate utility functions (Eqs. 14, 15 and 16) are used to derive the irrigation water demand function, in each reference area. To this end, water prices are parameterized from zero charge (actual charge) to a charge equal to 0.20 €/m^3 (this range of potential water prices was selected based on the current charges of irrigation water in Southern Europe). In addition, a number of new decision variables (i.e. other crops) are introduced into the multicriteria model. These are less demanding in irrigation water or even rain-fed crops that can provide to farmers a greater flexibility when facing higher water prices. Apparently, a set of additional constraints comes also along with these new variables.

Apart from a probable reaction, which is to change their crop mix, farmers have another alternative in order to reduce the economic burden of water charges, which is the application of deficit irrigation to the existing crops. To model this option, crop-water consumption becomes a decision variable, which is also introduced to the utility maximization model. Likewise, a set of additional constraints is applied to confine crop-water consumption to some desirable levels. The water–yield relationship is also estimated for all irrigated crops and the resulting second-degree polynomial functions are incorporated into the corresponding gross margin functions. In this way, the gross margin functions and, consequently, the relevant objective functions, include now the extra cost of irrigation water.

Two examples that highlight the relationship between water consumption and farmers' profit (in terms of gross margin) under deficit irrigation are presented in Fig. 4, for a set of

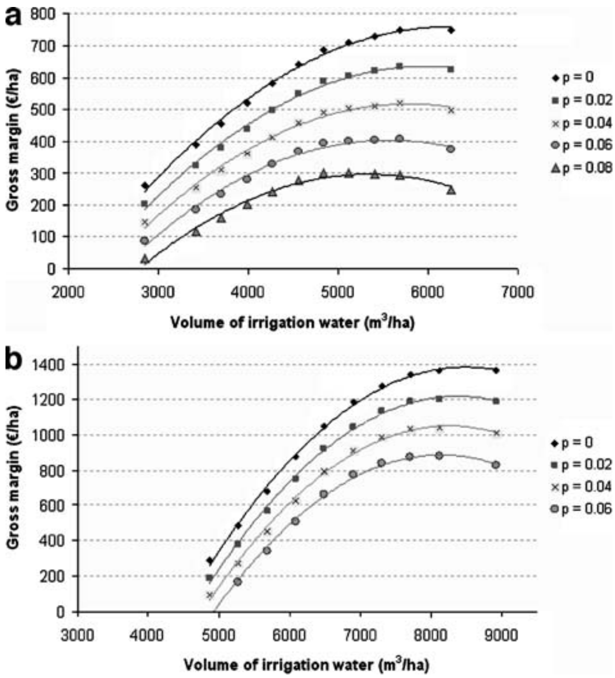


Fig. 4 Examples of water–profit functions. **a** Cotton cultivation under deficit irrigation. **b** Asparagus cultivation under deficit irrigation

reasonable water prices (p) and water restrictions. Both figures depict the trade-off between crop water reductions and farmers' gross margin. It is worth noting that according to these functions the maximum economic efficiency (profit maximization) is not always achieved at the yield maximization level. On the contrary, water prices higher than 0.02 €/m^3 imply water reductions in order to maximize the profit of cotton cultivation, whereas for the cultivation of asparagus the relevant price is 0.04 €/m^3.

5 Results and Discussion

5.1 Water Demand Functions

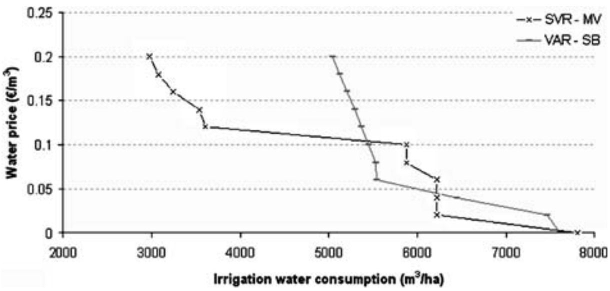
The final outcome of the MAUT implementation is the derivation of irrigation water demand curves for each reference area (cluster) in Loudias River Basin. Figures 5, 6 and 7 illustrate the water demand curves in three reference areas (Malgara, Giannitsa and Aravissos regions), as derived from both MAUF models. Their shape is more or less typical of irrigation water demand curves. Inelastic segments are present when farmers are not sensitive to higher prices, that is, when they neither alter their cropping patterns nor reduce the crop-water consumption. On the contrary, in elastic segments farmers respond to higher prices by reallocating their resources (of land or water).

