Cost-Effectiveness of Water Conservation Measures: A Multi-level Analysis with Policy Implications

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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, a mathematical programming model has been developed to simulate farmers' behaviour and their responses to different water policy scenarios. Specifically, the policy simulations selected are: alternative water pricing schemes (uniform volumetric and block-rate water tariffs), water use quota systems and water rights market. 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.**

Keywords— **Environmental degradation, water policies, cost-effectiveness analysis.**

I. 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 [1][2][3].

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) [4][5]. 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.

II. 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.

III. METHODOLOGICAL FRAMEWORK

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

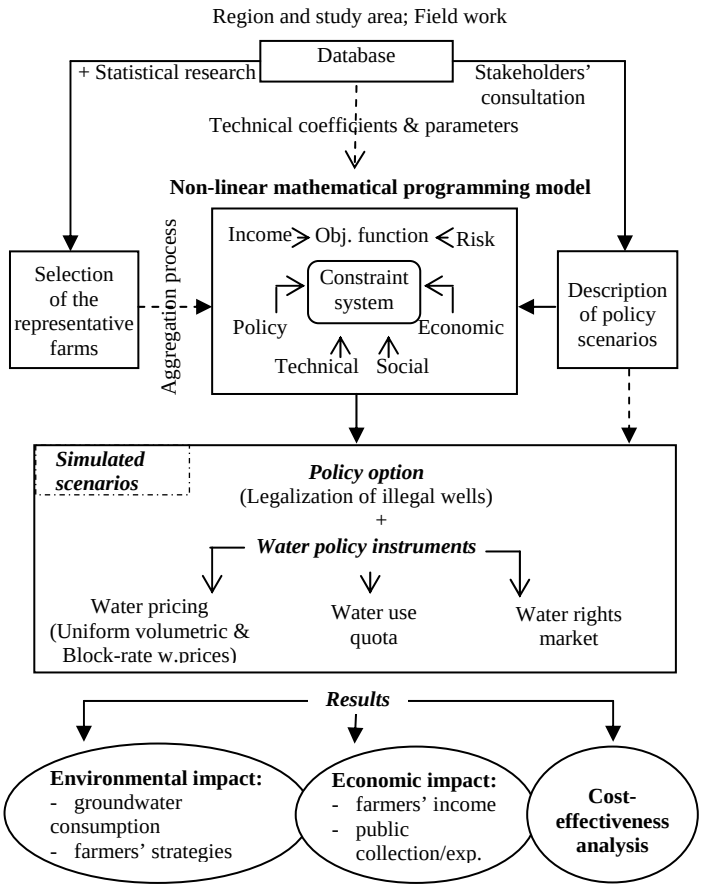


Fig. 1 Methodological scheme

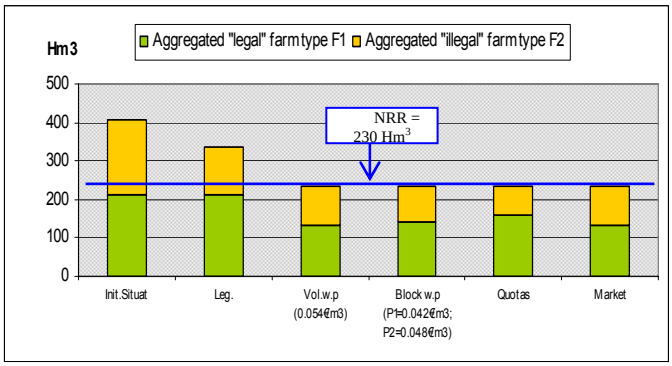
This analysis comprises the following parts:

1. Elaboration of a database supported by an ample field work carried out between 2005 and 2007 in the region that consists in formal and informal surveys and interviews to the main stakeholders involved.
2. Selection of the representative farms from an elaborated farm typology and irrigation associations' typology that represent the agricultural sector in the area.
3. 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;
4. Selection of simulated scenarios, both policy-driven and stakeholder-driven. They are namely the implementation of the on-going national water use quota system (water allotment rights), the application of alternative water pricing schemes (uniform volumetric and block-rate water tariffs), and the establishment of a water rights market. In all the simulated scanarios, it has been previously considered that all illegal wells have been legalized beforehand by paying an entry right fee;
5. 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.

IV. RESULTS AND DISCUSSION

Results (in figure 2) show 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)).



NRR: Natural Recharge Rate of the Western La Mancha Aquifer.

Fig. 2 Total water consumption with different policy options

Consequently, other measures will be necessary for an effective water management in this area. 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. The 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 than in the block-rate system. Indeed, 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 [6][7]. 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.

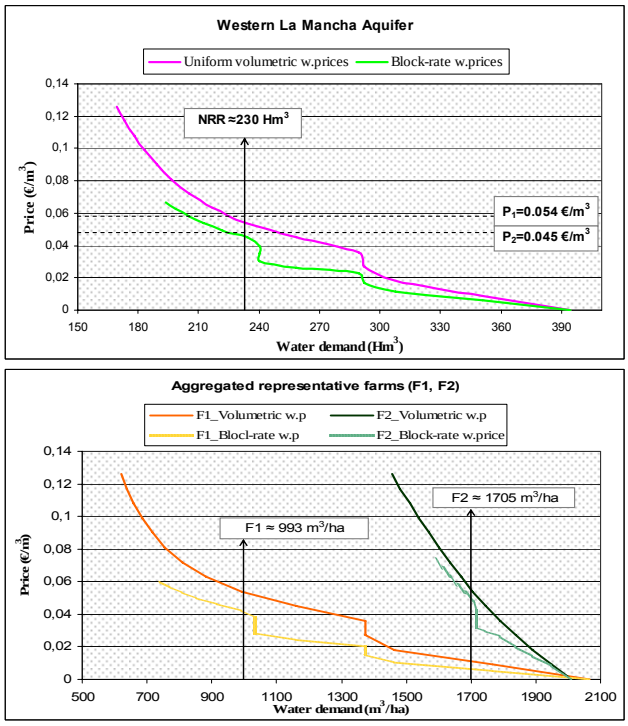


Fig. 3 Water demand curves

A quota use system and a water rights market have been also simulated to meet the objective of attaining the aquifer's recharge. Following [8] and other previous works of the authors [3][9][10], we have use cost-effectiveness analysis to identify the most cost-effective policy option for achieve the aquifer sustainability. Results (summarized in table 1) 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 1 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

V. 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. However, there are important differences between private and public costs: water tariffs are the most cost-effective system but entails important income losses to small farms; the quota system 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 casting doubts about the potential of this type of water market (non-perfect market).
- 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, policy enforcement capacity and level of social acceptance.
- Along these lines, it seems 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.

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