

An econometric system to assess the economic impact of water restriction policies in Spain

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Abstract

The objective of the Spanish government-funded project GESMO (Gestión integral del acuífero 08.29 Mancha Oriental), is to develop new tools for the evaluation and monitoring of water policies. These tools have to be capable of matching resource exploitation with reserve sustainability, applied to aquifer 08.29 in the Eastern Mancha, Spain. A decision support system (DSS), was developed as part of the GESMO project, that integrates two different systems within one computer application. One, an hydrogeological model, simulates the River Júcar basin and its associated aquifer. The other, an econometric system, is capable of predicting the evolution of regional crop maps, crop yields and crop prices, thus allowing the determination of the regional gross product of crops. This paper describes mainly the economic system of the DSS, a set of econometric models. Those used for crop allocations are the most important for the DSS. The approach followed for the specification of the DSS is proposed as a provisional method based on information from the pre-quota period to estimate likely responses of farmers in a post-quota period. A brief description of the overall structure of the DSS and an example of one of its possible applications are also included in the paper.

Additional key words: decision support system, econometric models, simulation, water management.

Resumen

Un sistema econométrico para medir el impacto económico de políticas de restricción de agua en España

El objetivo del proyecto GESMO (Gestión integral del acuífero 08.29 Mancha Oriental) financiado por el gobierno español, consiste en desarrollar nuevas herramientas para la evaluación y el seguimiento de las políticas del agua. Dichas herramientas deben ser capaces de adecuar la explotación de recursos a la reserva sostenible, aplicándolo al acuífero 08.29 de la Mancha Oriental, España. Como parte del proyecto GESMO se ha desarrollado un sistema de soporte a la decisión (DSS), que integra dos sistemas distintos en una aplicación informática. Uno de ellos consiste en un modelo hidrogeológico que simula la cuenca del río Júcar y su acuífero asociado. El otro es un sistema econométrico capaz de predecir la evolución del mapa regional de cultivos, el rendimiento de las cosechas y sus precios, todo ello encaminado al cálculo del producto regional bruto de los cultivos. Este artículo describe principalmente el sistema económico del DSS, formado por un conjunto de modelos econométricos. Los más importantes para el DSS son los que se utilizan para la asignación de cultivos. La aproximación seguida para su especificación se propone como una solución provisional al problema de la estimación de respuestas probables de los agricultores en un período post-cuota, basándose en la información proporcionada por el período pre-cuota. Se incluyen también en este artículo una breve descripción de la estructura completa del DSS y un ejemplo de una de sus posibles aplicaciones.

Palabras clave adicionales: gestión del agua, modelos econométricos, simulación, sistema de soporte a la decisión.

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Abbreviations used: CAP (Common Agricultural Policy), COP (cereal, oilseed and protein), DSS (decision support system), DW (Durbin-Watson), EI (regional electricity cost), GESMO (Gestión integral del acuífero 08.29 Mancha Oriental), GP (gross product), ITAP (Instituto Tecnológico Agronómico Provincial de Albacete), MAPA (Ministerio de Agricultura, Pesca y Alimentación), OI (other regional input costs).

Introduction

In the early part of the past century traditional farming in Mediterranean countries gradually began to be replaced by irrigated farm lands, making irrigation increasingly more common in those places with enough water available. This changeover generated several advantages. First, irrigated crops are more profitable than dry-land crops. Second, many of these crops are associated with agro-food industries whose activity boosts regional economic wealth. Finally, as a result of the change in the production system and the increase in profitability, a significant ancillary industry usually emerges specialised in canal building, drill testing and the installation of irrigation systems.

The need to balance regional economic advancement with conservation of natural resources has brought water policy to the environmental, social and economic forefront in countries where demand for water is high and the resource itself is scarce.

In Spain, effects of this kind are becoming more apparent in inland areas where intensive agriculture has always depended on exploitation of aquifers, whose piezometric levels have rapidly fallen in places such as Albacete and Ciudad Real. This fall has led to the continuous application of restrictive policies on the exploitation of water resources, based upon extraction quotas.

The objective of the Spanish government-funded GESMO project is to develop management tools to help in matching resource exploitation with reserve sustainability in the aquifer 08.29, located in Eastern Mancha, Spain (Martín de Santa Olalla *et al.*, 1999). Two types of end products should result from this project: i) a decision support system (DSS) for the definition of water-use policies, including economic-impact and reserve level simulators within a single multicriteria/multi-purpose decision-making environment; ii) measurement of monitoring and control systems employing teledetection and simulation of crop water needs.

This paper describes the specification and estimation of the economic subsystem of the DSS. This is made up of three groups of econometric models: i) crop allocation systems of equations based on CAP (Common Agricultural Policy), crop prices, assigned aquifer-water quota and piezometric levels which serve to dynamically simulate the areas devoted to crops; ii) agricultural yield models which allows prediction of the expected yields of crops; iii) time-series models with which to optionally make short-term predictions of agricultural prices.

Material and methods

General system description

The overall purpose of the DSS designed within the GESMO project is to provide a simulation tool helping to solve that problem for the Eastern-Mancha Irrigation Board, both with a short and a long term horizon, thus also helping them to better negotiate with the Júcar Hydrographic Confederation water restriction policies to be applied.

