Paper submitted for 13th IWRA World Water Congress 2008: "GLOBAL CHANGES and WATER RESOURCES: confronting the expanding and diversifying pressures"

1-4 September 2008, Montpellier, France

GROUNDWATER DEVELOPMENT AND WETLANDS PRESERVATION: ASSESSING THE IMPACT OF WATER CONSERVATION POLICIES

Irene Blanco* [(1)], Consuelo Varela-Ortega* and Guillermo Flichman**

** Department of Agricultural Economics, Polytechnic University of Madrid, Spain.*
*** International Center for Advanced Mediterranean Agronomic Studies (CIHEAM-IAMM), Montpellier, France*
(1) Corresponding author. Ciudad Universitaria. Avda. Complutense s/n. 28040, Madrid, Spain.
Tel.: (+34) 91 336 57 98; Fax: (+34) 91 336 57 97. E-mail address: irene.blanco@upm.es

Abstract

Groundwater in Spain, as in other arid or semiarid countries worldwide, has been intensely used for the expansion of irrigated agriculture. This booming development has induced a remarkable socioeconomic development in many rural areas but has produced far-reaching environmental problems. In the Spanish Western La Mancha Aquifer, the excessive, and sometimes illegal, water abstraction for irrigation agriculture has resulted in the Aquifer's overexploitation and has been responsible of the degradation of the associated wetlands "Tablas de Daimiel", an internationally reputed, Ramsar-nominated aquatic ecosystem. To undertake this analysis, an aggregated non-linear Mathematical Programming Model of constrained optimization has been built to simulate farmers' behaviour confronted to different policy scenarios (stakeholder-driven and policy-driven) under the uncertainty of climate and market variations. The policy simulations are namely the application of alternative water pricing schemes (uniform volumetric and block-rate water tariffs), the implementation of a water use quota system and the establishment of a water rights market. In all the simulated scenarios, it has been previously considered that all illegal wells have been legalized beforehand by paying an entry right fee. Results show that controlling illegal water mining is a necessary condition but it is not sufficient to recover the aquifer. Consequently, other measures will be necessary for an effective water management in this area. Among these, the block-rate water pricing scheme seems the most cost-effective system to reach the goal of aquifer sustainability but will entail important income losses in several farms. Therefore, we cannot conclude that a unique water conservation policy instrument will be the best overall solution for all types of holdings that will respond to efficiency as well as to equity considerations. It seems reasonable to make a combination of the tools proposed, even including additional measures that promote an environmental protection and develop sustainable agricultural systems.

Key words: ecosystem conservation, water policies, mathematical programming model, cost-effectiveness analysis.

1. Introduction

Groundwater in Spain, as in other arid or semiarid countries worldwide, has been intensely used for the expansion of irrigated agriculture due to its easy access, low cost of irrigation infrastructure and high farming profitability (Llamas and Martinez-Santos, 2006; Giordano and Villholth, 2007; Shah et al., 2007). This booming development has contributed significantly to stimulate the socioeconomic development and household food security in the rural areas. However, in many cases, the largely uncontrolled agricultural groundwater use has produced far-reaching environmental and social problems (water table depletion, groundwater quality degradation, destruction of associated wetlands and water ecosystem, proliferation of free-riding behaviors) (Schuyt 2005). This is an outstanding fact in several Spanish aquifers, in which groundwater is the primary water source for all uses, but it is specially remarkable in the Western La Mancha Aquifer, situated in the inland central region of Castilla-La Mancha in the Upper Guadiana river basin. In this area, the excessive, and sometimes illegal, water abstraction for irrigation agriculture has resulted in the Aquifer's overexploitation and has been responsible of the degradation of the associated wetlands of the national park "Tablas de Daimiel", an internationally reputed, Ramsar-nominated aquatic ecosystem of high ecological value (Varela-Ortega, 2007).

In the Western La Mancha Aquifer, as a consequence of the legal declaration of overexploitation in 1987, water authorities imposed in a typically top-down approach the constitution of groundwater use communities and the implementation of Water Abstraction Plans (WAP). These Plans forbid drilling new wells or deeper the existing ones, as well as limit the annual water abstractions depending on farm size by means of a quota system with no compensation. This program has been implemented without the agreement of the farmers who are the main stakeholders and has caused a strong social opposition. The nearly inexistent institutional arrangements between the regional government, water authorities and water users themselves, and the high enforcement cost of controlling water abstractions for agricultural irrigation have favored the proliferation of numerous illegal wells and the continuation of excessive water abstractions over the permitted volumes. Official sources estimate that nowadays near of the 50% of the existing extractions in the Western La Mancha Aquifer are not registered and the total aquifer abstractions exceeds the natural recharge rate of the aquifer at length, estimated to be 230 Hm^3 (CHG, 2007).

