# Dealing with the tradeoff between water for nature and water for rural livelihoods under climate uncertainties: lessons for water management

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## 1. Introduction: policy drivers for irrigation development and ecosystem conservation

Competing access to water resources and recurrent social conflicts are widespread throughout arid and semiarid countries worldwide. One of the world examples is the Mediterranean basin in which groundwater irrigation has been a key driver for agricultural development and for the stability of rural livelihoods (Benoit and Comeau, 2005). In Spain's southern littoral and its hinterland, groundwater irrigation expanded over the last decades as a response to non-subsidized individual actions of many private farmers. These profited from accessible low-cost drilling technologies, policy-driven profits for irrigation farming, and the higher resilience of subterranean waters to droughts (Llamas and Martinez Santos, 2006; Mukherji, 2006; Varela-Ortega, 2007). However, in Spain and elsewhere, ground-water based human development has come along with significant environmental damage to aquatic ecosystems, giving rise to acute social conflicts as environmental awareness expands progressively in society (Rosegrant *et al.*, 2002; Comp.Asses.Wat.Mng, 2007, Varela-Ortega, *forthcoming*). The Upper Guadiana basin in Spain's region of Castilla La Mancha provides an illustrative example of such a conflicting episode that has persisted over the years. Intensive use of groundwater has offset the endemic drought problems in the area and has given rise to an irrigation-based thriving economy of a once stagnated region. Yet, water pumping has led to the overexploitation of the large Western La Mancha aquifer (WLMA)[1] and the progressive degradation of the associated wetlands 'Tablas de Daimiel', listed in the Ramsar calatogue and a UNESCO Biosphere reserve (Varela-Ortega and Sumpsi, 1999; Baldock *et al.*, 2000; Ramsar, 2006; MIMAM, 2006). With the aim of finding a remedy to this ecological impact, the River Basin Authority (RBA) adopted a Water Abstraction Plan (WAP) from 1991 onwards based on the imposition of an area-based water quota regime (Table 1).

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[1] The aquifer surface is 5000 $Km^2$ and over pumping has reached close to 450 million cm largely surpassing the Natural Recharge rate set at 230 million cm.

**Table 1.** Water Abstraction Plan (Water Quotas) (2006)

| Farm size (ha) | 0-30 | 30-80 | >80 | Vineyard |
|---|---|---|---|---|
| Water quotas (m3/ha) | 2640 | 2000 | 1200 | 1000 |

Source: CHG (2006)

The quotas reduced considerably the entitled historical water rights of the irrigators (from an average of 4,200 cm per ha to 2,000 cm per ha) and created a long-lasting social unrest, free-riding behavior and uncontrolled drillings. The Water Administration not being capable of enforcing the policy to its full application, due to the large social costs implied. This situation, common to other world examples, exemplifies the difficulty to control ground water drillings in an open-access common-pool resources' structure as it entails high enforcement costs to the public authorities (Provencher and Burt 1994; Shah *et al.*, 2000; Schlager and López-Gunn 2006; Llamas and Martinez-Santos 2006; McCann *et al.*, 2005).

In parallel, the EU Common Agricultural Policy (CAP) launched in 1993 a special Agri-environmental program (AEP) in the area for conserving wetland ecosystems. The AEP established voluntary water reduction targets with income compensation payments to the farmers. The program was successfully implemented and met the environmental objectives of reducing water abstractions in the aquifer to the established limits (JCC-LM, 1999). However, it entailed large public costs and was later modified following the enacting of the EU Water Framework Directive (WFD) in 2000. Water quotas and compensation payments were lowered to meet the ecological and cost-effectiveness requirements of the WFD. A large proportion of the farmers abandoned the program and, taken together, it was no longer valid for recovering the aquifer to its natural recharge.

Table 2 shows the water use reduction levels and the correspondent payments.

**Table 2.** EU Agri-Environmental Program (2006)

| W. consumption reduction from WAP % | Payments ( €/ha) | |
|---|---|---|
| 50 % | 1- 40 ha | 209 |
| | 40-80 ha | 125 |
| | > 80 ha | 63 |
| 100 % | 1- 40 ha | 518 |
| | 40-80 ha | 311 |
| | > 80 ha | 155 |

Source: JCC-LM (2006)

At present, the RBA has approved a Special Plan of the Upper Guadiana (SPUG), aimed to reduce water abstractions in the aquifer by 272 million cm to meet its natural recharge set at 200 million cm. The plan seeks to comply with the WFD requirements of reaching the 'good ecological status of all water bodies' by 2027 (CHG, 2007). The SPUG includes different water conservation measures, such as purchasing water rights from the irrigators in the newly created Water Rights Exchange Center, the legalization of illegal wells, the closing-up of un-licensed bores, a reforestation plan and the support of extensive rainfed farming (Table 3).