In Table 5 an example of crop distribution for different water pricing scenarios is presented for the case of cluster 1. Low water prices imply the cultivation of water-consuming crops (rice, cotton, alfalfa). As the price of water is getting higher, the crop mix is being adapted to less water-intense crops, such as winter cereals or rain-fed agriculture. Water deficit practices are also taking place, especially when water prices are higher than 0.1 €/m^3. For example, when water price is set to 0.12 €/m^3, crop-water reductions on alfalfa and tomato irrigation are equal to 15% and 11% respectively, compared to the current water consumption.

Looking now at the differences of the two MAUF models, it can be seen that the second model (SVR-MV) provides smoother curves in comparison with the other one (VAR-SB). Besides, when subsidies are incorporated (i.e. the case of the first model), water demand elasticity is usually lower. This double effect can be partly attributed to farmers' reluctance to move away from subsidized crops. Hence, bearing in mind the future changes in the European Agricultural Policy – where subsidization of agricultural products will be reduced – the second model seems to describe a rather more realistic framework for future pricing scenarios.

Water pricing, according to the European and national water policy, should be designated at a river basin level. In other words, irrigation water charges have to be

Fig. 5 Irrigation water demand curve in cluster 1 (Malgara region)



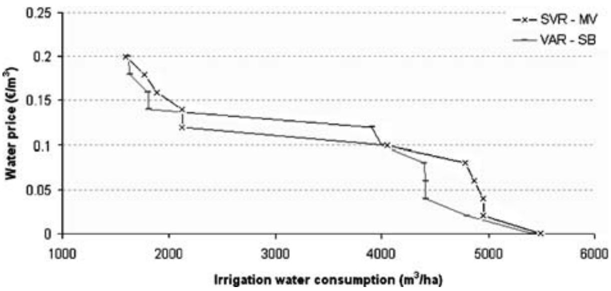


Fig. 6 Irrigation water demand curve in cluster 2 (Giannitsa region)

identical for all farmers practicing agriculture in the same area, irrespectively from differences in regional water demand functions. Therefore, a unique water demand curve function is, eventually, estimated for the whole study area (Loudias River Basin). Two distinct approaches could be alternatively implemented on this purpose: (a) the application of all the above mentioned methodology at the spatial level of the entire basin of Loudias River (i.e. without clustering analysis), or (b) the weighted addition of the individual (regional) demand curves that are already obtained (in relation to the total irrigated area of each cluster).

In this study, the second approach was selected because it usually results to smoother demand curves and simulates better farmers' behavior at the case of zero charging, which is the only point of the demand curve that can be compared to the actual situation (Gomez-Limon and Riesgo 2004; Latinopoulos 2006). Thereupon, all individual (regional) water demand functions, derived from the SVR-MV model, are weighted according to each region's share on the whole basin's irrigated area. Figure 8 illustrates the individual irrigation water demand curves, as well as the average (weighted) demand curve for the entire basin of Loudias River.

It should be noted that the implementation of MAUT in order to derive the irrigation water demand curves is based on the following assumptions: (a) the utility functions can reproduce a certain degree of accuracy concerning the behavior of the average farmer in each reference area, and (b) the average farmer has a unique utility function, at least in the short-time period (e.g. the period that is necessary in order to go through a new pricing policy, to undertake some farming decisions and also to implement them). For these reasons, there is a certain degree of uncertainty concerning the final weighting of the surrogate utility functions.