This situation is not sustainable and is against the spirit of the Water Framework Directive (WFD) (2000/60/EC), which proclaims the protection of water resources with the aim to achieve the "*good ecological status*" for all water bodies by 2015. In its article 9, the WFD proposes the implementation of water-pricing policies to provide by 2010 "*adequate incentive…to use water resources efficiently, and thereby contribute of the environmental objectives*" and establishes the principle of recovery of water services, including environmental and resources cost. In the case of groundwater, financial costs are fully recovered, but environmental costs are usually not reflected in the costs of water abstraction. Pricing methods may be efficient instruments to recover the full cost of the resource but their effectiveness will depend on the social acceptability and political feasibility (Rosegrant *et al.* 2002). Water-pricing policies and water use quota systems are some of the economic instruments most used in the management of water demand. However, several authors maintain that other policy options such as water markets may provide better water allocation efficiency than other regulatory approaches (see Easter *et al.*, 1998). In fact, the most recent researches in Common Pool Resources point out the resurgence of local level governance and institutional decentralization (Iglesias, 2002). Numerous works show how the apparent superiority of water markets is limited in real-world contexts, nevertheless, water trading mechanisms are become widely accepted in many countries (Rosegrant and Schleyer, 1996; Kemper 2002; Johansson *et al.*, 2002; Kemper *et al.* 2006; Garrido and Calatrava *in press*, among others).

In Spain, the 1999 amendments to the 1985 Water Act and the 2001 Law of the National Water Plan have strengthened the participation of the stakeholders in water institutions and have introduced the possibility to buy or sell water rights under a certain control of water authorities. Furthermore, this has been also reflected in the Special Plan for the Upper Guadiana (SPUG), launched in 2002 by the Spanish government with the aim to establish a sustainable use of water in this area (Annex I of the Spanish National Water Plan, 2001). The SPUG, recently approved in collaboration with the stakeholders (CHG, 2007), establishes important regulations to eliminate groundwater overdrafts and maintain the agrarian socio-economic structure in the Sub-Basin. The most innovative measure is the "Center of water rights exchange", a decentralized mechanism of water management.

In conclusion, the revision of the current water policies and the application of new cost-effective and environmentally sensitive policy instruments that guarantee effective public participation in water management processes, is one of the major tasks than have to be address by water managers and policy makers in Spain, and specially in the Upper Guadiana Basin.

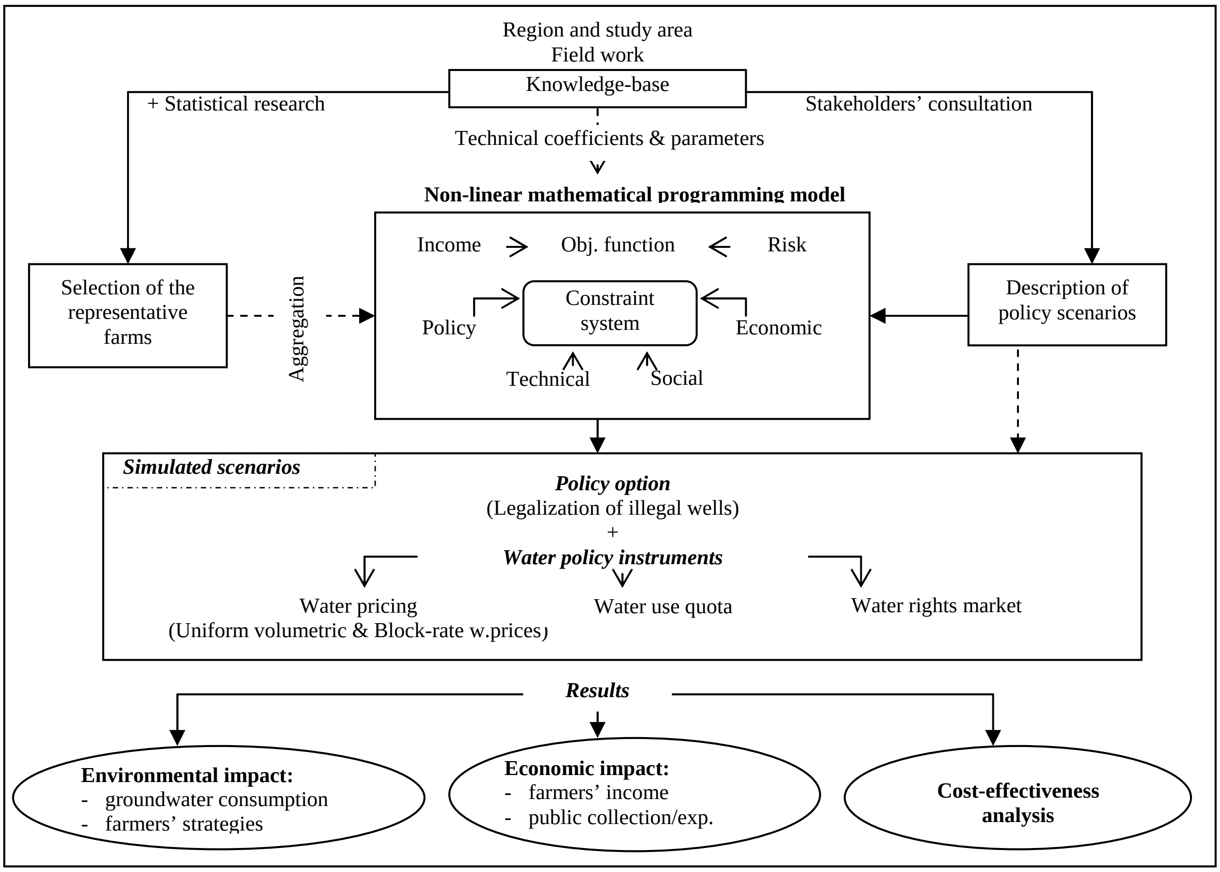
2. Objective of the research

In this context, the objective of this paper is to propose and analyze alternative water conservation policies that will attain a reduction in water consumption, compatible with the natural recharge rate of the Western La Mancha aquifer that will, ultimately, promote a sustainable groundwater management in the Upper Guadiana basin.

3. Methodological framework

The methodology can be summarized in the following scheme (see Figure 1).

Figure 1: Methodological scheme.



This analysis comprises the following parts:

(i) Elaboration of a knowledge-base supported by an ample field work and stakeholder consultation carried out between 2005 and 2007 in the EU funded NEWATER Project (farmers, irrigation community representatives, technical experts, river basin managers, regional government officials, environmental NGO's, farmers unions, private law firms);

(ii) Selection of the representative farms from an elaborated farm typology and irrigation associations' typology that represent the agricultural sector in the area;

(iii) Elaboration of an aggregated non-linear Mathematical Programming Model of constrained optimization built to simulate farmers' behavior under different water policy scenarios and risk situations as a result of climate as well as market prices variability. The MPM maximizes the regional expected utility, while keeping the specificity of the individual constraints (techniques, economic, social and political). This dual characteristic of the model permits the analysis at aggregated level (basin) as well as at disaggregated level (farm) and it complements previous modeling work carried out in the area of study;

(iv) Selection of simulated scenarios, both policy-driven and stakeholder-driven. They are namely the application of alternative water pricing schemes (uniform volumetric and block-rate water tariffs), the implementation of a water use quota system (water allotment rights) and the establishment of a water rights market. In all the simulated scenarios, it has been previously considered that all illegal wells have been legalized beforehand by paying an entry right fee;

(v) Cost-effectiveness analysis at different levels of aggregation: sub-basin level that is the aquifer perimeter and farm level, focusing on the two sides of the conflict (the "legal water abstractions" and the "illegal water abstractions"). A set of indicators has been used to represent the economic, social and environmental performances of irrigated systems.

Selection of the representative farms

The zone of study has been identified by two representative farm types (F1, F2), as show in Table 1. As excessive water abstraction from illegal pumping is one of the major problems in this area, farm types have been classified in two categories based on field work information and on the stakeholders' consultation process. One farm represents the legal irrigators (F1) that comply with the region's water abstraction quotas and a second farm (F2) represents the node of illegal water demand in the area (due to overpumping in registered wells or to the existence of non-registered wells).

Table 1: Aggregated representative farm types

Farm types	**Aggregated "legal" farm type F1**	**Aggregated "illegal" farm type F2**
Total surface (ha)	132,538	60,000
Average farm size	140	15
Irrigated surface (%)	60	80
Number of wells	16,719	22,917
Soil type (%)		
Bad sol	60	20
Good sol	40	80
Crop distribution (%)		
Barley	40.00	10.00
Wheat	15.19	10.00
Maize	1.00	-
Vegetables	13.15	38.50
Vineyard	25.00	40.00
Set-aside	5.66	1.50
Total area (%)	100	100
Surface weight (%)	69	31

***Source*:** Own elaboration based on official statistics (IES 2006; CHG, 2007) and farmers' surveys (2005-2007).

The model

The model used to carry out this analysis is a non-linear single-year static mathematical programming model (MPM) of constraint optimisation defined at regional scale (sub-basin aggregation). It optimizes the regional expected utility, as an aggregation of the expected utilities of the two farm types, while keeping the specificity of the individual constraints (techniques, economic, social and policy) (Buckwell *et al.* 1972, Deybe 1994, Abbas *et al.* 2005). The model was calibrated with the risk-aversion coefficient and validated using the PAD (Percent Absolute Deviation) parameter to verify the actual crop distribution in the area. PAD values range between 5.11 and 5.86 ranked in the upper limit of Hazell and Norton classification (Hazell and Norton, 1986).
Based on the mean-standard deviation analysis, the objective function of the model is:

$$MaxU = \sum_{f} \left(Z_{f} - \phi \cdot \sigma_{f} \right) \tag{1}$$

where U is the expected utility, Z_f the average net income by farm, ϕ the risk aversion coefficient and σ_f the standard deviation of the income distribution. Average farm income is calculated as follows:

$$Z_{f} = \sum_{c}\sum_{k}\sum_{r} gm_{c,k,r} \cdot X_{c,k,r,f} + md \cdot cp \cdot \sum_{c}\sum_{k}\sum_{r} sb_{c,r} \cdot X_{c,k,r,f} + md \cdot sfp_{f} \cdot numf_{f} \tag{2}$$
$$- oc \cdot \sum_{p} fla_{p,f} - hlp \cdot \sum_{p} hl_{p,f} - tpc_{f} - sirrg_{f} \cdot wtarif - well_{f} \cdot wellt$$

where $X_{c,k,r,f}$ are the decision-making variables representing the growing area by crop type (c) soil type (k), irrigation technique (r) and farm type (f); $gm_{c,k,r}$: gross margin; md modulation rate; cp coupling rate; $sb_{c,r}$ CAP aid ; sf_{pf} single farm payment; $numf_f$ number of farms; oc family labor opportunity cost; $fla_{p,f}$ family labor availability ; hlp wage for hired labor ; $hl_{p,f}$ hired labor ; tpc_f total abstraction costs ; $sirrg_f$ irrigated surface ; $wtarif$ water use tariff; $well_f$ number of registered wells; $wellt$ tax paid by well.

The standard deviation is generated by a set of states of nature defined by climate variability (crop yields) and market variability (crop prices) as follows:

$$\sigma_{f} = \left[\left(\sum_{sn}\sum_{sm} Z_{sn,sm,f} - Z \right)^{2} / N \right]^{1/2} \tag{3}$$

where $Z_{sn,sm,f}$ random income; N: combination of the different states of nature ($N=100$).

Land constraints:

$$\sum_{c}\sum_{r} X_{c,k,r,f} \leq surf_{k,f} \tag{4}$$
$$\sum_{c}\sum_{k}\sum_{ri} X_{c,k,ri,f} \leq sirrg_{f} \tag{5}$$

where $surf_{k,f}$ is available land, $sirrg_f$ potential irrigated surface

Labor constraints:

$$\sum_{c}\sum_{k}\sum_{r} lr_{c,r,p} \cdot X_{c,k,r,f} \leq fla_{p,f} + hl_{p,f} \tag{6}$$

where $lr_{c,r,p}$ is crop labor requirements; $fla_{p,f}$ family labor availability; $hl_{p,f}$ hired labor.

Water constraints (and some relevant hydrology equations):

$$\sum_{c}\sum_{k}\sum_{r} wr_{c,k,r} \cdot X_{c,k,r,f} \leq watera_{f} \tag{7}$$

where $wr_{ck,r}$ is crop water needs; $watera_f$ water availability.

$$tpc_{f} = \alpha_{f} \cdot \left(wc_{f} \right)^{2} + \beta_{f} \cdot wc_{f} + \delta_{f} \tag{8}$$

where tpc_f is total water abstraction costs; wc_f water consumption; σ_f, β_f, δ_f, coefficients of the polynomial function, which has been obtained with an econometric analysis from the experimental data collected in the field work.

Other policy relevant constraints: such as set aside requirements, cropping permits, etc.

Policy scenarios

The policy-driven scenarios are based on the public policies currently in force, such as the current CAP-2003 (applied in Spain with a 75% decoupling scheme) and the specific national water conservation policy applied in the Upper Guadiana basin that consists in a water quota regime (water abstraction plan) (CHG, 2006).

Along the knowledge-building experience of the NeWater project, the successive meetings and discussions with the stakeholders of the Guadiana basin have permitted the selection of other type of scenarios for this area. These stakeholder-driven scenarios reflect the stakeholders' opinions and concerns and have enriched substantially the prediction and simulation potential of the economic models. These relate to other types of policy-relevant instruments different form the ones currently in place, such as the legalization of the illegal irrigators, the adoption of water prices, the enforcement of a different area-based quota system and the establishment of a water rights' market. We can define the specific scenarios as follows:

1. Legalization of the illegal wells. All the illegal wells are legalized by paying an entry right fee of 6000 € per irrigated hectare (as reflected in the Special Water management Plan for the Upper Guadiana basin, CHG, 2007), (400 €/ha irrigated/year on a horizon of amortisation of 15 years). This value reflects two essential costs. On the one hand, the administrative cost paid by the legal farms since its creation (year 1985) and on the other hand, the opportunity cost of illegal water that was extracted during the last 15 years.
2. Uniform volumetric water pricing system, that is, a charge per volume applied measured as t €/m^3. We have considered a gradual increase of 0.009 €/m^3 in water price for fifteen price levels ($P_1, P_2, P_3 ... P_{15}$), starting from a value of 0 €/m^3 and ending in 0.126 €/ m^3.
3. Block-rate charge defined by a set of prices (t-t'' €/m^3) and quantities delivered (% of water allotment right) such as follows: (i) t, 0-33%; (ii) t', 33-66% ($t'>t$); (iii) t'', 66-100% ($t''>t'$).
4. Quota system: quotas are established according to the farms' irrigated surface to limit total water abstractions in the La Mancha aquifer compatible with its natural recharge rate set at 230 millions of m3 (CHG 2007).
5. Water rights market: a market exchange price is established using the dual values of the precedent simulation results of the quota system that assures water exchanges between water buyers and sellers. A transaction cost of 5% is considered.

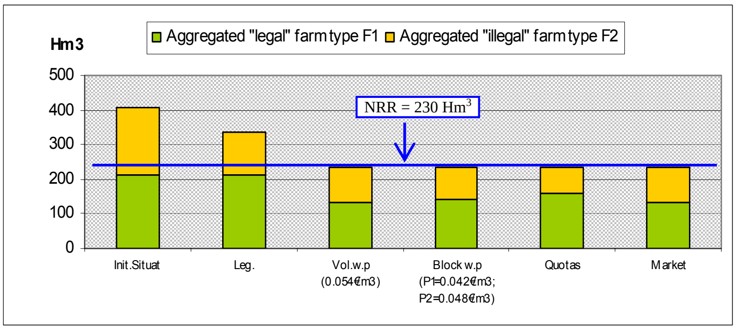
4. Results and discussion

4.1. The open access problem: policy option for legalizing the illegal wells

In the case of the Western La Mancha Aquifer, open access to ground water resources, free-riding and illegal drillings requires that all non-licensed wells should be legalized prior to establishing any other water conservation policy. As we have explained in the previous section, an entry fee of 6,000 € per hectare of irrigated land is charged.

Figure 2 shows the total water volume used with different policy options. According to official figures, simulations show that current water abstractions (407 million m3) exceed largely the maximum volume compatible with the sustainable management of the aquifer (213 million m3) (CHG, 2007).

Figure 2: Total water consumption with different policy options.



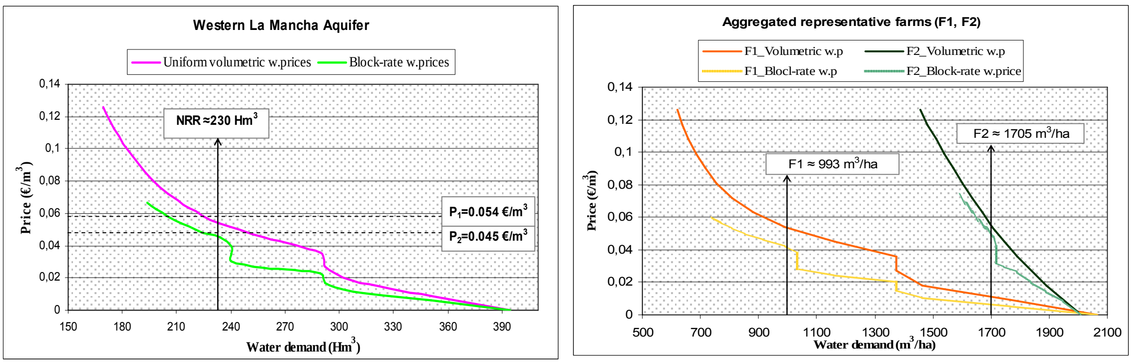
Aggregated results at sub-basin level (in figure 2) also indicate that controlling illegal water mining is a necessary condition but it is not sufficient to recover the aquifer. This policy option will contribute to reduce conflicts and social unrest among irrigators, establishing the basis for cooperation among economic agents, but this option will not decrease the volume of water extracted to the optimum desired level (230 Hm^3, which is the Natural Recharge Rate of the Western La Mancha Aquifer (NNR)). Consequently, other measures will be necessary for an effective water management in this area.

4.2. The role of water prices

Establishing water prices for recovering the costs of water services and inducing a more efficient water use, has been amply discussed in the literature (Johansson et al 2002; Rogers *et al.* 2002; Rosegrant *et al.* 2002, Tsur *et al.* 2004; Gomez-Limón and Riesgo 2004; Mejías *et al.*, 2004; Varela Ortega *et al.* 1998; Blanco and Varela 2007, among others). However, it has to be taken into account that technological as well as institutional and agronomic factors are binding and hence water demand tends to be inelastic at low price ranges. In consequence, volumetric pricing is often controversial and has limited application in real cases (de Fraiture and Perry 2002; Saleth and Dinar 2004).

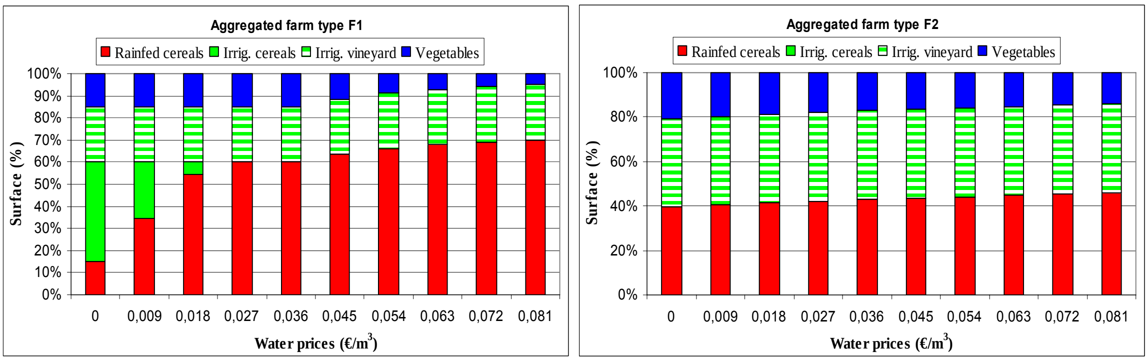
Figure 3 shows the results of the application of uniform volumetric and block-rate water prices on water demand in the Western La Mancha Aquifer. As we can see in this figure, the lower water demand curve corresponds in all cases to the block-rate water pricing system. These results indicate that to induce a reduction in water consumption of 30% close to the aquifer's sustainability target (NNR), higher prices are needed in the uniform volumetric system (0.054 €/m^3) than in the block-rate system (0.045 €/m^3). Furthermore, the uniform volumetric system produces a higher income loss than the block-rate pricing system but it also provides greater collections for the water agencies (Varela-Ortega *et al.*, 1998).

Figure 3: Water demand curves.



In both cases, the water demand responses are very different according to the farm analysed. The aggregated farm F2 shows a much more stressed inelastic trend than the aggregated farm F1. The introduction of progressive water prices induces farmers to change the production techniques and the irrigation systems, as well as to switch strategies to less water-intensive crops, leading to an extension of the growing study area. In the "aggregated farm" F2, these adaptative techniques are strongly limited due to their small size and low crop diversification. Figure 4 shows farmers' strategies at low-medium price rates when a uniform volumetric system is applied.

Figure 4: Farmers' cropping strategies with uniform volumetric water prices.



4.3. The implementation of a quota system

In the region of La Mancha, the quota system that we have simulated is set to meet the objective of attaining the aquifer's recharge, which is 233.8 Hm3 per year. This volume corresponds to the volume reached when applying a water price of 0.054 m3/ha (with a uniform volumetric system) (see section 4.2) and is distributed according to the area weights of each of the representative farms (see table 1), F1 (161.3 Hm^3, 1,217.61 m^3/ha) and F2 (72.5 Hm^3, 1,208.4 m^3/ha).

Table 3 in the next section shows that the application of this type of quota favours the larger more flexible farm (aggregated farm type F1), as farm income loss is barely 6% in comparison to the smaller farm (aggregated farm type F2) that looses 57% of its income gains. Revenue collection by the water Authority is high in this latter F2 farm (198 €/ha), former an 'illegal' irrigated farm, as it had to pay the legalization fee to enter the quota system. In comparison, the larger farm pays only a small charge to the Water Authority for each registered well (4.50 €/ha). Public expenditure refers to the CAP subsidies paid by the government that depend on the cropping pattern selected by each type of farm (more CAP subsidized crops entail higher government payments). Both farms receive equivalent amounts of subsidies.

4.4. Establishing a water right's market

The water rights market simulated in this research is defined by a system in which two agents (in this case, farms F1 and F2) are authorized to exchange their extractions rights, voluntarily negotiating the exchange conditions. The market is an intra-sectoral market (the agricultural sector), bound geographically to the area of the Western La Mancha aquifer and limited to exchange a maximum global water volume of 233.8 Hm^3 that corresponds to the aquifer's annual recharge rate. This upper limit guarantees that the WFD condition of aquifer's protection is met. The quotas assigned for farms F1 and F2 in the previous section (161.38 and 72.5 Hm^3 respectively), are the initial water endowments for each farm, that is, their water property rights to enter the market.

The dual water values obtained when a quota system is applied, delimit the potential exchange price interval. As shown in Table 2, price rates between 0.04 y 0.15 €/m^3 will induce a market exchange as global utility increases. The exchange price selected is 0.10 €/m^3. Table 3 shows the comparative effects of the different policy options on the private and public sectors (i.e farm income and net public expenditure).

Table 2: Water rights market whit potential exchange prices.

Price of the exchange (€/m^3)	Global utility gain regarding the water quota system (thousand of €)	Utility gain per farm regarding water quota system (thousand of €)		Water rights market	
		F1	F2	Theoretical	Real
0.04-0.05					
0.05	+1,896	-4	+1,901	YES	NO: F1 leaves the market
0.06-0.11					
0.06	+1,882	+273	+1,608	YES	YES
0.11	+1,810	+1,630	+179	YES	YES
0.12-0.15					
0.12	+1,795	+1,895	-100	YES	NO: F2 leaves the market

Table 3: Effects on the private and public sectors of the application of different policy options in the two representative farms of the western La Mancha aquifer.

Policies	**Farmers' income (€/ha)**		**Public revenue (€/ha)**		**Public expenditure (€/ha)**		**Net public expenditure (€/ha)**	
	F1	F2	F1	F2	F1	F2	F1	F2
Baseline	607.72	1,268.51	4.50	-	102.68	27.29	98.18	27.29
Uniform v.w.p	460.46	583.77	58.17	321.66	90.22	60.29	32.05	- 261.37
Block-rate w.p	471.92	594.45	46.71	310.98	90.22	60.29	43.51	-250.68
Quota system	568.75	541.38	4.50	197.92	85.27	70.98	80.77	-126.94
Water market	536.78	624.64	4.50	228.30	90.03	60.70	85.53	-167.60

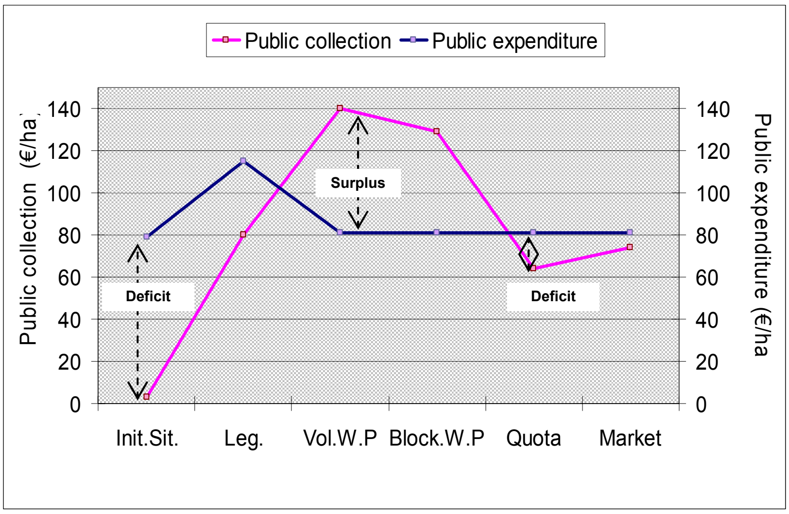
Results indicate that the aggregated large farm F1 (former legal) sells 28.7 Hm^3 to the aggregated small farm F2 (former illegal). Water consumption, once the transaction is finished, is 132.68 Hm^3 (1,002 m^3/ha) for farm F1 and 101.12 Hm^3 (1,685.3 m^3/ha) for farm F2. These values are quite close to the ones obtained when pricing policies are applied and correspond to similar crop mix adaptation strategies followed by the farmers.

Comparing the three types of policy instruments, when a water market is established, the effects on farm profitability vary across farm types. In general, as shown in table 3, a water market favours the small intensive water-buyer farm F2. Although income loss is considerably high (51%) (1,268.51 to 624.64 €/ha) when this farm enters the market and buys water, this loss is smaller than in the case of the other types of instruments. Conversely, in the large farm F1, a net water seller, income decreases by 11.67%, a larger reduction than in the case of a quota system (6.4%) but lower than in the case of the application of water pricing policies (24.2% and 22.3%, with a uniform volumetric and a block-rate systems respectively). Although this farm collects the proceeds from selling water, it has to pay the transaction costs entailed by the market operation that are estimated at 5% of total receipts. Public expenditure relative to CAP aids is equivalent in the market system to the other types of instruments, but the net government revenue collected is smaller. As shown in table 3, net public expenditure for farm F1 (85.53 €/ha) is the highest of all management instruments analyzed. These results evidence that neither a market system nor a water pricing system produce similar effects in all types of farms and that the selection of the most cost-effective water management instrument (in accordance with the WFD) has to take into account institutional and structural factors as well.

4.5. Cost-effectiveness of water policy options

Following Turner *et al.*, 2004 and other previous works of the authors, we have use cost-effectiveness analysis to identify the most cost-effective policy option for achieve the aquifer sustainability. We have compared the social net costs of the different simulated policy options that comply with the same objective of reducing the global water extractions of the aquifer to reach its sustainable recharge, estimated to be 230 Hm^3. Social net costs are the sum of the private costs and public costs related with each policy option (following Varela and Sumpsi, 1999; Seeman *et al.* 2006; Blanco 2007; Varela-Ortega, 2007). Private costs represent the net income loss to the farmers from the baseline scenario in each option. Public costs represent the net value of public expenditures (subsidies) and public collection (water tariffs, taxes, legalization fee) for each policy option. Figure 5 and Table 4 show the public costs and the net social cost for each policy option simulated in the study area.

Figure 5: Public cost of different water policies in the Western La Mancha Aquifer.



Results (summarized in table 4) indicate that the most cost-effective instrument is the block-rate water pricing system (ranked 1) because it allows reaching the objective with the lowest social cost (179.51 €/ha). The uniform volumetric water pricing system (ranked 2) produces shyly a higher social cost (179.71 €/ha). The water rights market policy is ranked in third position (social cost of 180.25) but it entails the lowest private cost (249.71 €/ha). Finally, the water use quota system is ranked in forth position. This management instrument produces the highest net social cost (193.57 €/ha) and the lowest public benefits (60.08 €/ha).

Table 4: Net social cost of the water policies simulated in the Western La Mancha aquifer.

Index	**Water policy option**			
	Uniform V.w.p (P=0.054 €/m^3)	**Block-Rate w.p** (P'=0.045 €/m^3)	**Water use quotas**	**Water rights market**
Private cost (€/ha)	315.25	303.82	253.66	249.71
Public cost (€/ha)	-135.54	-124.31	-60.08	-69.46
Net social cost (€/ha)	179.71	179.51	193.57	180.25
Range	**2**	**1**	**4**	**3**

5. Conclusions and policy recommendations

- Controlling illegal water mining (i.e. legalizing illegals) is a necessary condition but it is not sufficient to recover the aquifer. Complementary policies for water conservation have to be put in place.
- Aggregated results show that overall cost-effectiveness is not substantially different across policy options, ranking for a maximum of 194 €/ha in the quota system to 179 €/ha for the block-rate tariff. However, there are important differences between private and public costs:
    - Water pricing policies (ranked 1 and 2) are the most cost-effective system to reach the goal of aquifer's sustainability. Yet, they will entail important income losses to small farms with less flexible cropping patterns (such as vineyards) and could therefore put at risk their viability.
    - On the contrary, the quota system (ranked 4) has the highest social cost but induces lower income losses to the farmers.
    - The w. rights market has the lowest private cost but higher public costs. Its cost-effectiveness is ranked medium (ranked 3) casting doubts about the potential of this type of water market for achieving an efficient assignment of water resources. This can be explained because a perfect market requires that a certain number of important hypothesis be respected, which is not the case in our model (second rank solutions): (a) the initial property rights distribution is not neutral, since farm F2 have paid a legalisation price to enter the market; (b) buyers and sellers are not numerous, with only one buyer (farm F1) and only one seller (farm F2); (c) transaction costs could have been included in the model and their effect could be larger than expected. Several authors have also indicated that attaining first-best allocations via markets alone are unlikely (Ahmed and Sampath, 1988; Rosegrant and Schleyer, 1996; Easter and Feder, 1998).
- Therefore, we cannot conclude that a unique water conservation policy instrument will be the best overall solution for all types of holdings and farmers that will respond to efficiency as well as to equity considerations (similar results were obtained by Johansson *et al.*, 2002 and Tsur *et al.*, 2003 among others). The choice of a political instrument will require the carrying out of additional studies where other criteria, not considered in this research, should be taken into consideration, such as long term recurrent costs, agreement of users, institutional capacity (administration, monitoring and enforcement) and the transaction costs related to the implementation of the selected policy measures.
- Along these lines, it seems reasonable to make a combination of the proposed tools, such as water pricing plus the establishment of a quota system, and also, it would be very advisable for the region of the Upper Guadiana Basin to promote the integration of agricultural policies and water policies to develop sustainable agricultural systems (cross compliance measures) and the protection of water bodies according to the principles of the WFD and the new CAP.

Acknowledgements

This paper has been based on the work developed for the CIHEAM MSc at the Mediterranean Agronomic Institute of Montpellier (IAMM), in collaboration with the Polytechnique University of Madrid (UPM) and within the framework of the EU project NeWater (New Approaches to Adaptive Water Management under Uncertainty) (nº: FP6-2003-GLOBAL-2-SUSTDEV-6.3.2 – 511179-2) (2005-2009). The authors wish to acknowledge the EU project NEWATER, and Caja Madrid Foundation for providing research funds for this study.

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