**Table 3.** Programmed measures in the Special Plan of the Upper Guadiana (SPUG) (2007 to 2027).

| **SPUG measures (2007-2027)** | **Water volume recovered ($Hm^3$)** |
|---|---|
| 1. Water Rights Exchange Center | 144 |
| → Legalisation of illegal wells | -32 |
| 2. Reforestation plan | 96 |
| 3. Management and control measures | 48 |
| 4. Agricultural measures | 16 |
| Total | 272 |

Source: CHG (2007)

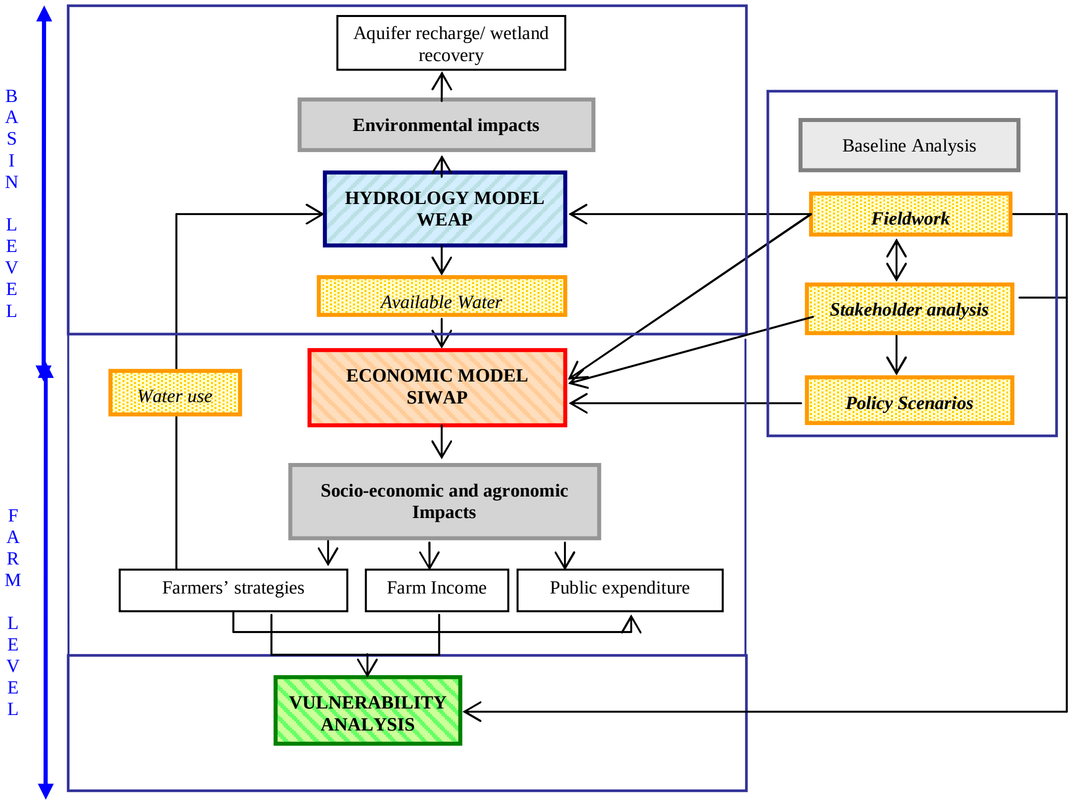
Clearly enough, agricultural policies and water policies, both EU and regional, share the common objective of natural resources conservation. In the Guadiana basin, the long-lasting lack of integration and mismatching of agricultural and water policies has frequently resulted in non-coherent and disruptive outcomes, presided by social unrest in the rural communities. Then a further integration of these two types of policies is a major challenge for adapting to new forms of water management.

In this context ***the objective of this research*** is to explore a series of policy-based options for balancing the maintenance of rural livelihoods and the protection of groundwater systems in the area of the Western La Mancha Aquifer (WLMA). It looks at the vulnerability and the capacity to adapt of the ecological and social systems that face uncertain and changing water and climate regimes. Specifically, the paper analyzes the environmental and socio-economic effects of the dynamics of agricultural policies and water policies applied in the aquifer's region under different climate conditions. The research focuses, in the first place, on a short-term analysis of the agricultural and water policies currently in force in the district, both at farm and basin levels. Secondly, a long-term analysis foresees the effects of future policies and climate scenarios along the time span set by the RBA to accomplish the recovery of the aquifer required by the WFD provisions.

## 2. Methodological framework: modeling integration

The methodology developed to undertake this analysis is shown in Figure 1 and intends to replicate the complexity of the dynamic behavior of the social and ecological systems. It comprises four main parts: (i) A baseline analysis supported by an ample field work and stakeholder consultation carried out from 2005 to 2007 (farmers, irrigation community representatives, technical experts, river basin managers, regional government officials, environmental NGO's, farmers unions); (ii) development of a farm-based mathematical programming model (MPM) that simulates the farmers behavior confronted to different agricultural and water policy scenarios; (iii) Development of a hydrology model, (WEAP) (Water Evaluation and Planning System) that permits the up-scaling of the farm-based results on water consumption obtained in the economic model to the basin level and thus assess the impacts of the different policies on the aquifer's recharge; (iv) Integration of the hydrology and economic models for analyzing the short-term and long-term dynamics of climate and water policy scenarios.

**Figure 1.** Methodological scheme.



From the baseline analysis and for the modeling purpose, we have selected a set of four statistically-based and field-work supported representative farms that characterize the farming variety in the area: a small vineyard farm of 8ha (F1), a medium size farm diversified with horticulture crops of 24ha (F2), a medium-size with less cropping diversification and cereal production of 30ha (F3) and a large farm of lower quality soil with diversify cropping potential of 70ha (F4).

### 2.1. The economic model

The model is a farm-based non-linear single-period mathematical programming model (MPM) of constrained optimization that maximizes a utility function (U) subject to technical, economic and policy constraints. It is based on previous works by the author adding more complexity and scope in the water, agricultural and institutional parameters. The model can be summarized as follows:

***Objective function***

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

where $U$ is the expected utility; $Z$, average net income; $\phi$, risk aversion coefficient and $\sigma$, standard deviation of the income distribution. Average farm income is calculated as follows:

$$Z = \sum_c \sum_k \sum_r gm_{c,k,r} \cdot X_{c,k,r} + \left[ \sum_c \sum_k \sum_r subs_{c,r} \cdot X_{c,k,r} \cdot coup + sfp \right] \cdot mdu - foc \cdot \sum_p fla_p - hlp \cdot \sum_p hl_p - w\mathrm{cos}ts \tag{2}$$

where $X_{c,k,r,}$ are the decision-making variables representing the growing area by crop type ($c$) soil type ($k$) and irrigation technique ($r$); $gm_{c,k,r}$ : gross margin; $subs_{c,r}$: CAP support; $coup$: coupling rate; $spf$: single farm payment. $mdu$: modulation rate; .$foc$: family labor opportunity cost; $fla_p$: family labor availability; $hlp$: hired labor wage; $hl_p$: hired labor; $wcost$: water costs (including water pumping costs, water area tariffs and well levies ).

The standard deviation is defined by climate variability (crop yields) and market variability (crop prices) as follows:

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

where $Z_{\mathrm{sn,sm}}$: random income as a function of the state of market prices (sm) and of the state of nature (sn); N: combination of the different states (N=100).

***Land constraints***

$$\sum_c \sum_k \sum_r X_{c,k,r} \le surf_k \quad (4) \qquad \sum_c \sum_k \sum_{ri} X_{c,k,r} \le sirrg \quad (5)$$

where $surf$: available land; $sirrg$: potential irrigated surface.

***Labor constraints***

$$\sum_c \sum_k \sum_r lr_{c,r,p} \cdot X_{c,k,r} \le fla_p + hl_p \tag{6}$$

where $lr_{c,r,p}$ : crop labor requirements.

***Water availability constraints***

$$\sum_c \sum_k \sum_r wneed_{c,k} \cdot X_{c,k,r} \le wava \cdot sirrg \cdot h_r \tag{7}$$

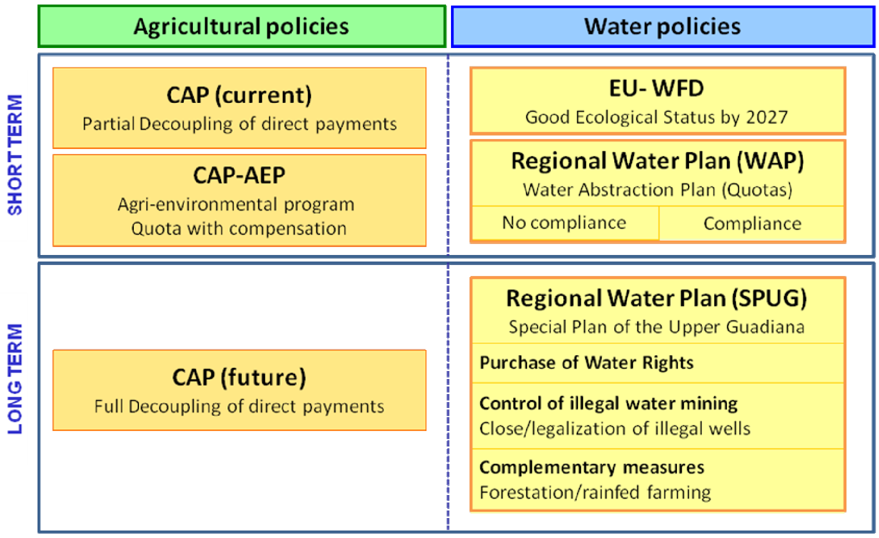
where $wneed_{c,k}$: crop water needs; $wava$: water availability;$h_r$: technical efficiency coefficient.

