Assessing Water Policies and Farmers' Vulnerability in Groundwater Irrigation Systems

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1. Rural livelihoods vs. wetland conservation in the Upper Guadiana: policy context

Increasing competition for water resources is becoming a major social, economic and environmental problem in many arid and semiarid regions worldwide. Spain is the most arid country in Europe and water use as well as water depletion and environmental degradation have slowly become a matter of social concern.

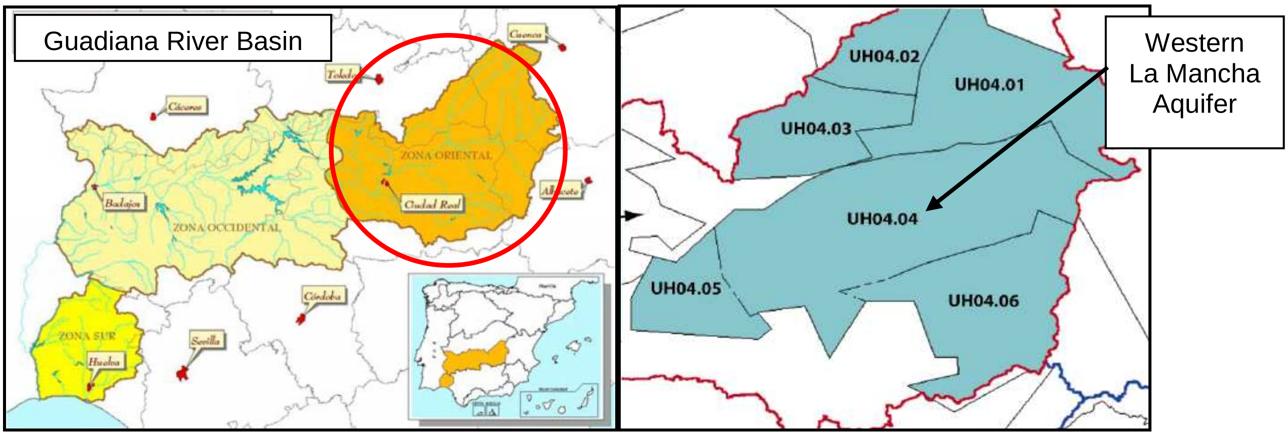
In the Upper Guadiana basin (UGB), situated in the southern central plateau of Spain, groundwater has been the major driver for developing irrigated agriculture and hence for sustaining thriving rural livelihoods. In the last decades, the ever-mounting expansion of groundwater irrigated agriculture has been fostered by yield-based Common Agricultural Policy (CAP) programs, the development of modern hydrology and irrigation technologies and private initiative (Varela-Ortega, 2007a, Llamas and Martinez-Santos, 2006). However, the great irrigation development in the area led to the overexploitation of the Western La Mancha aquifer and provoked the degradation of the highly valuable Ramsar-catalogued wetlands of the National Park of Las Tablas de Daimiel.

This conflict “agriculture development-nature conservation” resulted in intense social conflicts among farmers, environmental NGOs, regional administration departments (agriculture and environment) and the River Basin Authority. This posed a difficult challenge to the Water Administration which had to reach two confronted objectives: 1) the good ecological status of all water bodies (EU Water Framework Directive) and 2) the satisfaction of water demands to maintain rural livelihoods.

For this purpose a Water Management Regime (Water Abstraction Plan) was launched in the area during the early 90’s to recover the over-drafted aquifer, restricted water extractions and re-defined the previously established water allotment rights of the private irrigators by reducing substantially their entitled water assignments, to annual maximum levels of water consumption depending on farm size. Farmers are not granted any compensation payments for their derived income loss and, hence, the social burden of the policy is supported directly by the farmers. Thus, strong opposition has arisen from situated irrigators, and the Spanish authorities have not been capable of fully developing the water use limitation policy. As a result, high enforcement costs have contributed to a limited uptake of the policy and to the continuation of excessive water mining above the legally permitted levels.

In this conflicting environment water managers and policy makers are proclaiming the need for adaptive water management policies. These policies, reflected in the newly enacted Special Plan for the Upper Guadiana (SPUG) (CHG, 2007), seek to promote environmental sustainability through the elimination of groundwater overdrafts and to maintain the rural and agrarian socio-economic structure by launching special complementary rural development programs, in which an assessment of farmers vulnerability is crucial for the programme's success.