More detailed DSS objectives are:

1. Adapt the general USGS Modflow model to a broader architecture, substituting the input files with a global database and designing a simple windows-based input-output interface.
2. Design a general aquifer recharge model based on historical rainfall and levels of water in the Júcar river.
3. Use crop transpiration and irrigation models to calculate the demand for water for any crop map in the target area.
4. Design an econometric model to dynamically determine crop maps from input variables that specifically include the water quota.
5. Design an econometric model to calculate crop yields from specific input variables.
6. Design an econometric model to forecast short-term crop prices from historical values.
7. Integrate all these elements in a global DSS able to evaluate complex climatic, regulatory and economic scenarios as a whole. Design different tools which can be used to evaluate these scenarios both for the short and long term.

The global system architecture is shown in Figure 1.

The sectorial economic impact subsystem is composed of several models. Their goal is to dynamically determine, on the basis of water availability (quota), some agricultural policies (subsidies, set-aside rates) and also of the average piezometric level (determined by means of the hydrogeological impact subsystem), the regional gross product of crops (gross output less gross input) every year up to a target year. Such models are built on the basis of econometric techniques. The hydrogeological impact subsystem simulates the evolution of the aquifer up to the target year depending on the meteorology specified in the scenarios and the crop map determined in the sectorial economic impact model. The result is, for each year, the map of the average water depth in the saturated layer (measured by the piezometric levels) of the aquifer in accordance with the grid specified when defining the system.

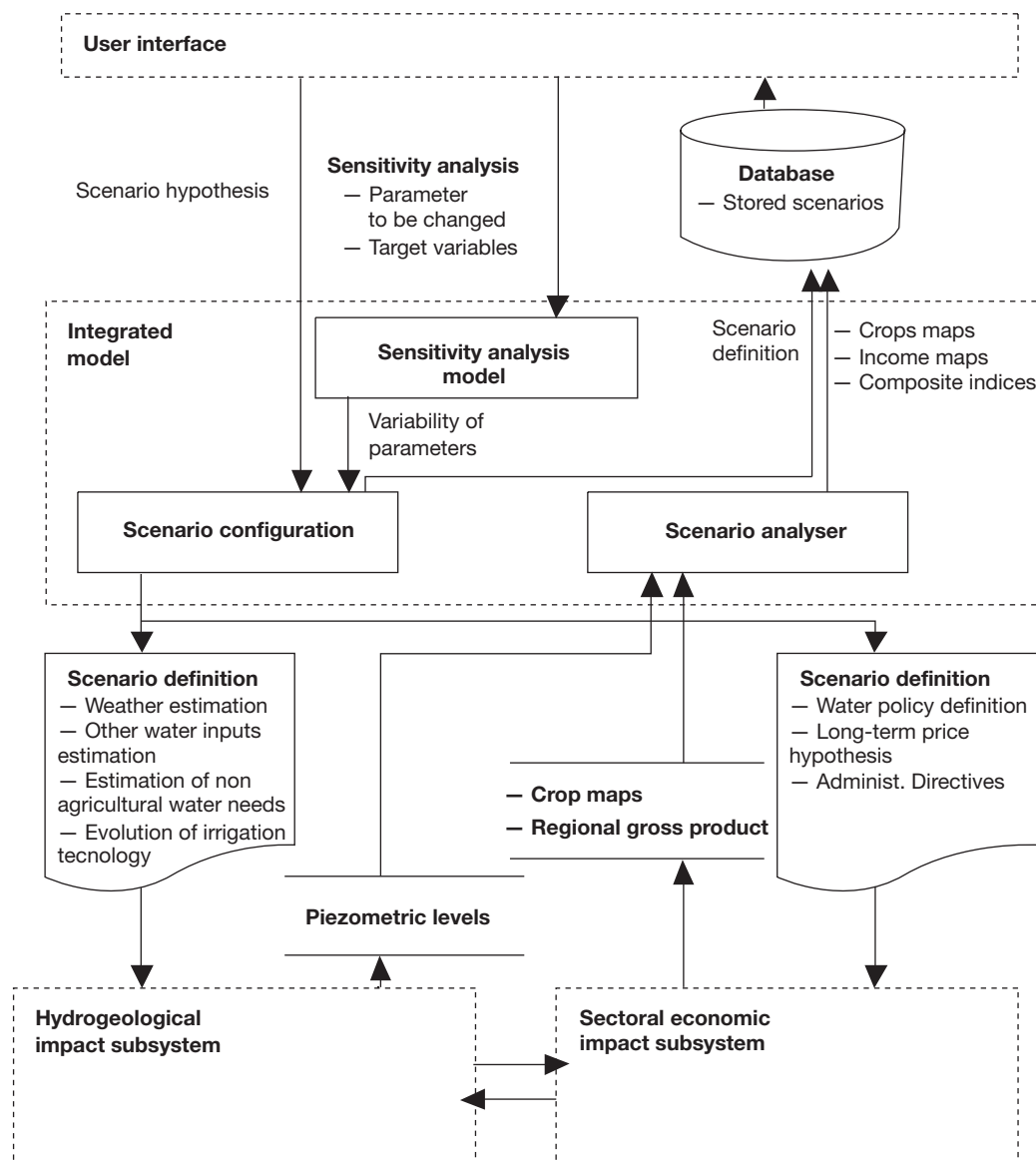


Figure 1. Sketch of the global architecture of the DSS (decision support system).

The auxiliary subsystem helps to integrate the results of both previous subsystems, to configure scenarios and to automatically generate new ones. Additionally, the auxiliary subsystem allows for automatic sensitivity analysis of selected parameters. It also enables the display of simulation results in different formats (tables and graphics).