***Other policy relevant constraints:*** cropping permits, set side requirements, etc.

The problem-solving instrument used is GAMS. 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 policy scenarios** simulated are shown in Figure 2.

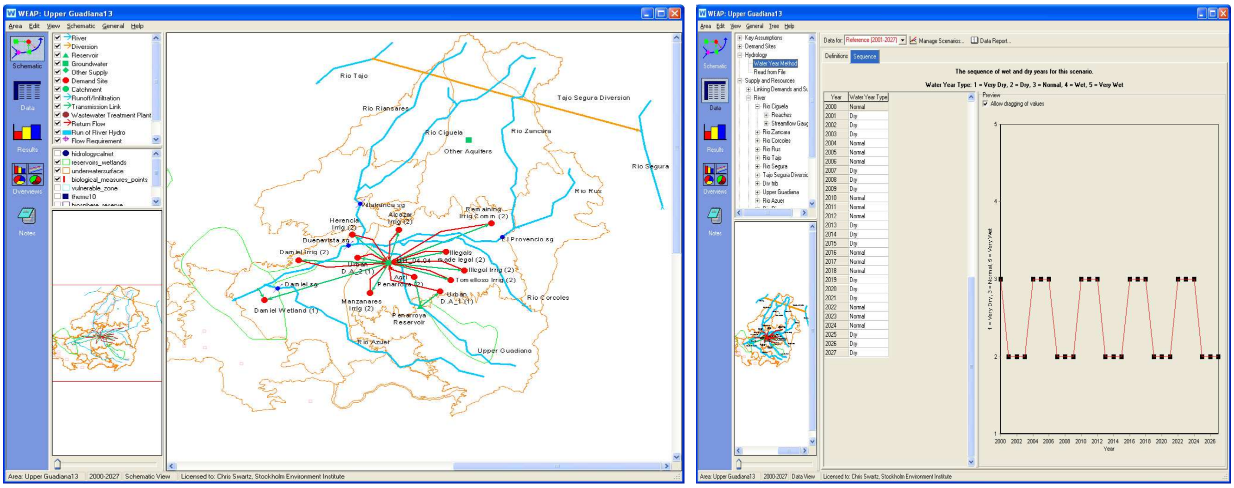
**Figure 2.** Agricultural and water policy scenarios in the short and long term.



### 2.2. Hydrology model

To quantify the impacts to aquifer storage in the basin under the different agricultural and water policies described above, the scenario-driven water resources modeling platform WEAP (Water Evaluator and Planning System) (SEI, 2008) was implemented. The WEAP modeling platform allows integration of pertinent demand and supply-based information together with hydrologic simulation capabilities to facilitate an integrative analysis of a user-defined range of issues and uncertainties, including those related to climate, watershed conditions, anticipated demand, ecosystem needs, regulatory drivers, operational objectives, and infrastructure. The user-defined demand structure and water allocation priority and supply preference designations drive the linear programming allocation algorithm for the water balance, allowing robust analysis of water allocation ‘trade offs’ within possible future hydrologic and ecologic regimes developed in a scenario framework (SEI, 2008). The use of WEAP and its user-friendly interfaces makes it particularly useful as a multi-scale water management tool and its robustness has been proven in a variety of worldwide applications (Purkey *et al.*, 1998; Levité *et al.* ,2003; Yates *et al.*, 2005; Purkey *et al.*, 2007; Assaf and Saadeh, 2008; Purkey *et al.*, 2008). The WEAP model has been specified, calibrated and validated for the Guadiana river basin[2] (Varela-Ortega *et al.* 2006a; Varela-Ortega *et al.* 2008; Varela-Ortega, *forthcoming*). Its graphical representation is shown in Figure 3.

**Figure 3.** WEAP layout of the Upper Guadiana basin and the generated climate sequence chosen for the analysis



The sequence of wet and dry years for this scenario.

Water Year Type: 1 = Very Dry, 2 = Dry, 3 = Normal, 4 = Wet, 5 = