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PUBLIC POLICIES FOR GROUNDWATER CONSERVATION: A VULNERABILITY ANALYSIS IN IRRIGATION AGRICULTURE

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1 Introduction: the 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. Water issues and region-based rivalry for water are progressively high in the political agendas and public debates, as societal concern towards the nation's distribution of water property rights and towards environmental issues expand progressively in the Spanish society.

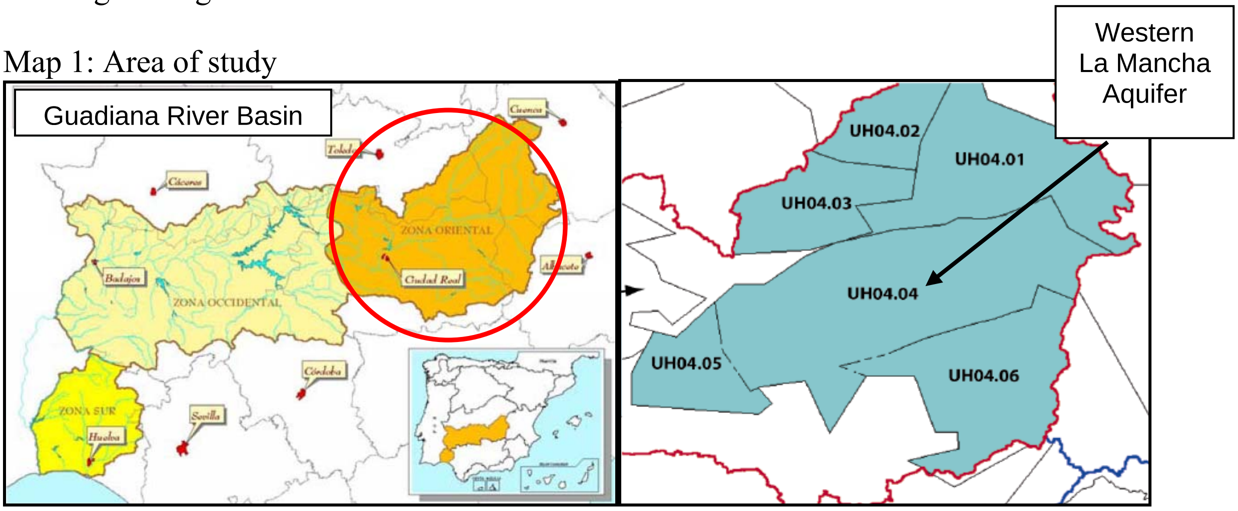
In the Upper Guadiana basin (UGB), situated in Spain's inland southern region of Castilla-La Mancha, groundwater has been the major driver for developing irrigated agriculture and hence for sustaining thriving rural livelihoods. In the last decades, the ever-mounting expansion of groundwater irrigated 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). Easy access, low infrastructure costs and high profitability, have encouraged individual farmers to invest in ground water irrigation transformations that have ensued impressive welfare achievements of a former stagnated region. However, uncontrolled irrigation development has led to the over-exploitation of the large Western La Mancha aquifer and the deterioration of the valuable internationally reputed Ramsar-catalogued wetlands of 'Las Tablas de Daimiel'.

The Water Management Regime (Water Abstraction Plan) 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. This compulsory program establishes different annual maximum levels of water consumption depending on farm size, larger farms having the highest water limitations. 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. Nevertheless, and in spite of well grounded environmental concerns aimed to recover the aquifer and the associated wetlands, the Spanish authorities have not been capable of fully developing the water use limitation policy. In Spain, public ownership of water (that includes groundwater after the 1985 Water Act) determines that irrigators are usufructuaries of water allotment rights through government concessions. Therefore, a strong opposition has arisen from situated irrigators when public authorities have resorted, for environmental reasons, to restrict the use of groundwater. Irrigators will likely oppose any changes of the prevailing property rights structure when limitations are imposed to consume water volumes below their historical water allotment rights. 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 context, currently policy makers are preoccupied in the Upper Guadiana basin (and elsewhere in Spain) on how to design and implement cost-effective and socially accepted water management policies. These policies will seek for complementary policy objectives of conserving water resources and maintain its good ecological status (as proclaimed by the EU Water Framework Directive, WFD) without inflicting a major burden to the farmers' economy and to the overall socio-economic development in the area. The prevailing institutional framework of the Upper Guadiana basin has not induced more efficient water management practices and therefore water managers and policy makers with direct responsibility in the UGB, 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. The SPUG establishes appropriate regulations, incentive structures and institutional settings that ensure societal transparency and the active participation of stakeholders.

The area of study, shown in Map 1, comprises the irrigated lands along the Western La Mancha aquifer that extends over 5.500 squared km and covers twenty Irrigation Communities totalling an irrigated surface of around 140.000 ha.

Map 1: Area of study



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

2 Methodological framework: Integrating socio-economic, hydrologic and vulnerability analyses

In this conflicting environment, the aim of this research is to contribute to explore the potential of establishing a participatory stakeholder-based adaptive water resources management (AWRM) regime in the UGB by focusing on the vulnerability of the private agrarian sector to water use limitations and to the public sector policy enforcement.

The research will focus in the analysis and understanding of how water policies that impose a strict water quota system 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 what will be their capacity to adapt to sharp decreases in water availability as well as to other restrictions in the use of production factors imposed by agricultural polices (i.e. nitrate contamination protection required by the new CAP). How the policy enforcement capacity of the water authority to impose the programmed water quotas will affect the vulnerability of the different types of farmers (legal and illegal drillings) is also one of the main questions in our analysis [1]

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 as well as deeper insights into the potential of new and adaptive management modes for the UGB.

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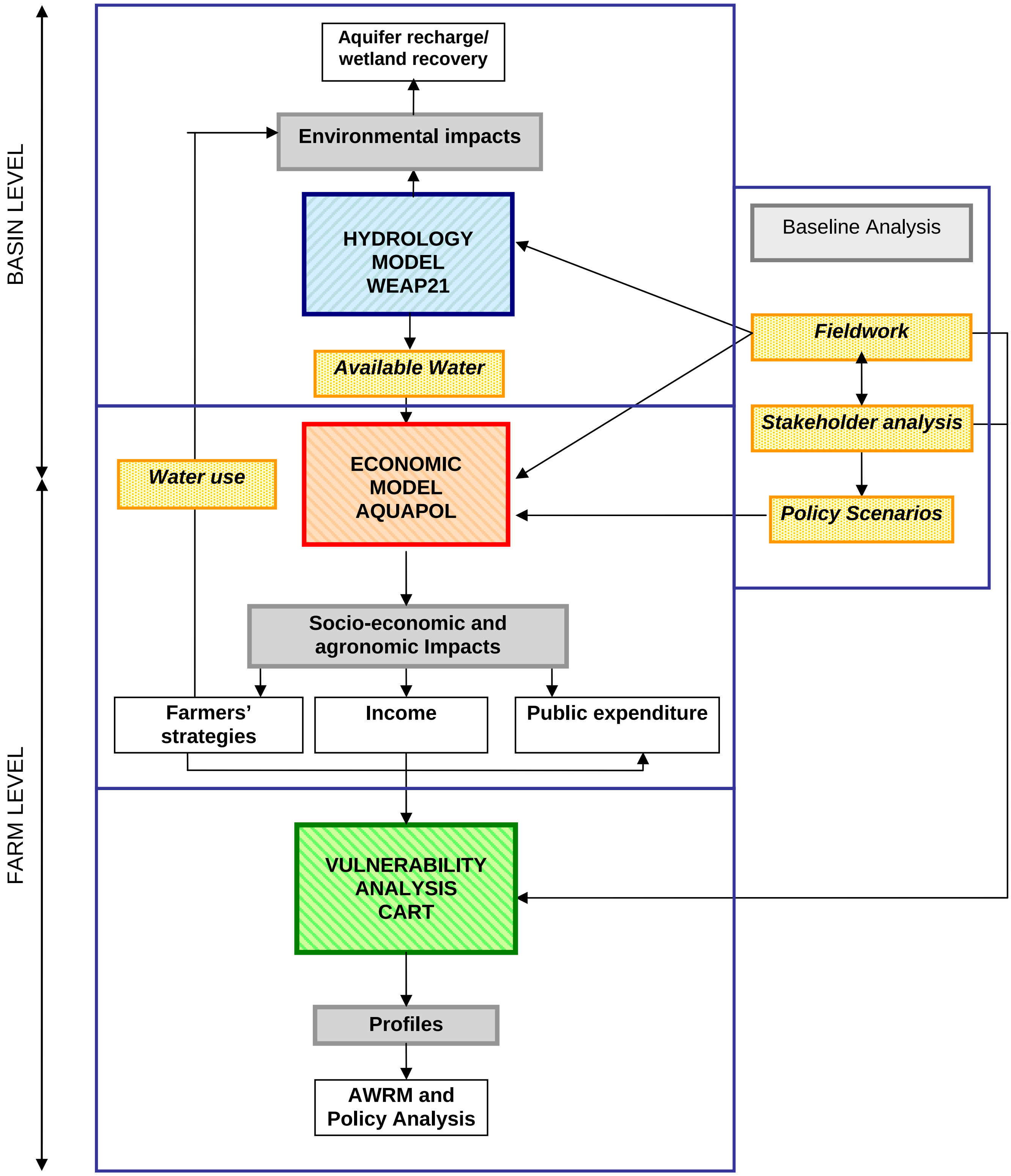
[1] This research has been carried out within the context of the EU project NEWATER (New Approaches to Adaptive Water Management under Uncertainty), FP6-2003-GLOBAL-2-SUSTDEV-6.3.2-511179-2, DG Research (2005-2008)

Figure 1. Methodological framework integrating hydrology model, agro-economic model and vulnerability assessment



The methodology comprises a sequence of analyses divided into four blocks and includes two levels of aggregation (farm and basin level). Block (a) is the baseline analysis, bock (b) is the economic modelling, block (c) is the hydrology component and block (d) 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 in 2005, 2006 and 2007, and the Newater project stakeholder meetings (including central and regional government officials, river basin managers, irrigators, Irrigation Communities, farmers' unions, environmental NGO's and research institutions.) (Sorisi, 2006, Varela-Ortega et al 2006).

Based on the field work and stakeholder analysis, 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. Table A1 (in annex) shows the characteristics of all Irrigation Communities of the Western La Mancha aquifer, including the selected five. Table 1 describes the statistically-based representative farms.

To complement the baseline analysis, we have constructed a set of real farms selected during the experts' fieldwork interviews that best represent the area of study. In these real farms, we conducted special fieldwork surveys and direct interviews to obtain all technical, social, agronomic and policy parameters for the subsequent modelling analysis. The set of real farms is used for the vulnerability analysis in the fourth part of the methodology.

Table 1: Irrigation communities (IC) and selected farm types

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

Based on the data of the representative farms of table 1, Figure 2 shows the profiles of the farm types. Profiles are based on the main characteristics of the farms that area relevant for our analysis. These include structural parameters such as farm size, percentage of irrigated land and crop mix and water related parameters such as water use over the Water Abstraction Plan volumes. Profiles show the variety of baseline characteristics of the farms that represent the area of study

Figure 2: Farm types' profiles

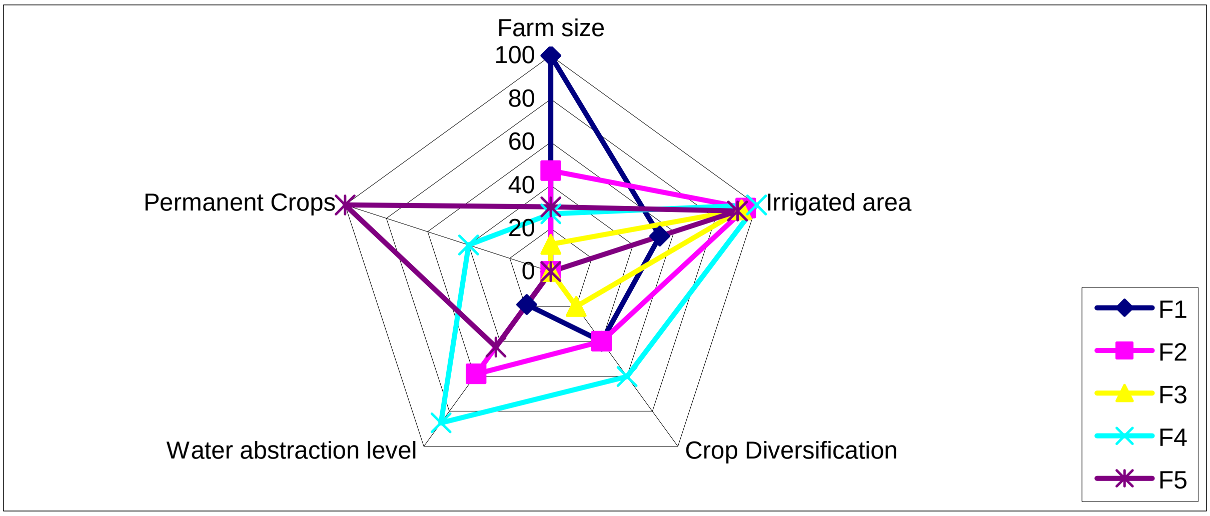


Table 2: Representative Farm types and real farms

Representative farm type	Real farm	Farm category	Surface (ha)	Crop diversification (num. different crops)	Vineyard	Irrigated surface (%)
F1 – Big farms	E3_A3	BLD	150	3	NO	91
	E21_T1	BLD	305	3	YES	34
	E17_M1	BLD	400	3	NO	75
	E5_A5	BLD	242	2	NO	100
	E8_A8	BLD	315	2	NO	84
	E2_A2	BD	550	5	NO	100
	E4_A4	BD	500	4	YES	100
	E6_A6	BD	1200	7	YES	57
	E11_D3	BD	130	6	YES	100
F2 – Medium size farms and little crop diversification	E9_D1	MLD	73	2	NO	49
	E19_M3	MLD	68	3	YES	100
	E20_M4	MLD	77	1	NO	91
	E10_D2	MLD	68,5	3	YES	99
F3 – Small farms and little crop diversification	E14_H2	SLD	21	2	NO	100
	E16_H4	SLD	17	3	YES	59
	E1_A1	SLD	17	3	YES	29
	E7_A7	SLD	19	3	NO	100
F4 – Medium size farms and large crop diversification	E18_M2	SD	40	4	YES	100
	E12_D4	MD	65	4	YES	100
	E13_H1	MD	64	4	YES	100
	E15_H3	MD	55	4	YES	64
F5 – Vineyard (Medium size farms and little crop diversification)	E22_T2	SLD	45	1	YES	89
	E23_T3	MLD	54	2	YES	93
	E24_T4	MLD	50	1	YES	100
	E25_T5	MLD	85	3	YES	100

Source: Own elaboration from fieldwork. Varela et al, 2007.

BLD: big farm – little crop diversification; BD: big farm - large crop diversification; MLD: medium size - little crop diversification; MD: medium size and large crop diversification; SLD: small farm - little crop diversification; SD: small farm – large crop diversification.

(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 (a quota system) 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 on the model developed in the first phase of the Newater project (Varela-Ortega et al, 2006) adding new parameters and a more ample empirical scope. The model incorporates risk parameters and maximizes a utility function (U) subject to technical, economic and policy constraints.

The objective function maximizes a utility function defined by a gross margin (Z) and a risk vector, where ϕ is the risk aversion coefficient and σ is 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.

The model can be summarized as follows:

Objective function:

$$MaxU = Z - \phi \cdot \sigma \tag{1}$$

$$\begin{aligned} Z = {} & \sum_{c}\sum_{k}\sum_{r} gm_{c,k,r} \cdot X_{c,k,r} + \left[\sum_{c}\sum_{k}\sum_{r} subs_{c,r} \cdot X_{c,k,r} \cdot coup + sfp \right] \cdot mdu \\ & - foc \cdot \sum_{p} fla_{p} - hlp \cdot \sum_{p} hl_{p} - wac \cdot wc - canon \cdot sirrg - nwell \cdot twell \end{aligned} \tag{2}$$

Where 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.

$gm_{c,k,r}$: represents the gross margin by crop type (c), soil (k) and technique (r). $X_{c,k,r}$: are the decision-making variables representing the cropped area. $subs_{c,r}$: denotes CAP support by crop type (c) and selected technique (r) that is coupled to production. *coup*: is the support coupling level. *spf*: is the single farm payment. *mdu*: is the support modulation factor .*foc*: represents the family labor opportunity cost. fla_p: represents the season's family labor availability (dependent on year's cropping period). *hlp*: denotes the hired labor wage. hl_p: is total hired labor

Risk equation:

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

where $Z_{sn,sm}$: is the random income as a function of the state of market prices (sm) and of the state of nature (sn) reflected in yield variations. N=100 represents the combination of the 10 states of nature-yield variability and 10 states of market variability.

The maximization of the objective function is subject to the following constraints

Land constraint

$$\sum_{c}\sum_{k}\sum_{r} X_{c,k,r} \leq surf_{k} \tag{4}$$

where *surf*: is the agricultural area by soil type (k).

Irrigated surface constraint

$$\sum_{c}\sum_{k}\sum_{ri} X_{c,k,r} \leq sirrg \tag{5}$$

where *sirrg*: is the total irrigated surface in the farm

Labor constraints

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

where $lr_{c,r,p}$ are labor requirements by crop type (c), technique (r) and cropping period (p).

Water availability constraints

$$\sum_{c}\sum_{k}\sum_{r} wneed_{c,k} \cdot X_{c,k,r} \leq wava \cdot sirrg \cdot h_{r} \qquad 7)$$

where $wneed_{c,k}$: water needs by crop and soil. *wava*: water availability. h_r: the technical efficiency coefficient.

And other policy constraints (cropping permits, set side requirements etc)

The problem-solving instrument used is GAMS (General Algebraic Modeling System). The technical coefficients and parameters of the model were obtained from the fieldwork. 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.

Table 3 shows the water availability on each representative farm for the three scenarios. 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 (see table 2) that allows a complete array of differential results used in the farms vulnerability analysis of the following stage of the methodology.

Table 3. Water policy scenarios: water availability

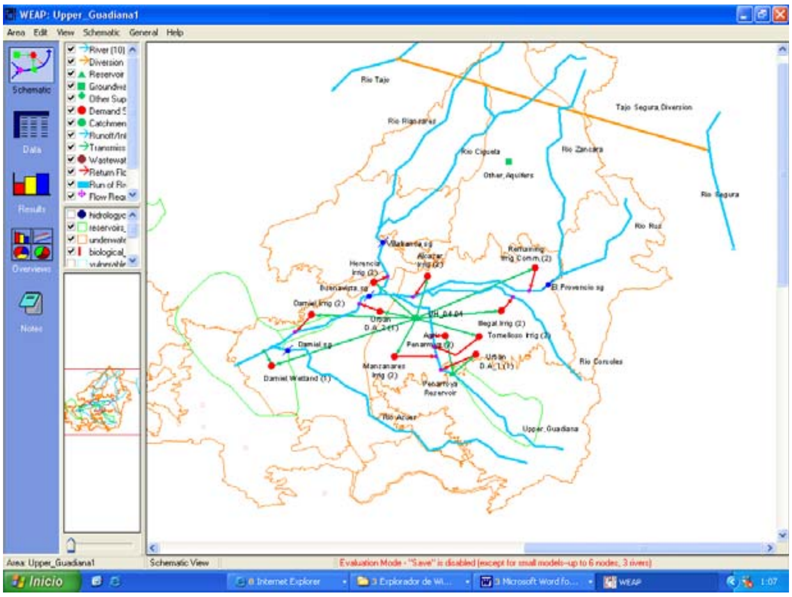
Policy Scenario Water Quotas	Water availability (m3/ha)	
Historical Water Rights	F1	4270
	F2	
	F3	
	F4	
	F5	
Current situation*	F1	1980
	F2	3750
	F3	2640
	F4	3900
	F5	1480
Water abstraction Plan	F1	1635
	F2	2275
	F3	2640
	F4	1984
	F5	1000

* field work data

Source: CHG (Confederación Hidrográfica del Guadiana (2006)

(c) Hydrology analysis: The Upper Guadiana hydrology was represented by the **hydrology model** WEAP (Water Evaluation and Planning System) (SEI, 2005). The model has been adapted, calibrated and validated for the Upper Guadiana basin in the framework of the project Newater (Varela et al 2006a) and permits the analysis of different hydrological parameters in different climate and policy scenarios. The integration of the hydrology and economic models starts with the mapping into the WEAP layout of the selected representative farms in the geographical locations of the irrigation communities of the basin. Further, the same policy scenarios are simulated in both models using the scenario building sequence of the WEAP module. The WEAP model permits the up-scaling at basin's level of the results obtained in the economic model and the analysis, for different climate scenarios, of the overall availability of water resources in the basin and the recharge capacity of the aquifer.

Map 2: WEAP layout: Irrigation Communities in the Upper Guadiana basin



Evaluation Mode - "Save" is disabled (except for small models-up to 6 nodes, 3 rivers)

(d) 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 objective function in the analysis is vulnerability defined by two types of indicators as dependent variables (see table 4). These vulnerability indicators are defined by 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, 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 in water-scarce policy scenarios. A large farm may have a considerably high percent income loss relative to its total income and still be capable to adapt and continue operating. Conversely, a small farm may have a smaller percent income loss that, in absolute terms, would be sufficiently high as to make the farm fall below the economic viability threshold and be forced to stop operating. The economic viability threshold is defined as 'minimum survival income' calculated from Spain's official data of the 'minimum inter-professional annual wage rate'2.

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 4). 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).

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[2] Minimum annual inter-professional wage rate (salario mínimo interprofesional anual), for 2007 is 7988.4 €/year

Table 4: 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)

The criteria followed to classify farms into the four vulnerability classes are shown in table 5. The highest class of vulnerability is related to a threshold of economic viability. When farm income is equal or below 50% of the minimum survival income, a farm is considered to be highly vulnerable to diminishing water volumes. The MSI was calculated from the official 2007 minimum inter-professional annual wage rate in Spain that amounts to 7988.4 €/year. As GDP per capita was 23000 € in 2006, 50% over the minimum survival income equals approximately half of per capita GDP and therefore a farmer that reaches an income level lower that the MSI can be considered highly vulnerable to water consumption limitations.

The three lower classes of vulnerability relate to the application of the Water Abstraction Plan (WAP). Farms that would loose up to 35% of their farm income with the new allocations are considered to have low vulnerability to water stress conditions and when income loss is in the range of 35% to 50% or above 50%, vulnerability is respectively medium and high.

Table 5: 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: The last part of the methodological framework is the analysis of the of the vulnerability classification tree based on structural and institutional characteristics in the farms. This analysis 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.

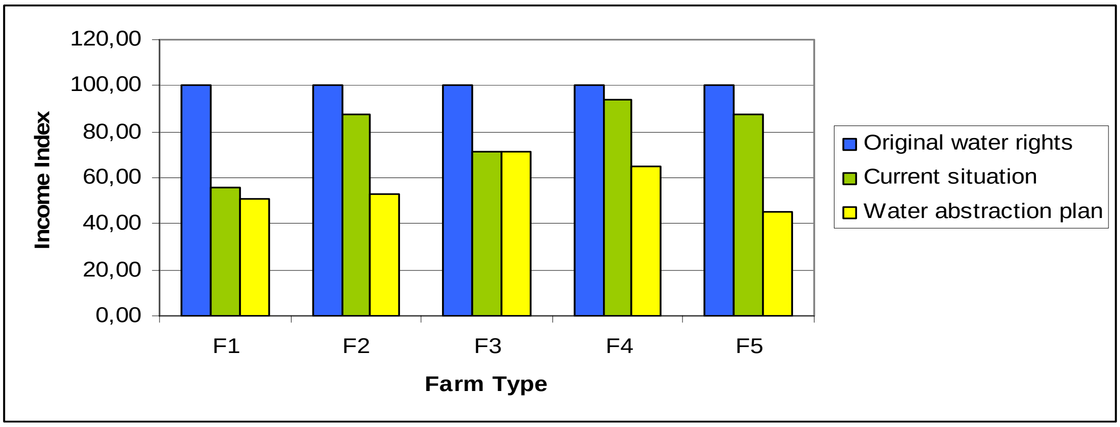
3. Results and discussion

Results of the economic model:

The simulation results are shown in Figure 2 that depicts the effects of the application of different water policy scenarios (water quotas) in the five representative farms (see table 2). The WAP induces a decrease in water consumption in all farm types relative to the historical water rights and the current situation (as shown in table 3 in the previous section). Complying with the WAP provokes substantial **farm income losses** to all farms. However, as shown in figure 3 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. On the contrary, diversified farms tend to loose a lower proportion of their farm income as their short-term adaptive capacity to water scarcity is higher (F3 and F4, especially F3, which grows only annual crops).

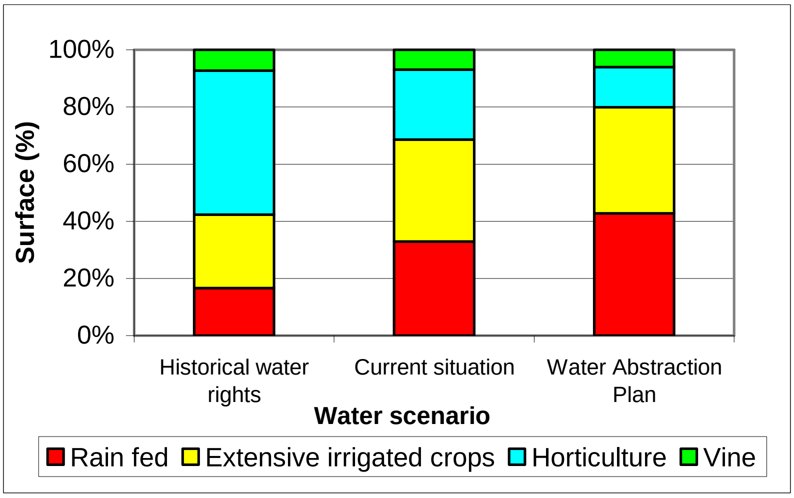
However comparing total farm income with respect to the minimum survival income level, small farms have a larger income loss and farms that feature a rigid cropping pattern, such as vineyards (F5), are prone to abandon irrigated production.

Figure 3: Effect of the application of Water Policies on farm income across farm types



As figure 4 shows, when water volumes diminish **cropping patterns** are likely to change to less water intensive crops for the area’s average farm. Rain fed farming increases progressively as less water is available, extensive irrigation such as barley is maintained and horticulture crops diminish in the average farms, although different responses across farm types are expected according to their adaptive capacity in changing crop mix.

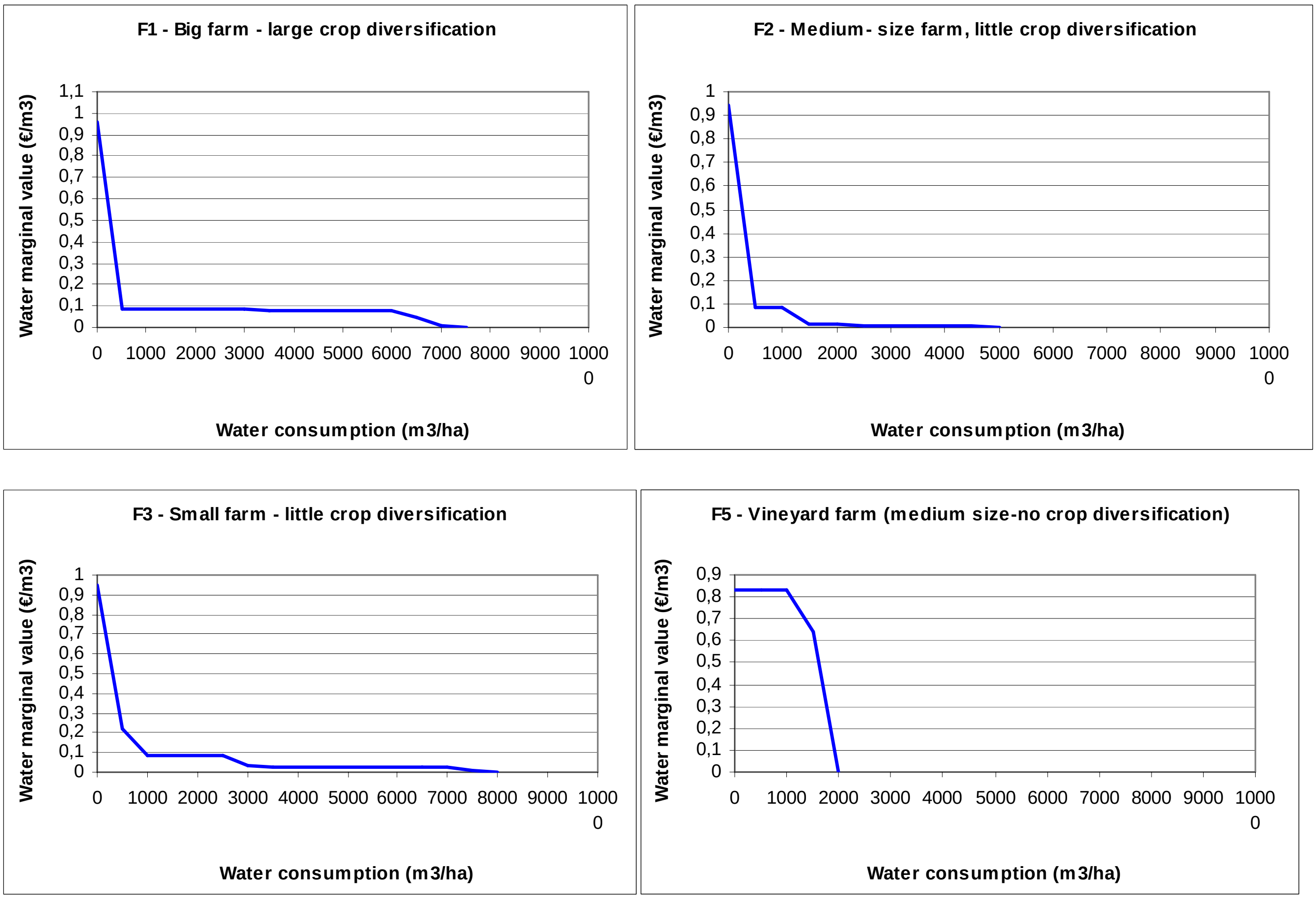
Figure 4: Effect of the water quotas policy on the cropping pattern in the aquifer



The adaptive capacity that farms have to different volumes of water can be analyzed looking at the **water dual values** (water marginal 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) . The value of water for farmers is not constant and increases as less water is supplied because farmers are likely to change their crops and technologies in response to water availability, as shown in the model results where cropping pattern changes according to the available water volumes and to the policy programs

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 shadow prices (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 (rain fed farming). When dual values of water are zero, the farm will not be willing to pay for an extra unit of water volume, that is, the farm will be satisfied with the amount of water available. 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.

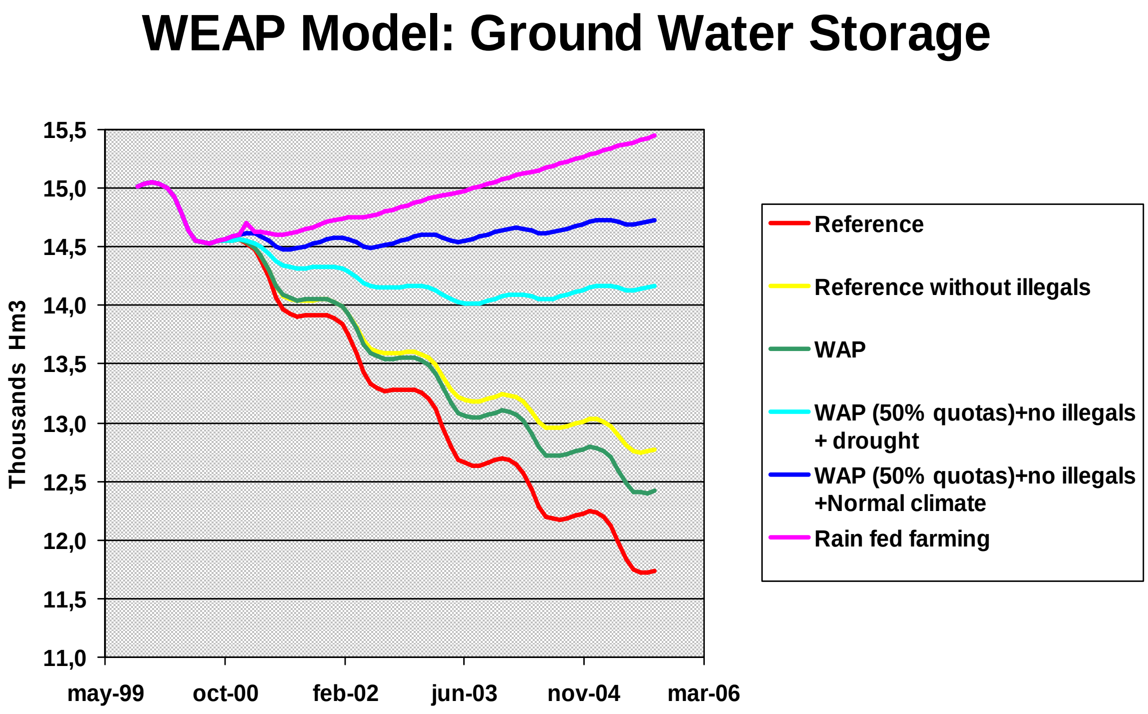
Figure 5 – Dual values of water across farm types from different levels of water availability



Results of the hydrology model:

The hydrology model (WEAP) permits to up-scale the farm level results of the economic model to the basin's level and analyze the effects of the policy scenarios on the overall recharge capacity of the aquifer. This can be shown by the WEAP results in the graph below. The simulation results of the WEAP model permit to assess the groundwater storage in the whole aquifer and therefore the aquifer recovery rates for the simulated policies and climate scenarios. For these simulations, the departure point in the reference scenario considers an initial storage capacity to the aquifer of 15.000 million m3, a value with which the aquifer is full and recovered. We can see in the graph that when the current Water Abstraction Plan (WAP) is applied, overall water use will diminish but it will not be sufficient to recover the aquifer due to the existence of illegal pumping. The aquifer recovers when WAP quotas are reduced (concessions are above the water use limits) and no drought spells are expected.

Figure 6 Aggregate effects of policy programs on the aquifer



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 index for the vulnerability analysis has been calculated based on the overpumping data and illegal drillings reported in 2006 as shown in table 6.

Table 6: Water policy enforcement rate

Water abstraction (Hm3)*	Total	Policy target	Over pumping	Overpumping rate (%)
	355	214	141	39,72
Number of wells	Total	Legal	Illegal	Rate of illegal wells
	39000	16000	23000	58,97
Average				49,35

Source: Own elaboration from CHG, 2006

The classification of water policy enforcement is the following:

% Overpumping: < 20% → High policy enforcement
20-30% → Medium policy enforcement
30-40% → Low policy enforcement
>40% → Very low policy enforcement

Based on the results of table 6, we can conclude that the policy enforcement level in the UGB can be considered low, as overpumping in the aquifer is close to 40% of total water abstractions (illegal wells are a higher percentage of total wells but these figures are less reliable and vary according to data sources).

Table 7 shows the indicators for the vulnerability analysis for each of the 25 farms selected in our study region. The first column shows the different farms (denoted by E1 to E25 and by the Irrigation Association shown in table 2), the second column shows the level of vulnerability according to the criteria selected in table 5, and the next two columns show income losses while the remaining columns show the prediction variables defined in table 4.

Table 7: 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 5

Figure 7: Real farms' profiles for different vulnerability levels

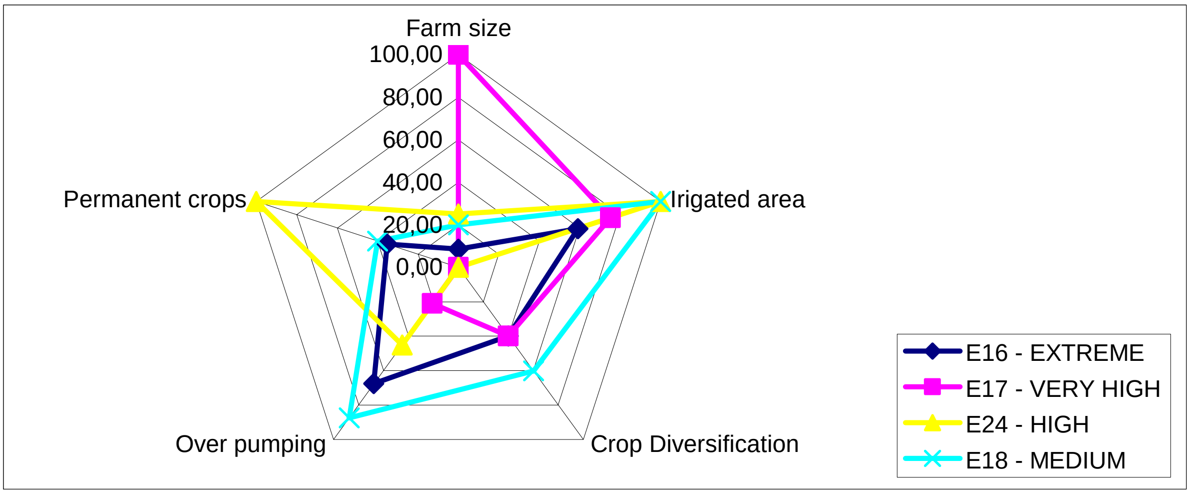


Figure 7 shows the farm profiles of four of the real farms, each of them with a different level of vulnerability. In this radar plot we can see how the different structural characteristics (farm size and permanent crops) and the different strategies (over pumping, irrigated area and crop diversification) 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.

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.

$$\begin{aligned}
IL &= Z_{hr} - Z_T \\
Z_T &= Z_{WAP} + \beta \cdot Z_{extra} \\
Z_T &= Z_{WAP} + \beta \cdot (Z_{act} - Z_{WAP}) \\
Z_T &= Z_{WAP} + \beta \cdot Z_{act} - \beta \cdot Z_{WAP} \\
Z_T &= (1-\beta) * Z_{WAP} + \beta \cdot Z_{act}
\end{aligned}$$

Where:

- IL: Income loss (€/ha)
- Z_{hr}: Farm income obtained with the historical water rights (€/ha)
- Z_T: Expected farm income in current situation (€/ha)
- Z_{WAP}: Farm income obtained complying with the Water Abstraction Plan (€/ha)
- β: Overpumping coefficient
- Z_{extra}: Farm income obtained using over-pumped water
- Z_{act}: Farm income obtained with actual consumption (€/ha)

Figure A1 (in annex) shows the CART classification tree of the vulnerability analysis. Farms are classified by vulnerability levels and results show that the most important explanatory variables are farm size, rate of over pumping and 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 (see table 8)

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.

Table 8: CART Classification of farms in vulnerability levels

Farm size	Over pumping	Water policy enforcement impact	Vulnerability
< =18 has			Extreme (100%)
	<= 1%		Very high (87,5%)
	>1%	0	Medium (75%)
(18-32] has	>1%	1,2, ó 3	Medium (100%)
(32-367] has	>1%	1,2, ó 3	High (100%)
> 367 has	>1%	1,2, ó 3	Very high (100%)

The next table shows the result of the sensitivity analysis to the policy enforcement capacity. This variable has proven to be an important explanatory variable for farm vulnerability and therefore policy enforcement capacity has to increase substantially to efface its impact. Table 9 shows the results of the new CART simulations in which overpumping has to fall to less than half (less than 20%) to eliminate its impact on farm vulnerability. That is, when the policy enforcement capacity increases to a level considered ‘high’ in our classification (less than 20% overpumping) then this variable is no longer determinant for explaining farm vulnerability classes.

Table 9: CART farms classification in levels of vulnerability. Increased water policy enforcement.

Farm size	Over pumping	Irrigated area	Vulnerability
< =18 has			Extreme (100%)
(18-42,5] has			Medium (87,5%)
> 42,5 has	<= 1%		Very high (75%)
> 42,5 has	>1%	<= 41,87 %	Medium (100%)
(42,5-59,5] has	>1%	> 41,87 %	High (100%)
> 59,5 has	>1%	> 41,87 %	Very high (100%)

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, agent-based modelling, 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 (not reported in full here), 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. This micro-scale vision is then aggregated to the basin-level by means of a hydrology model (WEAP, SEI 2006) coupled to the economic model by reproducing the same policy scenarios. Differential outcomes are predicted based on indicators of vulnerability combined through a rule tree using CART. This methodology shows the extension of IWRM to consider vulnerability and behavioural responses, core elements of AWRM.

- Looking at water conservation policies currently in force in the Upper Guadiana Basin, we can conclude, from the economic-hydrologic integrated analysis, that these policies will not be able to achieve the recuperation of the Western La Mancha aquifer, even though they will contribute to reduce water consumption in the farms. This situation would worsen in case of droughts.

- As a general policy recommendation, the present Water Plan of the UGB while responding to the EU WFD objectives will not meet the desired target of ensuring the good ecological status of the aquifer and revert it to to its natural recharge level 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, especially irrigation associations, the Water Authority and environmental groups. 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

Table A1: Irrigation Communities in the Western La Mancha aquifer

PROVINCE	**IRRIGATION COMMUNITY (IC)**	**Irrigated Surface**		**Number of irrigators**		**Average farm size**	**Number of registered wells**		**Hectares per well**
		Surface (ha)	**% in the aquifer**	**Number**	**% in the aquifer**	**Surface (ha)**	**Number**	**% in the aquifer**	**ha/well**
Ciudad Real	**Alcázar de San Juan**	**29380**	**22**	**912**	**11**	**32,2**	**1805**	**11**	**16,3**
	Arenas de San Juan	2136	2	120	1	17,8	258	2	8,3
	Argamasilla de Alba	5000	4	189	2	26,5	339	2	14,8
	Bolaños de Calatrava	2323	2	342	4	6,8	635	4	3,7
	Campo de Criptana	8314	6	579	7	14,4	1170	7	7,1
	Daimiel	**19920**	**15**	**1445**	**17**	**13,8**	**2859**	**17**	**7**
	Herencia	**3725**	**3**	**130**	**1**	**28,7**	**270**	**2**	**13,8**
	Manzanares	**17896**	**14**	**850**	**11**	**21,1**	**1786**	**11**	**10**
	Membrilla	386	0,3	240	3	1,6	345	2	1,1
	Socuéllamos	8830	7	608	7	14,5	1480	9	6
	Tomelloso	**4739**	**4**	**403**	**5**	**11,8**	**645**	**4**	**7,4**
	Torralba de Calatrava	4598	4	292	4	15,7	759	5	6
	Villarrubia de los Ojos	2956	2	336	4	8,8	1037	6	2,9
	Villarta de San Juan	3070	2	97	1	31,6	216	1	14,2
Cuenca	Mesas (Las)	2500	2	238	3	10,5	100	1	25
	Pedroñeras (Las)	2162	2	127	2	17	501	3	4,3
	Provencio (El)	3200	2	300	4	10,7	600	4	5,3
	San Clemente	2500,54	2	150	2	16,7	570	3	4,4
Albacete	Villarrobledo	8903	7	1078	13	8,3	1210	7	7,4
TOTAL	**Total from selected IC**	**75660**	**55**	**3740**	**45**	**20,2**	**7365**	**45**	**10,3**
	Total in the aquifer	**132.538,84**	**100**	**8.436**	**100**	**15,7**	**16.585**	**100**	**8**

Source: Varela et al., 2000, JCCM, 2004 y CHG, 2006 (data provided by the CHG planning department)

Table A2: Water policy enforcement impact index (0, no impact, 3 most negative impact)

WATER POLICY ENFORCEMENT IMPACT INDEX			
Over pumping (%)	Policy enforcement level	Farmers’ perception of the impact of the different water policy enforcement levels	Impact
0%	High	**“Positive**; the aquifer would recover and all the irrigators would have more water soon”	0
	Medium	**“Negative**; It is not fair that irrigants who do not comply with the water abstraction plan are not persecuted and sanctions. Their behaviour is bad for all the irrigators”	2
	Low	**“Very negative**; If policy enforcement is low illegal irrigators would steal water. Farmers who comply have lower income, but at the same time other farmers use as much water as the like. Legal farmers are damaged by illegal farmers who do not cooperate to the aquifer recovery.”	3
	Very low		3
0-20%	High	**“Very negative**; So little water is not enough to maintain the activity; there should be allowed a small margin over the quota. In this case there should not be sanctions.	3
	Medium	**“Negative**; Scarcity will be more and more serious and water restrictions will be larger. Farmers who use much more water than allowed should be controlled.”	3
	Low		2
	Very low		2
20-50%	High	**“Very negative**; it is not possible to comply with the water quotas; more water is necessary to subsist.”	3
	Medium		3
	Low	**“No impact**; There are farmers who need to consume more water than allowed by the quotas. Water rights should be better distributed.”	1
	Very low	**“Positive**; The water consumed is necessary for survival. There should be another solution in which other type of farmers is penalized”	0
> 50%	High	**“Very negative**; it is not possible to comply with the water quotas; more water is necessary to subsist”	3
	Medium		3
	Low	**“Positive**; The Water Abstraction Plan is too restrictive. It is not possible to maintain the farming activity with so little water. Another solution should be found.”	0
	Very low		0

Source: Field work, Varela et al., 2007a.

Figure A1: CART Classification tree