The user interface serves to define and store scenarios and also to select the analytical tools of the system to be used.

Structures of the hydrogeological and sectorial economic impact subsystems are very different. The former, based on finite differences, is a geographic nu-

merical model able to represent piezometric levels. The latter, a set of statistical/econometric equations, models prices, yields and land allocation trends.

The sectorial economic impact models

Figure 2 illustrates the structure and behaviour of the sectorial economic impact models.

The most important section of the economic subsystem is the crop allocation model, an econometric model that dynamically simulates the evolution of areas allocated to the main irrigated crops. To do so it relates

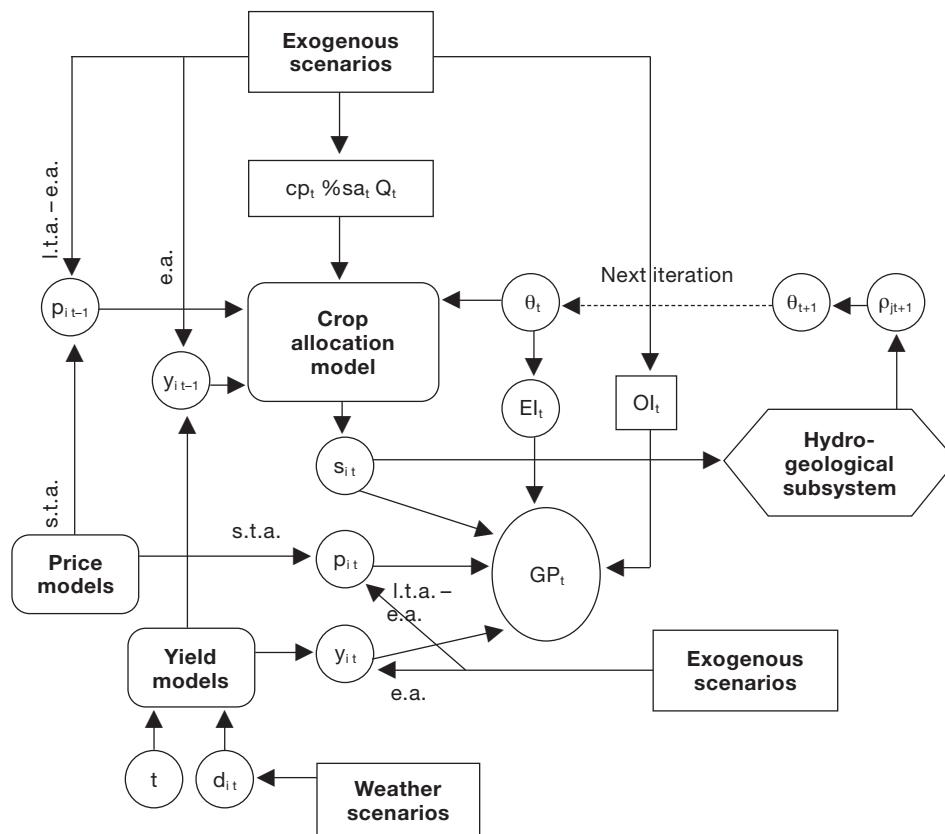


Figure 2. Structure and behaviour of the econometric models incorporated in DSS (decision support system). $i: 1, \dots, n$ crops. $j: 1, \dots, k$ grids. $t: 0, \dots, T$ years of simulation; all the initial values ($t: 0$) are exogenous. s : area. p : crop price. y : yield. ρ : piezometric level. θ : average piezometric level. cp : CAP compensatory payments. $\%sa$: CAP % set aside. Q : total irrigation quota. d : dummy for high, medium or low yields. GP : regional gross product. EI : regional electricity cost. OI : other regional input costs. $s.t.a.$: short term analyses. $l.t.a.$: long term analyses. $e.a.$: equilibrium analyses.

cultivated areas with several explanatory variables: delayed prices and yields, average piezometric level of the aquifer, compensatory payments, obligatory set-aside rates and water availability (quota). The estimated areas are used for both the calculation of the gross regional product and as hydrological subsystem inputs to obtain estimates of piezometric levels.

The DSS always has to use the crop allocation model whatever analysis might be conceived. However, the DSS can optionally use the two other sections of the sectoral economic impact model: the models for the estimation of yields and prices. Therefore, the values of these groups of variables may be either the outputs of the respective econometric models or exogenous scenarios assigned by the user. In fact, for analyses at equilibrium (*i.e.* analyses which try to identify long-term steady-states of the system) exogenous yields have to be provided to the DSS given that the yield

models use time trends as explanatory variables which would make impossible for the system to reach any equilibrium. Econometric price models (ARIMA) are expected to be used only for short-term analysis; long-term price expectations should be provided exogenously to the DSS, given the well-known characteristics of that kind of time series models. Given its higher importance within the DSS, only the crop allocation model is described here with detail.

The theoretical crop allocation model

The crop allocation model was developed before the quota policy was enacted. Hence, although the model is intended to evaluate likely responses during the post-quota period, its parameters could only be estimated based on information from the pre-quota period. The

approach we propose here is focused on solving this problem and should be seen as provisional until data corresponding to the post-quota period become available. This approach could be interesting for other researchers face with the same situation.

Before the enforcement of quotas, the main restriction on the allocation of surface area was land availability. In that period, farmers allocated a portion of their land to each crop. This portion varied according to the profitability that the crop offered. Thus, for the pre-quota period it is generally possible to estimate econometric relationships of the form

$$\lambda_{it} = \frac{s_{it}}{\sum_1^n s_{it}} = \varphi_i(A_t, S_t, \varepsilon_t) \quad i = 1, \dots, n \quad [1]$$

where s_{it} is the surface area allocated to crop i in t , A_t is an n -dimensional vector in which each element a_{it} measures the profitability of crop i in t , $S_t = \sum_1^n s_{it}$ and ε_t is an error term. This system of equations explains how the λ_{it} portions change over time in terms of relative changes in the profitability of each crop and the availability of arable land.

Multiplying each s_{it} in [1] by v_i , the average unit needs for each kind of crop, yields

$$f_{it} = \frac{v_i s_{it}}{\sum_1^n v_i s_{it}} = \psi_i(A_t, Q_t^*, \varepsilon_t) \quad i = 1, \dots, n \quad [2]$$

$q_i = v_i s_{it}$ is then an estimate of the annual water-needs of the surface s_{it} and $Q_t^* = \sum_1^n v_i s_{it}$ is the estimate of total regional water-needs. Here, water-needs are used as proxies for water consumption assuming that farmers of the region supply water to crops proportionally to their theoretical needs. Once each v_i is known, the ψ_i functions can be estimated for the pre-quota period.

This way, f_{ij} is an estimate of the fraction that q_i represents over Q_t^* , while the ψ_i functions reflect decisions about the allocation of those (estimated) water-consumption fractions which are related to the profitability of crops and Q_t^* . For estimations concerning the post-quota period, Q_t^* will be replaced by the quota Q_t and, given a scenario A_t^o , the estimate of s_{it} will be

$$\hat{s}_{it} = \frac{Q_t^* \hat{f}_{it}(A_t^o, Q_t^*, 0)}{v_i} \quad i = 1, \dots, n$$

The model uses functional forms which ensure, for every t , the *additivity restrictions*

$$\sum_i \hat{f}_{it} = 1 \quad \hat{f}_{it} \geq 0 \quad \forall i$$

This is achieved with the multinomial extension of the logit model, due to Theil (1969), which is extensively employed in surface-allocation models (Bewley *et al.*, 1987; Allanson, 1988; Burton, 1992; Ibáñez and Pérez, 1999):

$$f_i = \frac{\exp(h_i + \varepsilon_i)}{\sum_j \exp(h_j + \varepsilon_j)} \quad i, j = 1, \dots, n$$

where

$$h_i = \alpha_i + \sum_k \beta_{ik} \log x_k \quad i = 1, \dots, n$$

x_k are explanatory variables, ε_i are random shocks and α_i and β_{ik} are unknown parameters.

It is assumed that the variance-covariance matrix of the shock vector is of the form $(\Sigma \otimes I)$, where Σ is a square $n \times n$ matrix whose elements σ^2_{ij} represent variances when $i = j$, and covariances when $i \neq j$, and where \otimes is the Kroneker product.

The ψ functions chosen admit the following linearisation (Bewley, 1986):

$$\log\left(\frac{f_i}{f^*}\right) = A_i + \sum_k B_{ik} \log x_k + u_i \quad i = 1, \dots, n \quad [3]$$

where f^* is the geometric mean of the f_i fractions and where

$$A_i = \alpha_i - \frac{1}{n} \sum_1^n \alpha_i; B_{ij} = \beta_{ij} - \frac{1}{n} \sum_1^n \beta_{ij}; u_i = \varepsilon_i - \frac{1}{n} \sum_1^n \varepsilon_i \quad [4]$$

The variance-covariance matrix of the new shock terms maintains the form $(\Omega \otimes I)$; however, the matrix Ω is now singular due to the fact that the sum of the n u_i -terms is null. The rank of such a matrix is $(n-1)$.

The explained, or dependent, variables of the linearised models [3] have no clear economic meaning and so it is difficult to add dynamic-adjustment schemes to these models with a theoretical support. Thus, two schemas with the *ad hoc* inclusion of lagged dependent variables have been tested:

— *Restricted dynamic specification*: $n-1$ dependent variables are included in every Eq. [3]; each of them is lagged one period (one must be eliminated since [4] would imply the existence of perfect multicollinearity). This specification is similar to that of the partial-adjustment generalized model (Hunt and Upcher, 1979).

— *Unrestricted dynamic specification*: the dependent variable itself is included in every Eq. [3], but lagged one period. This specification is similar to the well-

known simple partial-adjustment model, or Nerlove's model. In this case, it can be observed (Bewley *et al.*, 1987) that the relationships [4] imply that all parameters associated with lagged dependent variables are the same in the n equations.

The empirical crop allocation model

Given the form of the shock variance-covariance matrix, the parameters of all the ψ functions must be estimated as a group. Due to the singularity of the Ω matrix, it is necessary to eliminate one arbitrarily chosen equation before making the estimation; however, the parameters of the eliminated equation are recovered by [4].

The estimation has been calculated by applying the Full Information Maximum Likelihood method to historical data series. The choice between each restricted or unrestricted dynamic specification has been made according to a ratio test of the likelihood of either approach.

Profitability of each crop has been reflected by the return/ha (area times yield) or by the price obtained for each crop. Specifications have included $(n-1)$ ratios of the return or price with respect to one used for reference purposes. In 1993-1994, the compensatory payments given to COP (cereal, oilseed and protein) crops established in 1992 by the reform of the CAP, were added. For those years, the set-aside rates stipulated by the reform were also included as explanatory variables. Production costs were not considered as such, but the average piezometric level of the aquifer was included since this is a variable directly related to the cost of water. The average piezometric level is the output of the other main subsystem of the DSS, the hydrologic model of the aquifer.

Data employed are annual and correspond to the period 1973-1994; data on cultivated areas and yields correspond to the province of Albacete, which is the aquifer's exploitation area. Prices obtained by farmers are national and will be addressed further when the price estimation model is described. Data on surfaces, yields, and prices are taken from the Yearbook of Agricultural Statistics (*Anuario de Estadística Agraria*), a publication of the Ministerio de Agricultura, Pesca y Alimentación (MAPA, 1985-1997), the Spanish agency for agriculture, pisciculture and food. Estimates of each crop's water need were supplied by the Instituto Tecnológico Agronómico Provincial de Albacete

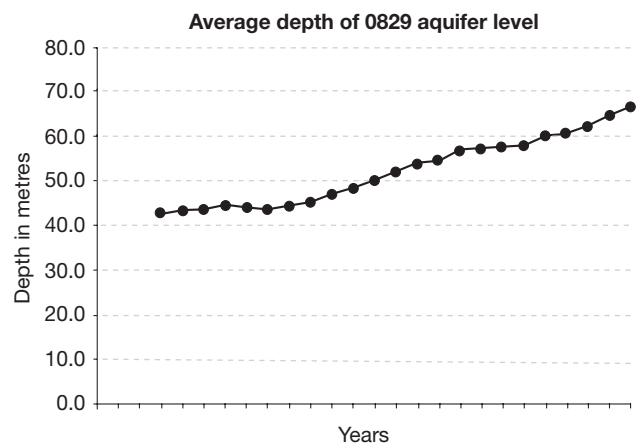


Figure 3. Trend in the depth of «08.29 Mancha Oriental» aquifer level.

(ITAP). Average piezometric levels were calculated by averaging the mean annual depths obtained by probing 11 spots corresponding to the different hydrogeological areas of the aquifer 8.29 (Fernández, 1996). The measure chosen for each area corresponds to the median depth of all measures pertaining to the same area and covering the historical series 1973-94. Figure 3 shows the path of the calculated average depth, which reflects the progressive overexploitation of the aquifer.

Crops considered are those planted most frequently and/or those with the highest value within the area, evaluated in 1994. These include; wheat, barley, corn, sunflower, lucerne, potato, garlic, onion and other vegetables (lettuce, melon, pepper, tomato, green beans, peas, fava beans). Thus $n=9$ for the allocation system shown in [3]. The direct, single stage estimation of the corresponding 8 equations would have given rise to a problem of degrees of freedom. To avoid this, a hierarchical-allocation scheme was chosen, which is customary in other surface-allocation models (see, for example, Wolfgarten, 1989; Burton, 1992; Ibáñez and Pérez, 1999). This scheme assumes that the farmer will proceed by stages, first allocating groups of crops and then separating each group into its component crops. Each stage implies the estimation of a system of type [3], which ensures the overall additive consistency of the schema.

Figure 4 illustrates the hierarchical structure adopted. As the figure shows, in the first stage water volumes are allocated to COP and non-COP crops (S-I allocation system). This way of grouping seems realistic given the fact that COP crops have support prices and other aids to ensure a significant part of each year's incomes,

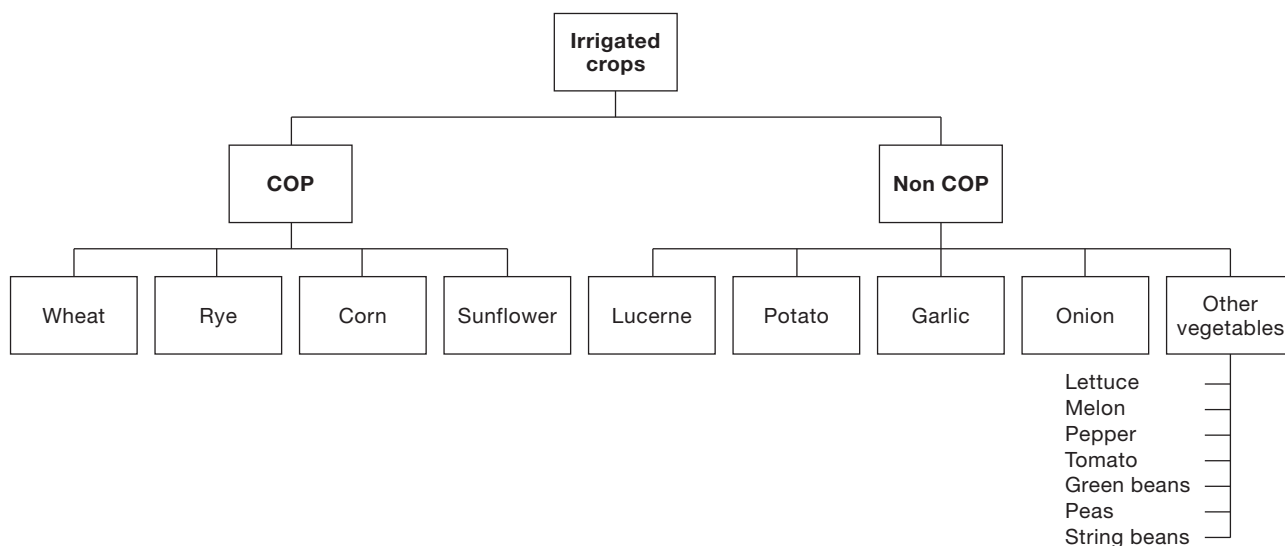


Figure 4. Hierarchical structure of the crop allocation model.

whereas the other crops lack such insurance against risk. Thereafter, the volume of water corresponding to each modelled COP crop is specified by means of the S-II allocation system, and that of the non-COP crops by means of the S-III system.

As can be seen in Eq. [4], the parameters of Eq. [3] measure deviations from average values, implying that a zero value of any of these parameters does not mean a non-significant effect of its corresponding explanatory variable but rather an average effect. The consequence is that the conventional t-statistics have no value for the validation of the estimated Eq. [3]. Hence the final validation of the estimated crop allocation equations took into account:

i) Their ability to recreate historical data series, evaluated by comparing graphs of actual and predicted values as well as by means of Theil's U_2 -statistics (Kost, 1980).

ii) The rationality of the elasticities derived from parameter estimates.

Estimated short-run elasticities, shown in Table 1, describe the average percentage change in the volume of water allocated to each crop, or group of crops, in response to a one percent change of the variable given in the top row, all else being equal.

The main check for the rationality of the estimated elasticities is that all of the own income or price elasticities are positive (except in the case of potato, where the value is virtually zero). The existence of positive signs outside the principal diagonals can be attributed to associations among crops within the traditional

rotations of the area. A 1% increase in the total amount of water (the remaining variables being unchanged) is associated with an average 0.32% increase in the allocation of water to COP crops and with an average 0.61% decrease in the allocation of water to the other crops. As a result, the allocation of an increase of the quota Q_t for the groups of crops in the S-I system is not likely to be homothetic. In other words, the farmer is likely to respond to greater availability of water for a given year by favouring COP crops. Similarly, if the amount of water for COP crops increases by 1%, all else being equal, corn would be the favoured crop. Finally, an increase of 1% in the amount of water available to the non-COP crops would favour lucerne and onion.

Elasticities relative to the average piezometric level must be interpreted in a similar way. In response to a 1% increase of the piezometric level (*i.e.* an increase of water extraction cost), the favoured crops would be the COP group once again, and more specifically wheat and barley. The favoured non-COP crops would be potato, garlic and other vegetables.

Models for agricultural-yield estimation

In order to provide estimations of the yield per hectare for each crop i , the DSS include regression equations which can be optionally used by the user, as explained before. Such equations have the following general specification

$$y_{it} = \mu_i + \alpha_i t + \beta_i (h_i/p_{it}) + \delta_i s_{it} + \gamma d_{it} + \varepsilon_{it} \quad [5]$$

Table 1. Estimated average elasticities of water allocation to each crop or group with respect to returns or prices, total needs and piezometric levels (1972-1994)

Water allocated to ¹		Returns (S-II price)				Total group water need	Piezo-metric level	
		COP	Non-COP					
S-I	COP	+0.049	-0.049			+0.3200	+0.0732	
	Non-COP	-0.094	+0.094			-0.6133	-0.1404	
		Wheat	Barley	Sunflower	Corn			
S-II	Wheat	+1.861	+1.066	-0.104	-2.823	-2.7329	+5.8588	
	Barley	+0.257	+0.632	+0.217	-1.106	-1.1136	+2.8273	
	Sunflower	-0.843	+0.931	+0.906	-0.994	-0.2664	-3.4540	
	Corn	-0.056	-0.456	-0.236	+0.747	+0.5977	-0.6127	
		Potato	Lucerne	Garlic	Onion	Other		
S-III	Potato	-0.010	-0.017	-0.003	-0.025	+0.054	-0.4286	+0.2491
	Lucerne	-0.059	+0.046	+0.038	-0.034	+0.009	+0.4971	-0.5864
	Garlic	+0.185	-0.002	+0.126	-0.096	-0.213	-0.2607	+0.3601
	Onion	+0.142	-0.033	-0.126	+0.212	-0.195	+0.0878	-0.0641
	Other	+0.012	-0.150	-0.070	-0.032	+0.240	-1.6155	+2.3542

¹ S-I: allocation system S-I. S-II: allocation system S-II. S-III: allocation system S-III. COP: cereal, oilseed and protein.

where y_{it} = yield, t = time trend, h_t = fertilizer price index, p_{it} = crop price, s_{it} = area, d_{it} = dummy variable and ε_{it} = random shock.

The linear trend is meant to show the effect arising from employment of new varieties and production technologies. The quotient between the fertilizers' price index and the price obtained by farmers allows taking the relative profitability of that important production input into account. The variable representing cultivated areas tries to catch the effect on yields of allocating crops to soils of varying quality. Finally, the dummy variables are used to classify yields into three qualitative groups, namely high, normal or low, on the base of sampled information and to characterize respectively each group by $d_{it} = 1$, $d_{it} = 0$ and $d_{it} = -1$. Thus, in designing scenarios for the DSS, just a single variable, the dummy d_{it} , is needed to represent good ($d_{it} = 1$), average ($d_{it} = 0$) or bad ($d_{it} = -1$) weather conditions.

Price prediction model

The limited extension of the area in which this work is applied imposes certain restrictions on the methodology to be employed for modelling prices. Farmers do not limit themselves to selling in markets within their

own province. Commonly, they will trade in surrounding markets as well, as long as prices offered are appealing enough. Similarly, farmers of other regions may come to local markets when it is advantageous for them to do so. Thus, physical-output values corresponding to the province of Albacete (which are the only ones which can be estimated using the DSS) are likely to provide only very limited information with regard to prices obtained by farmers in the area. This turns out to be an impediment to the estimation of prices by means of inverted demand models, in which prices are mainly dependent on outputs. Hence, ARIMA models (Box and Jenkins, 1976) were used instead, which, as is well known, allow for predictions based only on data series concerning prices observed over time.

Since the price models has also a limited role for the functioning of the DSS, they are not explained further here.

The calculation of the gross regional product

The DSS obtain the regional gross product (GP) (gross output less gross input) by means of

$$GP_t = \sum_i s_{it} y_{it} p_{it} - EI_t - OI_t \quad [6]$$

where: s_{it} is the area allocated to crop i in t ; y_{it} is the yield of crop i in t ; p_{it} is the price of crop i in t ; EI_t is the regional electricity cost in t ; and OI_t are other regional input costs in t .

Regional cost of electricity was directly related by regression to the average piezometric level of the aquifer. Such regression is employed to estimate EI_t from every average piezometric level, θ_t , calculated in the hydrologic section of the DSS (see Fig. 2).

Other input costs, OI_t , are taken as fixed and equal to its average historic values. Once again, an exogenous value for this variable can be supplied to the DSS.

Accumulated gross product throughout a period of time is also calculated by the DSS. This is an interesting index for analysing and comparing results from long-term simulations under different scenarios

$$AGP_T = \sum_{t=1}^T GP_t \quad [7]$$

All quantities of the economic section of the DSS are corrected for inflation by dividing each monetary value by the retail price index. A discount rate may be easily incorporated to AGP's expression for the DSS to calculate its actual value. Here, a null discount rate has been arbitrarily considered.

Results and discussion

Here we illustrate the utility of both the sectoral economic impact subsystem and the complete DSS by means of two different analyses. Firstly, two simulations

of the isolated sectoral economic impact subsystem were carried out to assess the impact of a *ceteris paribus* restriction on the total quantity of water available for irrigation in the study area. In both simulations, the subsystem was allowed to evolve until equilibrium is reached. As it is explained before, both prices and yields have to be provided exogenously for this kind of analysis.

As a simplifying assumption, both simulations consider zero regional cost (*i.e.* $EI_t = OI_t = 0$ for every t). In this way, gross product equals gross output throughout the analysis. In scenario #1 all the exogenous variables were maintained constant since 1995 at their real 1994 values. Particularly, total water needs (or quota) were kept stable at 728.4 hm³. Values for scenario #2 were kept constant at their 1994 levels, except for the total quota, which has levelled out at a constant value of 655.6 hm³ since 1995 (10% less than that in #1). Tables 2, 3 and 4 gather the results for water allocations, surfaces and gross output values resulting from these simulations.

As can be observed in the tables, a reduction of 10% in the total availability of water causes a reduction of 8.2% in the total irrigated area and a loss in regional gross output of 5%. The COP crops are the most heavily impacted, with a loss of 10% of their surface and of 17% of its output relative to the base scenario.

A brief explanation is necessary before presenting the analysis using the complete DSS. This system has shown stable steady-states for all of the long term simulations which maintain a constant scenario for

Table 2. Results of simulation: equilibrium water allocations (hm³)

Crop ¹	Actual 1994	%	SC1	%	SC2	%	(SC2-SC1)*100/SC1
Wheat	15.1	2.1	17.0	2.3	20.9	3.2	22.9
Barley	81.1	11.1	84.8	11.6	84.2	12.8	-0.7
Sunflower	190.8	26.2	207.7	28.5	184.6	28.2	-11.1
Corn	281.9	38.7	260.9	35.8	207.3	31.6	-20.5
<i>COP crops</i>	569.0	78.1	570.4	78.3	496.9	75.8	-12.9
Potato	29.6	4.1	27.7	3.8	27.7	4.2	0.0
Lucerne	74.4	10.2	65.1	8.9	65.7	10.0	0.9
Garlic	11.5	1.6	14.2	1.9	14.2	2.2	0.0
Onion	22.2	3.0	29.0	4.0	29.2	4.5	0.7
Other vegetables	21.7	3.0	22.0	3.0	21.8	3.3	-0.9
<i>Non-COP crops</i>	159.4	21.9	158.0	21.7	158.6	24.2	0.4
Total	728.4	100.0	728.4	100.0	655.6	100.0	-10.0

¹ COP crops have a reduction of 12.9%; non-COP crops have an increase of 0.4%. Total availability of water has a reduction of 10%. SC1: scenario 1. SC2: scenario 2.

Table 3. Results of simulation: equilibrium surfaces (ha)

Crop ¹	Actual 1994	%	SC1	%	SC2	%	(SC2-SC1)*100/SC1
Wheat	2,976	3.2	3,345	3.5	4,098	4.7	22.5
Barley	18,374	19.8	19,210	20.3	19,066	22.0	-0.7
Sunflower	26,030	28.0	28,335	30.0	25,190	29.0	-11.1
Corn	27,525	29.7	25,469	26.9	20,237	23.3	-20.5
<i>COP crops</i>	74,906	80.7	76,359	80.8	68,592	79.0	-10.2
Potato	2,915	3.1	2,727	2.9	2,729	3.1	0.1
Lucerne	6,564	7.1	5,741	6.1	5,793	6.7	0.9
Garlic	2,153	2.3	2,654	2.8	2,660	3.1	0.2
Onion	2,345	2.5	3,067	3.2	3,083	3.6	0.5
Other vegetables	3,933	4.2	3,990	4.2	3,952	4.6	-1.0
<i>Non-COP crops</i>	17,909	19.3	18,178	19.2	18,218	21.0	0.2
Total	92,815	100.0	94,537	100.0	86,810	100.0	-8.2

¹ COP crops have a loss of 10.2%; non-COP crops have an increase of 0.2%. Total surface has a reduction of 8.2%. SC1: scenario 1. SC2: scenario 2.

control variables (including yields and prices). This very interesting result means that both regional gross product and piezometric levels of the aquifer, under a constant environment, are able to reach long-term stationary values. However, the existence of steady-states must be examined carefully: long-term equilibria of the system could occur at an overexploitation point, that is, a stationary, empty aquifer. This result is effectively obtained with the DSS under certain intensive-exploitation scenarios (*i.e.* quotas and crop prices too high).

That previous result led to our second illustrative analysis: a sensitivity analysis where the value of quota is varied and the system is simulated, for every quota,

until equilibrium is reached. Figure 5 shows equilibria curves for the regional gross product and the piezometric levels obtained in that way for some fixed scenario of all exogenous variables other than quota.

The upper curve, corresponding to regional gross product equilibria, shows a maximum for a value of the quota around 3,600 m³ ha⁻¹ yr⁻¹. This value can be taken as the desirable quota from a long-term point of view, given that the corresponding equilibrium for the piezometric level is high enough to ensure sustainability of the aquifer. Of course, curves of Figure 5 will vary if the assigned scenario is altered. The DSS permits exploration of variations of the desired quota calculated under various situations.

Table 4. Results of simulation: equilibrium gross output values (millions of €)

Crop ¹	Actual 1994	%	SC1	%	SC2	%	(SC2-SC1)*100/SC1
Wheat	1.87	1.0	2.11	1.1	2.58	1.4	22.5
Barley	11.18	6.0	11.69	6.1	11.61	6.4	-0.7
Sunflower	7.64	4.1	8.32	4.3	7.40	4.1	-11.1
Corn	46.03	24.6	42.59	22.3	33.84	18.5	-20.5
<i>COP crops</i>	66.74	35.7	64.72	33.8	55.43	30.4	-16.8
Potato	15.66	8.4	14.64	7.7	14.66	8.0	0.1
Lucerne	39.1	20.9	34.20	17.9	34.51	18.9	0.9
Garlic	17.36	9.3	21.40	11.2	21.45	11.8	0.2
Onion	25.74	13.8	33.66	17.6	33.85	18.6	0.5
Other vegetables	22.45	12.0	22.78	11.9	22.56	12.4	-1.0
<i>Non-COP crops</i>	120.3	64.3	126.68	66.2	127.02	69.6	0.3
Total	187.03	100.0	191.40	100.0	182.45	100.0	-4.9

¹ COP crops have a loss of 16.8%; non-COP crops have an increase of 0.3%. Total gross output has a reduction of 4.9%. SC1: scenario 1. SC2: scenario 2.

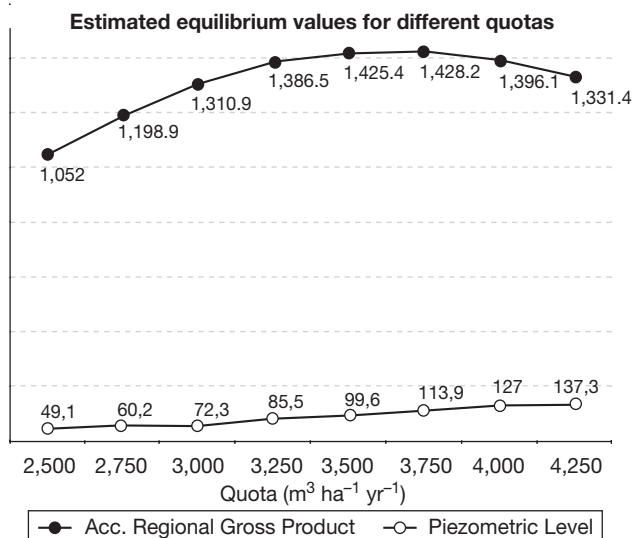


Figure 5. Steady-states of gross regional product and piezometric level for different values of quota.

Conclusions

The system designed amounts to an innovation in the field of decision support systems for managing water resources. Its main feature, hydrogeological criteria combination with agricultural sector economics (the biggest loser as far as water restriction policies are concerned) produces a tool to analyse the two aspects of these policies both in short- and long-term scenarios.

The system has been validated and delivered to Irrigator Corporation, where it is used to plan the agricultural year and design irrigation policies which are then submitted to the Hydrographic Confederation of the Júcar.

It is planned to develop the system to admit a very wide range of water resource management measures (transfers, collection of surface water, recharging pools, etc.) and extend the econometric model to more accurately estimate the trend in costs of production, introducing advances in irrigation technology, etc.

The Spanish National Hydrologic Plan (2001) introduces deep changes in water management at national level with a decisive influence in the Eastern-Mancha aquifer. The main innovations include the transfer of water from basin to basin, a new use of surface water, new government regulation of irrigation system, supporting increased irrigation efficien-

cy, etc. This new framework leads to significant evolution of the system in order to support these new scenarios of water policies, far more complex than the former.

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