Map 1: Area of study – The Western La Mancha aquifer (5500 squared km and 140000 ha of irrigated surface)



Source: Own elaboration from CHG (2007), Llamas and Martínez-Santos (2005) and IGME (1999)

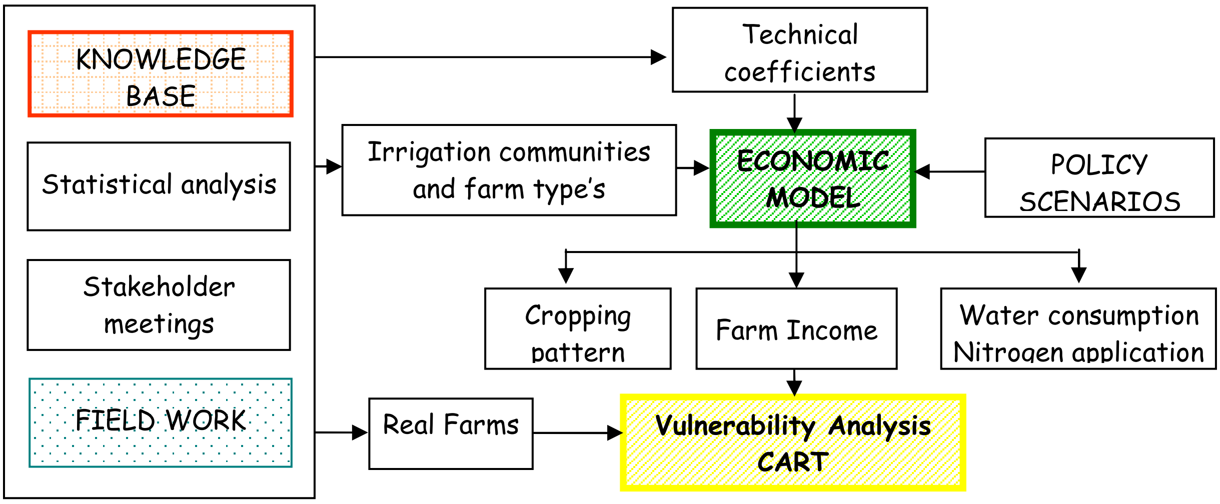
2. Methodological framework: integrating agro-economic and vulnerability analyses

In this conflicting environment, the aim of this research is to contribute to explore the different management options, existing or suggested, in the UGB by assessing the economic and land use impacts and focusing on the vulnerability of the private agrarian sector to water conservation policies.

The research will focus in the analysis and understanding of how different water management options affect different farmers, farm types, crop mix and technologies. How vulnerable different farmers will be to these policies, how they will cope with them and how the policy enforcement capacity of the water authority affects the different types of farmers (legal and illegal drillings) are also some of the main questions in our analysis.

The methodology developed for this research is summarized in Figure 1 and is based on the integration of quantitative and qualitative aspects that allows obtaining richer and more ample results.

Figure 1: Methodological framework integrating agro-economic model and vulnerability assessment



The methodology comprises a sequence of analyses divided into three blocks. Block (a) is the baseline analysis, bock (b) is the economic modelling and block (c) is the vulnerability analysis and AWRM policy analysis. The blocks are explained as follows:

(a) ***Baseline Analysis:*** Elaboration of a data and information base supported by ample field work and expert consultations carried out in the area of study, stakeholder meetings, interviews and statistical analysis (Sorisi, 2006, Varela-Ortega et al 2006).

A farm typology for five Irrigation Communities (Water User Associations) was constructed to characterize the agricultural systems, modes of production and cropping selection of the area of study. The selected representative farms correspond to five Irrigation Communities of the UGB and are described in Table 1. The five farms represent the variety of different farms in the aquifer in terms of size and crop diversification. Thus, the set of 25 real farms of the field work data base are represented by one of the representative farm types. This fact is very relevant as for the vulnerability analysis real farms are needed.

Table 1: Selected farm types and irrigation communities (IC)

Farm	IC	Surface (has)	Level of coverage in the IC (% of area)	Level of coverage in the sub-region of La Mancha (% of area)	Cropping patterns
F1	Alcázar de San Juan	150	40	51	43% Rain fed / 37% Extensive irrigated Crops / 20% Horticulture
F2	Daimiel	70	16	51	10% Rain fed / 57% Extensive irrigated Crops / 33% Horticulture
F3	Herencia	19	22	20	10% Rain fed / 74% Extensive irrigated Crops / 16% Horticulture
F4	Manzanares	40	19	23	5% Rain fed / 24% Extensive irrigated Crops / 31% Horticulture / 40% Vineyard
F5	Tomelloso	45	29	23	11% Rain fed / 89% Vineyard

(b) Agro-Economic analysis: To analyze the impact of the application of water conservation polices in irrigated agriculture of the area of study we have developed an ***agro-economic model*** that describes the behavior of the farmers confronted with water conservation policies (quota system or tariffs) and agricultural policies (new CAP programs). The model is a farm-based non-linear single-period mathematical programming model (MPM) of constrained optimization that is based in previous works by the authors. It incorporates risk parameters and maximizes a utility function (U) subject to technical, economic and policy constraints.

The model can be summarized as follows:

Maximize $U = f(x)$, $f(x) = Z-R$

Subject to the following constraints (land, labour, water, policy…): $g(x) \in S_1$,

$$x \in S_2$$

The objective function maximizes a utility function defined by a gross margin (Z) and a risk vector, which depends on the risk aversion coefficient and the sum of the standard deviations of Z as a function of different states of nature that consider climate as well as market prices variability. In this model, “x” is the vector of the decision-making variables or vector of the activities defined by a given crop-growing area and by an associated production technique, irrigation method and soil type (S). The problem-solving instrument used is GAMS (General Algebraic Modeling System). The technical coefficients and parameters of the model were obtained from field work and interviews with stakeholders. The model was duly calibrated and validated, using the risk aversion coefficient as calibration parameter and the comparative data on crop distribution, land and labor parameters in the study area.

The water policy scenarios simulated include:

(i) The current official Water Abstraction Plan (WAP) defined by different levels of water quotas dependent on farm size. The average quota is 1700 m^3/ha, ranging from a maximum of 2640 m^3/ha (for farms under 30has) to 1000 m^3/ha (for vineyards).

(ii) The actual water volumes consumed in the farms, obtained in the field work for each of the farms in the study region

(iii) The historical water quotas granted to the irrigators that were equally distributed at 4270 m^3/ha.

(iv) A volumetric water tariff of 0.08 €/m^3, which would produce a water consumption similar to the aquifer natural recharge rate.

Simulations of the policy scenarios in the MPM have been carried out for the set of five representative farms and for a set of 25 real farms that allows a complete array of differential results used in the farms vulnerability analysis of the following stage of the methodology.

(c) Vulnerability analysis: The results of the economic model are used as inputs for the vulnerability assessment, as well as the stakeholder-driven drivers and indicators of vulnerability of the different farm types that were obtained from the stakeholder analysis (baseline analysis).

The vulnerability analysis is divided into two phases:

1. Determination of farm's vulnerability (for each real farm) according to two different farm income variables.
2. Once the farms vulnerability is determined, there is a classification process which will highlight the main variables which determine farmer's vulnerability in terms of income loss. The identification of these variables will be very much useful for policy development and prioritizing actions.

Vulnerability is defined by two types of indicators corresponding to two different farm income variables: (i) farm income loss measured as the percent loss of farm income when water availability decreases and (ii) the percent deviation of total income gained in the farm from the minimum income that will allow the farm to continue operating (calculated from the official 2007 minimum inter-professional annual wage rate in Spain that amounts to 7988.4 €/year), that is, the threshold for economic viability. These two measurements were considered to capture the relative and absolute income loss that water stress conditions inflict to the different farm types and, hence, their capacity to continue operating above the economic viability threshold in water-scarce policy scenarios.

Measuring economic vulnerability by means of relative and absolute income loss has been used in the literature mainly in economic analysis, stressing the fact that it is one of the many facets of vulnerability (Coudouel and Hentschel, 2000). As vulnerability is dependent to access to production inputs, such as land, water , labor and technologies, comparable quantitative measurements, such as income variability, provide relative comparisons aw well as absolute thresholds (sometimes called poverty profiles) that can provide information to policy makers to identify economic viability of the different individuals and their characteristics (Alwang et al. 2001).

The prediction variables include structural parameters such as farm size and irrigated land, agronomic indicators such as crop mix, farming techniques and irrigation technologies, water consumption decisions such as overpumping rate and institutional factors such as policy enforcement capacity. This last indicator reflects the capacity that the Water Authority has to enforce the water abstraction plan in the area and consequently the ability that irrigators will have to engage in free-riding behaviour and pump more water than the permitted volumes.

The two indicators of income loss are used to classify the farms in four vulnerability classes: extreme, very high, high and medium (see

Table ***2***), and the criteria followed to classify farms into the four vulnerability classes are shown in

Table 3. This classification is an input for the farm vulnerability analysis (following Downing, et al. 2001, see also Downing et al. 2006) based on the farms' principal characteristics using the CART method (Classification and Regression Trees, Steinberg and Colla, 2007; see Stephen and Downing 2001 for a review of vulnerability methods including CART).

Table 2: Vulnerability prediction variables

Objective variable	Indicator	Prediction variables
Vulnerability	Rate of Income loss (%) Rate of actual Farm Income to minimum survival income (%)	Farm size (ha.)
		Crops diversification (number of major crops)
		Irrigated Area (%)
		Permanent crops in the farm (yes/no)
		Over pumping (%)
		Water policy enforcement impact (index)

Table 3: Criteria for the determination of vulnerability levels

Indicator Category	Criteria	Level of vulnerability
Difference from m.s.i.	<= 50%	EXTREME
Income loss	> 50%	VERY HIGH
Income loss	35- 50%	HIGH
Income loss	< 35%	MEDIUM

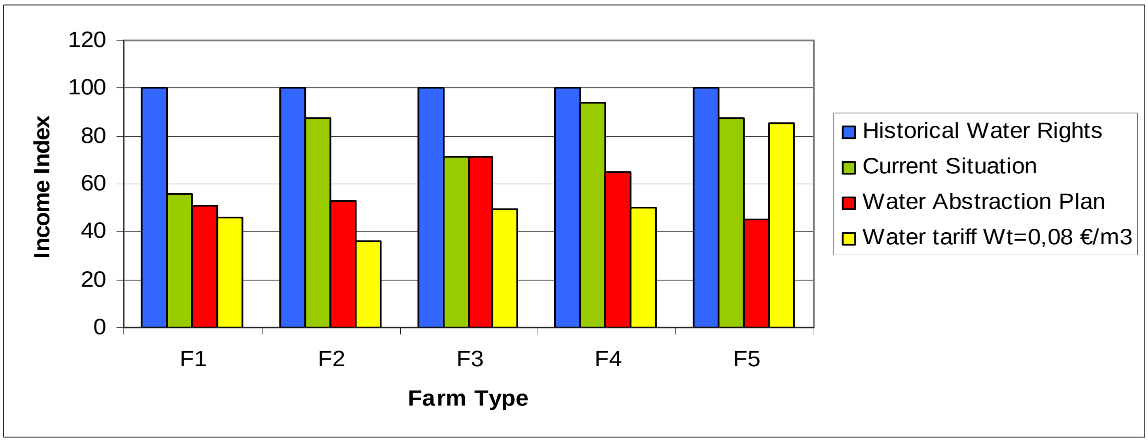
Farm classification tree and policy analysis: Finally, the analysis of the of the vulnerability classification tree elaborates the differential impacts that water conservation policies (i.e. different levels of water quotas with no compensation) as well as the policy enforcement capacity of the river basin authority will have on the irrigation sector of the UGB. Hence, this analysis permits prediction of which farm types will be more responsive to the new Special Plan of the Upper Guadiana basin, which farms will need specific targeted programs and which farms will be more vulnerable to periods of water scarcity, drought spells and other economic stresses.

3. Results and discussion

Results of the economic model: quotas vs. tariffs

The simulation results are shown in Figure 2 that depicts the impact of the application of different water policy scenarios on farm income in the five representative farms (Table 1).

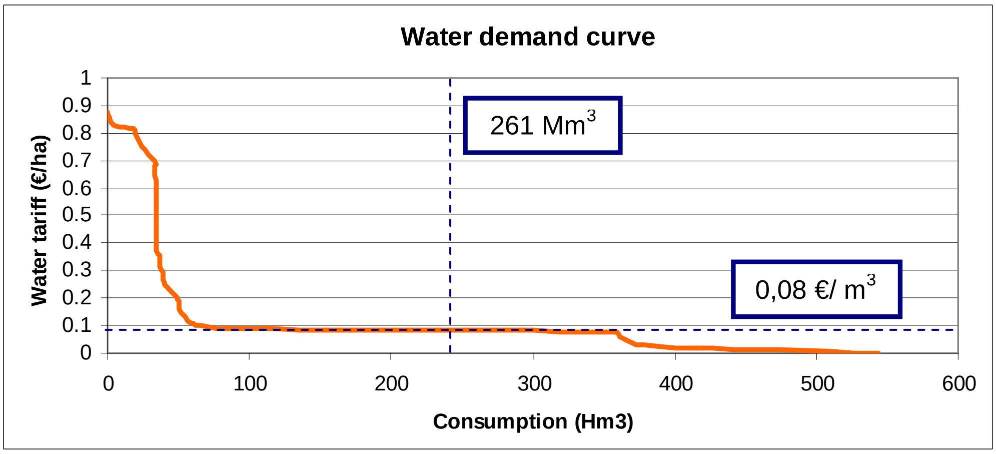
Figure 2: Effect of the application of Water Policies on farm income across farm types



The WAP induces a decrease in water consumption in all farm types relative to the historical water rights and the current situation. Complying with the WAP provokes substantial **farm income losses** to all farms. However, as shown in Figure 2 below, bigger farms with a high percentage of irrigated area face higher income losses (F1), as water quotas are proportionally lower in larger farms. Income loss is especially acute in small non-diversified farms, such as vineyard groves (F5) that have a very small adaptive capacity to water stress conditions. However comparing total farm income with respect to the minimum survival income level, small farms have a larger income loss and farms that feature a rigid cropping pattern, such as vineyards (F5), are prone to abandon irrigated production.

The simulation of a water tariff as an alternative policy instrument let us analyze the adequateness of the water quotas system as the instrument chosen to recover the aquifer and rationalize water use. The tariff simulated is a volumetric water tariff which corresponds to the tariff leading to water consumption close to 230 Mm^3, the natural recharge rate of the aquifer and the objective of the WAP, and is equal to 0.08 €/m^3.

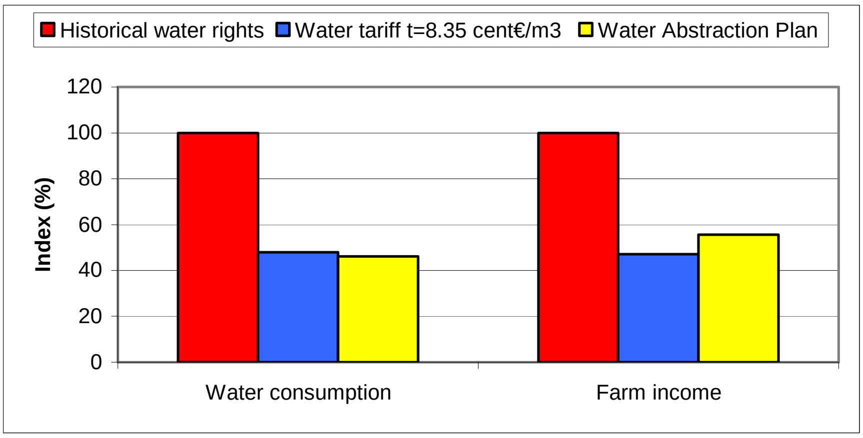
Figure 3: Water consumption in the aquifer at different tariff levels (water demand curve)



The impact of the water tariff is highly different among different farm types. We can observe (Figure 2) that for most farms the water tariff leads to severe income losses. Only the representative farm F5 obtains higher farm income under this policy. This reveals the high added value of irrigated vineyards such as farm F5, and this must be considered when designing this type of policies.

In aggregated terms (Figure 4), we can see that for very similar water consumption income loss for farmers is larger with the application of this water tariff. However we must not forget that water tariffs produces revenues to the water users associations that can be used for improving infrastructures or for financing accompanying measures.

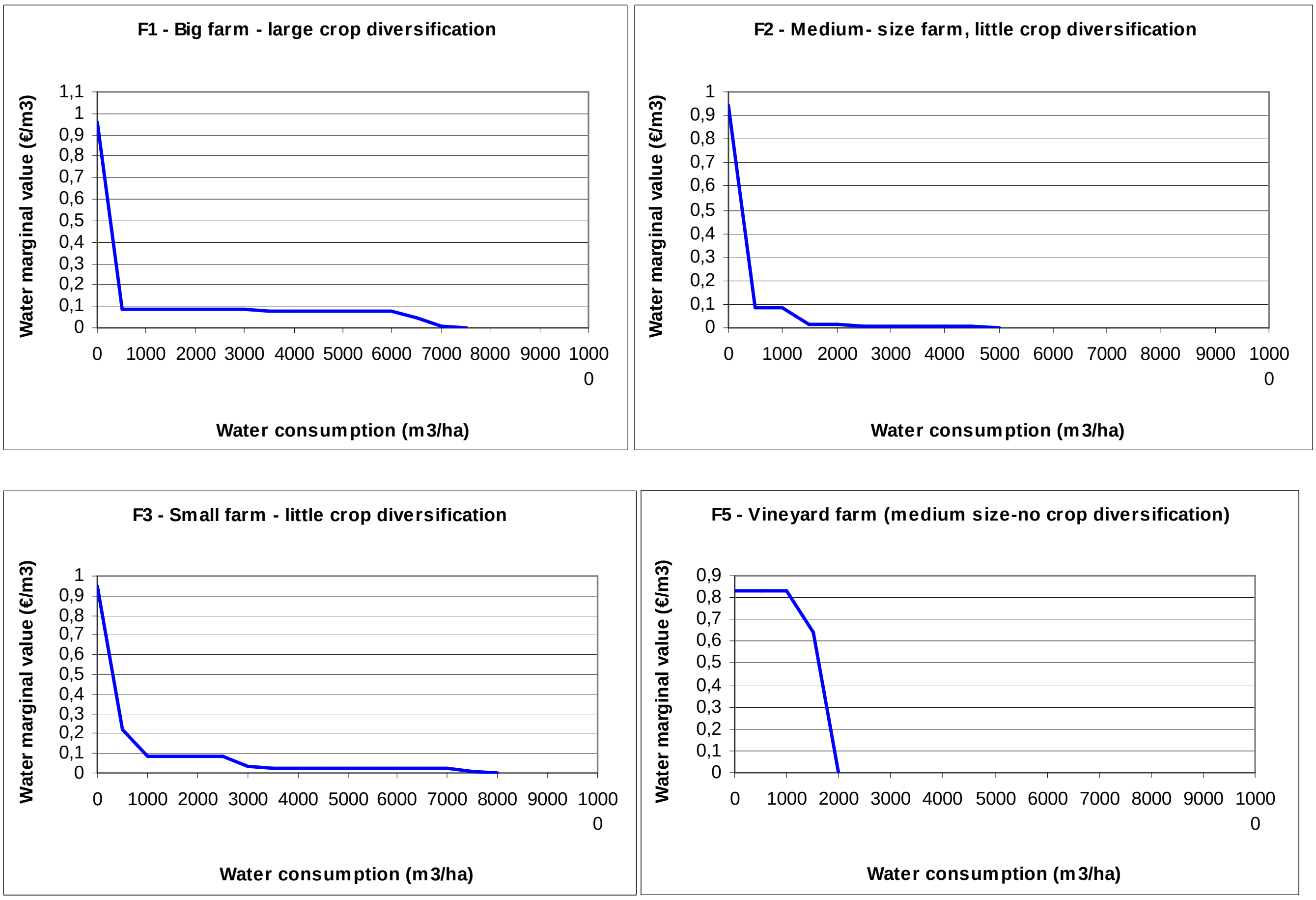
Figure 4: Water consumption and farm income under different policy options (aquifer level)



The adaptive capacity that farms have to different volumes of water can be analyzed looking at the **water dual values** in the model results. Using marginal values of water to assess the impact of water conservation policies has been discussed extensively in the literature as average values can be ambiguous or misleading (Johansson et al, 2002, Turner et al 2004, Hanemann 2006, among others).

Figure 5 shows the dual values of water for different levels of water availability across farm types obtained in the model simulations. The 'water demand curves' constructed using water dual values show that farm types have distinctive adaptive capacity to water availability. This is reflected in their comparative ability to adjust their cropping patterns, technologies and farming operations. We can see that medium-size farm F2, that grows annual cash crops has a high short-term adaptive capacity as it will operate with 5000 m3 per ha, as compared to its smaller counterpart F4 that, due to size limitations, requires a larger volume of water (7500 m3 per ha) . In contrast, the small vineyard farm F5 is highly adapted to lower water volumes (2000 m3 per ha) due to the use of efficient irrigation technologies such as drip irrigation, widely used in vine groves in the area.

Figure 5: Dual values of water across farm types from different levels of water availability



Results of the vulnerability analysis:

A key explanatory variable for assessing vulnerability is the water policy enforcement impact. This indicator reflects farmers' response to water shortage and illegal behaviour to minimize vulnerability to water stress conditions. Based on the Stakeholder consultations and meetings we can conclude that there is an inverse relationship between the policy enforcement capacity of the water authority to strictly apply the Water Abstraction Plan and the level of vulnerability of the legal irrigated farms. A farm that operates under legal provisions and complies with the granted volumes of the WAP, will be more vulnerable the lower the capacity of the Water Authority to enforce the quota system of the WAP. If the WA is incapable to enforce the WAP quotas, illegal drillings and abstractions will take place and thus legal irrigators will be penalized as they will be granted smaller water volumes in the following periods to recover the exhausted aquifer.

The water policy enforcement level for the vulnerability analysis has been calculated based on the overpumping data of 40% reported in 2006 by the Guadiana RBA (total abstractions = 355Mm^3; policy target = 214Mm^3) (CHG, 2006). Based on this, we consider the policy enforcement level in the UGB is low. The impact of this low water policy enforcement level is introduced in the analysis by an index (0 = positive impact; 1 = no impact; 2 = negative impact; 3 = very negative impact) determined through specific interviews with stakeholders who were asked to say how the actual enforcement level affects each type of farmer according to the abstraction level in the farm (legal or illegal farmers).

The dependent variable, farm income loss, has been calculated as the percentage reduction of total income when water allotments are reduced from the initial historical water volumes to the volumes established in the Water Abstraction Plan. As part of the actual water volumes consumed in the farms come, in some cases, by pumping more water than the permitted water volumes, current income has been calculated as a weighted average of two components. One that accounts for the farm income obtained with the official water allotments established in the WAP and the other that accounts for the extra water volumes used in the farm. The weight of each component corresponds to (1- β) and β, where β is the probability of having water consumptions over the permitted quota, and has been estimated by the current over pumping rate in the aquifer.

Table 4 shows the indicators for the vulnerability analysis for each of the 25 farms selected in our study region.

Table 4: Indicators for the vulnerability analysis

Farm	Vulnerability	% Income loss	Difference from minimum survival income (%)	Farm Size (ha)	Crop diversification	Permanent crops	Irrigated area (%)	Over pumping (%)	Water policy Enforcement Impact
E1_A1	EXTREME	201	13	17	3	YES	29	157	0
E2_A2	VERY HIGH	61	2604	550	5	NO	100	0	3
E3_A3	HIGH	47	976	150	3	NO	91	21	1
E4_A4	HIGH	44	3070	500	4	YES	100	111	0
E5_A5	VERY HIGH	55	1162	242	2	NO	100	0	3
E6_A6	VERY HIGH	57	5024	1200	7	YES	57	0	3
E7_A7	MEDIUM	33	51	19	3	NO	100	14	2
E8_A8	HIGH	47	1587	315	2	NO	84	32	1
E9_D1	HIGH	35	309	73	2	NO	49	65	0
E10_D2	VERY HIGH	55	455	68,5	3	YES	99	0	3
E11_D3	HIGH	45	736	130	6	YES	100	39	1
E12_D4	HIGH	37	510	65	4	YES	100	19	2
E13_H1	VERY HIGH	56	425	64	4	YES	100	0	3
E14_H2	MEDIUM	29	98	21	2	NO	100	0	3
E15_H3	VERY HIGH	50	279	55	4	YES	64	0	3
E16_H4	EXTREME	20	47	17	3	YES	59	75	0
E17_M1	VERY HIGH	52	1565	400	3	NO	75	21	1
E18_M2	MEDIUM	24	260	40	4	YES	100	97	0
E19_M3	HIGH	45	413	68	3	YES	100	1	2
E20_M4	VERY HIGH	48	359	77	1	NO	91	0	3
E21_T1	MEDIUM	22	1143	305	3	YES	34	55	0
E22_T2	HIGH	38	143	45	1	YES	89	48	1
E23_T3	HIGH	40	155	54	2	YES	93	50	1
E24_T4	HIGH	41	150	50	1	YES	100	50	1
E25_T5	HIGH	45	495	85	3	YES	100	8	2

Key: Farms are a sample from the irrigated communities (A, D, H, M and T) noted in Table 1. Vulnerability classes are as derived in Table 3

Figure 6: Real farms' profiles for different vulnerability levels

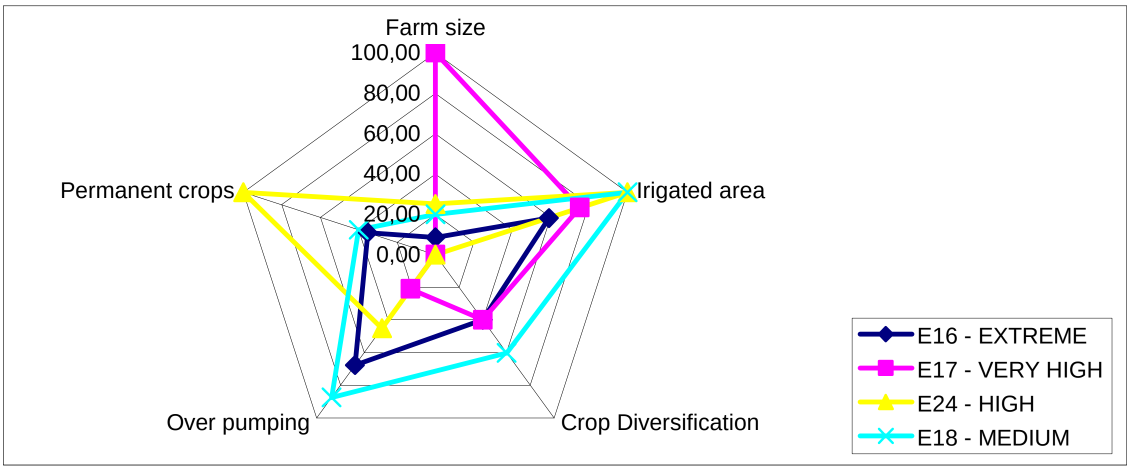


Figure 6 shows the farm profiles of four of the real farms, each of them with a different level of vulnerability. In this radar plot we can see how the different structural characteristics (farm size and permanent crops) and the different strategies (over pumping, irrigated area and crop diversification) lead to different vulnerability levels. Small farms, with little crop diversification and a low proportion of irrigated surface present extreme vulnerability (real farm E16). Large farms with a low level of over pumping (real farm E17) show a very high vulnerability level. The level of over pumping is a key variable for vulnerability classes. As we can see in the plot, the higher the level of over pumping the lower the vulnerability, except for farm E16, a small vineyard farm with almost null adaptive capacity that is extremely vulnerable.

Figure A 1 (in annex) shows the CART classification tree of the vulnerability analysis.

Farms are classified by vulnerability levels and results show that the main explanatory variables correspond to structural factors (farm size), behavioural factors (rate of over pumping) and institutional factors (policy enforcement impact index). In fact, structural parameters such as farm size play a major role, evidencing that economies of scale are present for some farm strata. Small farms of less than 20 ha are extremely vulnerable to water use limitations as medium-size and larger farms in the range of 20-30 ha have a medium vulnerability and show a greater adaptive capacity to water stress. However, this trend is reverted for larger holdings from 30 to 365 ha that are highly vulnerable farms and farms over 365 ha that present very high vulnerability, and the absence of economies of scales (amply discussed in the specialized literature) is evidenced for this farm strata.

In our analysis, farms in the medium-size range (that show a comparative lower vulnerability) that choose to overpump illegally to increase moderately their water volumes are more vulnerable than other farms that extract more water illegally. These farms choose to extract larger volumes of illegal water given the low policy enforcement capacity of the WA in the

UGB. If the policy enforcement capacity of the Water authority increases, this tendency is reversed as the risk related to overpumping will be higher, farmers will be more easily caught and penalized and the number of closed unregistered wells will increase.

4. Conclusions

- The analysis of vulnerability in water resource planning is one element in robust policy development. This paper shows two essential progressions in vulnerability assessment:
    - From simple profiles to economic vulnerability. Techniques like CART (and KnETs, see Bharwani et al., 2006) combine the drivers of vulnerability in logical rule trees that indicate critical thresholds that result in one farm being more exposed to environmental, economic and policy impacts than another. Such rule trees highlight the relationship between predictor variables and outcomes.
    - From baseline, current vulnerability to behavioural responses. Economic analysis, rule trees, and stakeholder role-playing seek to represent how the current configuration of risk might be altered under different environmental stresses, in response to economic shocks, or as a result of policy interventions.
- The starting point for the analysis of water vulnerability in the Upper Guadiana is a thorough description of the baseline vulnerability, including an analysis of stakeholders (Sorisi 2006, Varela et al. 2006b) and surveys and interviews with farmers throughout the region (Varela et al 2007). This paper presents an innovative analysis that links this baseline vulnerability to a farm-based agro-economic modelling of policy-relevant scenarios.
- The water quotas system produces in average a softer impact on farm income than the tariff system. However, in terms of cost-effectiveness the volumetric tariff is a better option, which in addition is beneficial for some farm types, such as vineyards, where irrigation produces a high added value and where the water quotas system is highly restrictive.

- The model integration presented in this work proves that, in the specific case of the Upper Guadiana, different farm types stand diverse policy impacts and that structural, behavioural and institutional aspects play a major role in those impacts. This is highly relevant and must be considered during the design of the programmes and measures under development in the context of the SPUG implementation and the new basin management plans.
- The present Water Plan of the UGB while responding to the EU WFD objectives will not be fully accepted unless new institutional arrangements are put in place. These will require decisive stakeholder involvement. Enforcing these policies, or any imposed strict water quota system, is a difficult task that will require efficient and socially-accepted instruments as well as a transparent and participatory process of all stakeholders involved. As the cost of the Water Abstraction Plan is supported largely by the irrigators, there is a need to seek for a more flexible distribution of water allotments among farmers and for complementary measures of rural development that will ensure the maintenance of rural livelihoods in the area. These programs are envisaged in the recently launched Special Plan of the Upper Guadiana (including a water bank) and will need to be targeted specifically to the different types of farm economies in the area. Participatory adaptive water resource management recognising the differential vulnerability of stakeholders is essential.

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ANNEX

Figure A 1: ***CART Classification tree***