To cope with this uncertainty, a sensitivity analysis was performed, according to which the weights of the various objectives were altered from their initial value. Then, the MAUFs were optimized (in all reference areas) for a given set of weighs (at a range of ±30% of their

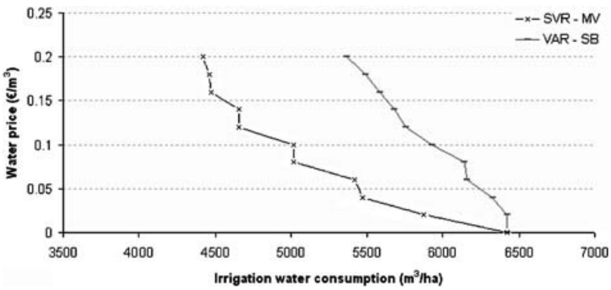


Fig. 7 Irrigation water demand curve in cluster 3 (Aravissos region)

Table 5 Crop distribution for various pricing scenarios – cluster 1 (Malgara region)

Crops	Current crop distribution	Water price (€/m³)								
		0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.20
Soft wheat	3.33	4.50	4.50	2.25	2.25	1.47	–	–	–	–
Corn	11.20	0.75	0.75	–	–	–	–	–	–	–
Rice	42.71	39.50	39.50	39.50	34.80	34.80	22.30	22.30	22.30	22.30
Cotton (irrigated)	22.56	9.57	9.57	9.57	8.09	8.09	4.79	4.79	–	–
Sugar beet	3.79	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Alfalfa	9.75	4.94	4.94	5.64	11.20	11.20	9.74	9.74	9.74	9.20
Tomato	2.26	2.59	2.59	2.59	2.19	2.19	1.30	1.30	1.30	1.30
Cabbage	0.45	–	–	–	–	–	–	–	–	–
Peaches	1.95	2.97	2.97	2.97	2.51	2.51	1.48	1.48	1.48	–
Barley	–	22.50	22.50	22.50	22.50	22.50	22.75	22.75	22.75	22.75
Cotton (non-irrigated)	–	5.43	5.43	5.43	6.91	8.72	28.20	28.20	32.98	35.00
Set aside	2.00	5.25	5.25	7.55	7.55	6.52	7.45	7.45	7.45	7.45

initial values) in order take the weighting uncertainty into account when estimating the irrigation water demand functions. Table 6 presents the outcome of the aforementioned procedure, that is, the maximum water demand variation (among the selected reference areas) in each weighting scenario. According to this table, there is not a sign of significant alteration of the water demand level (i.e. not a sign of great uncertainty) due to a presumable weighting misperception (±20% for the selected range of weights). It should be also pointed out that GM and LB weight variations induce a greater level of uncertainty (compared to the other objectives) in the water demand functions.

5.2 Spatial Impact of Water Pricing in the River Basin

5.2.1 Water Consumption Reductions

One further point that is worth mentioning is that water consumption varies notably among regions: cluster 1 has the highest actual water consumption (7,900 m^3/ha/year), followed by cluster 5 (7,190 m^3/ha/year) and cluster 4 (6,455 m^3/ha/year). Cluster 6 has the lowest consumption (3,380 m^3/ha/year), as the main cultivations in this region are the winter

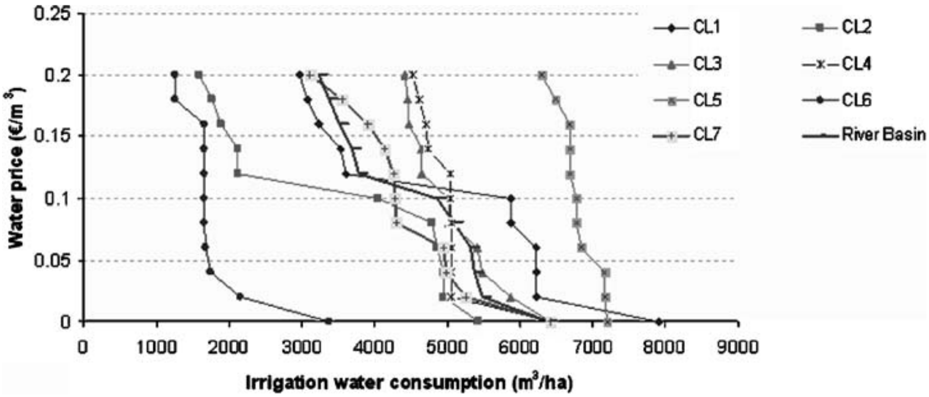


Fig. 8 Aggregate water demand

Table 6 Sensitivity analysis: the effect of variable weights on water demand levels

Parameter	GM (±10%)	GM (±20%)	GM (±30%)	LB (±10%)	LB (±20%)	LB (±30%)	SB (±10%)	SB (±20%)	SB (±30%)	MV (±10%)	MV (±20%)	MV (±30%)
Range of annual water consumption	(−11.8%) (+17.5%)	(−15.8%) (+17.5%)	(−16.8%) (+20.7%)	(−7.6%) (+9.1%)	(−14.5%) (+16.4%)	(−19.1%) (+17.4%)	(−2.5%) (+1.1%)	(−5.6%) (+3.3%)	(−8.7%) (+3.3%)	(−1.6%) (+0.9%)	(−2.9%) (+2.3%)	(−4.6%) (+3.5%)

cereals. The slope of the demand curve is also quite different among the regions. Namely, water reductions are sizeable at higher charges in the first and second cluster but are minor in clusters 3 and 5.

The overall effect of water pricing on water reductions is illustrated in Table 7. Three indicative pricing scenarios, from 0.02 €/m^3 up to 0.10 €/m^3, are examined in order to cover a range of reasonable future water charges. As shown in Table 7, water savings are substantial in most regions, even for the case of the low charging scenario. Therefore, contrary to previous results from relevant studies, there is no evidence of inelastic demand at low water prices. In the aggregate, i.e. at the river basin level, the implementation of these pricing scenarios generates reductions in water consumption from 14% up to 24%.

Concerning now the spatial differentiation in water consumption, it should be pointed out that the most important relative water savings are taking place in the less irrigated region, which is cluster 6. A possible explanation is that in this area water productivity is lower than in the rest of Loudias River Basin. On the other hand, in cluster 5, even a 0.10 €/m^3 pricing scenario results to very limited water savings (5.8% of the current situation). The reason is that, in this area: (a) water productivity is very high, (b) the current crop mix is characterized by peaches monoculture (notable market constraints favor thus the status quo patterns) and (c) the risk objectives are not considered by farmers' decision making (putting thus on the same level marginal water productivity and marginal water utility).

Irrigation water pricing, though, apart from its contribution to water savings can also induce some indirect negative effects on the agricultural sector. Specifically, higher water charges usually imply losses on farmers' income due to:

a. Increased production costs, as a consequence of higher water charges that are directly collected from water authorities (public revenues).

Table 7 Water reductions in selected pricing scenarios in all regions

	Water price (€/m^3)		
	0.02	0.06	0.10
	Water consumption reduction (m^3/ha)		
Cluster 1	−1,676 (−21.2%)	−1,676 (−21.2%)	−2,021 (−25.6%)
Cluster 2	−481 (−8.8%)	−564 (−10.4%)	−1,387 (−25.5%)
Cluster 3	−547 (−8.5%)	−1,003 (−15.6%)	−1,407 (−21.9%)
Cluster 4	−1,393 (−21.6%)	−1,393 (−21.6%)	−1,410 (−21.8%)
Cluster 5	−34 (−0.5%)	−339 (−4.7%)	−419 (−5.8%)
Cluster 6	−1,222 (−36.1%)	−1,695 (−50.2%)	−1,712 (−50.6%)
Cluster 7	−1,158 (−18.1%)	−1,463 (−22.9%)	−2,130 (−33.2%)
River basin	−921 (−13.9%)	−1,077 (−16.6%)	−1,540 (−24.3%)

b. Changes in cropping patterns, by introducing less profitable crops as substitutes for the more valuable water-intensive ones.
c. Deficit irrigation, which results to lower yields and, consequently, to lower income.

According to Table 8, there is a notable reduction of farm income (gross margin) in all reference areas and for various pricing scenarios. However, just like in the case of water savings, these income losses have not the same magnitude in all clusters. Namely, major impact is anticipated in cluster 1, where farmers are losing up to 74% of their actual profits in the 0.10 €/m^3 pricing scenario. The reason is that, in this specific area, all cultivated crops (rice, cotton, alfalfa) are intensively irrigated and, thus, volumetric water pricing causes a steep increase to the variable costs of production (income losses are not proportional to water savings). Similar results were also found for cluster 6, but in that particular case, the loss in farmers' profits is analogous to the corresponding water reductions. In the mid-term, agriculture in these areas is going to be economically unsustainable and a large percentage of farmers may run off their farming activities. On the other hand, the economic impact of water pricing is moderate (e.g. income losses are less than 20% of the actual revenues) in other regions due to: (a) alternative, less water intensive, but still profitable cropping patterns (e.g. clusters 3 and 7), or to (b) the invariability of cropping patterns when water productivity is very high (cluster 5).

Finally, irrigation water pricing is also associated with social impacts to the rural areas, as it is usually related to reductions in farm labor inputs and consequently to the employment in the primary sector. However, in the present case study, the potential social effects of pricing were negligible as compared to the economic ones. Namely, the average reduction of farmers employment in the region of Loudias River Basin, where regional differences were noted once again, was found equal to 6% and 8% at the 0.02 and 0.10 €/m^3 pricing scenarios, respectively.

6 Conclusions

The irrational use of water in agriculture is often responsible for several problems concerning pollution or depletion of water resources. On the other hand, a possible limited water availability in the future could be crucial for the sustainability of irrigated agriculture and the economic viability of the rural sector. The application of water pricing may be

Table 8 Gross Margin reductions in selected pricing scenarios in all regions

	Water price (€/m^3)		
	0.02	0.06	0.10
	Gross margin decrease (€/ha)		
Cluster 1	−238 (−24.5%)	−487 (−50.2%)	−718 (−74.0%)
Cluster 2	−100 (−6.6%)	−307 (−20.3%)	−406 (−26.8%)
Cluster 3	−108 (−3.7%)	−327 (−11.3%)	−536 (−18.5%)
Cluster 4	−808 (−25.4%)	−1,008 (−31.6%)	−1,211 (−37.9%)
Cluster 5	−134 (−3.4%)	−430 (−10.9%)	−711 (−18.1%)
Cluster 6	−343 (−46.4%)	−413 (−55.8%)	−479 (−64.7%)
Cluster 7	−63 (−2.3%)	−267 (−9.9%)	−454 (−16.9%)
River basin	−248 (−12.4%)	−467 (−25.0%)	−645 (−34.9%)

conducive to protect water resources from harmful agricultural activities. However, it is essential that any pricing policy should mitigate, as far as possible, the potential impact on agricultural development and farmers' welfare, but also, it should equally partition these negative effects among all farmers.

There are three main conclusions derived from the methodology employed in this paper and the analysis of the representative for Northern Greece irrigated area at the river basin level. First of all, if water pricing is going to be implemented as a policy tool, a number of environmental, economic and social consequences will arise, such as:

a. *Preservation of water resources*: Even at low water charges (0.02 €/m^3), farmers are going to alter their current agricultural decisions, resulting to water savings equal to 14% at the river basin level (these savings are almost doubled when price increases to 0.10 €/m^3).
b. *Loss of farmers' income:* Farm income will fall by 12% at low pricing scenarios, while higher water prices will entail significant reductions (e.g. 35% income losses at 0.10 €/m^3) that may generate, in the medium and long term, serious economic implications to the agricultural sector.
c. *Reduction of farmers' employment*: Higher water charges are inducing losses on farmers' employment. However, no major problems are estimated at reasonable water pricing levels (up to 0.10 €/m^3).

Another conclusion, which arises from the comparison of the estimated demand curves, is that these curves differ significantly from place to place. The implementation of alternative pricing scenarios will have various and unequal effects concerning the effectiveness of this kind of policy. Therefore, the application of a common water pricing policy to the entire river basin, as recommended by the WFD, looks like a complicated task. Policy makers that are planning to charge volumetric prices on irrigation water should take under consideration all the inequalities of the pricing mechanism. In this sense, the use of an additive water demand function at the river basin level can be recommended so as to provide a synthesis of regional agricultural decision making for several pricing policies. The resulted (additive) MAUF incorporates a number of local characteristics that are affecting farmers' behavior. Thus, it can be considered as a close approximation to the average water pricing implications, at the river basin level.

Finally, the use of crop-water consumption as decision variable in the multicriteria decision making model has a significant effect on the elasticity of demand (lower elasticity), mainly at higher water charges. The reason is that farmers' ability to use deficient water quantities in order to reduce water consumption becomes a real alternative at the point, where, changing cropping patterns will entail the choice of low-profit non-irrigated crops. Therefore, at these pricing scenarios, deficient irrigation seems to be the best solution as it subtracts less from farmers' gross margin than any potential change in the crop mix.

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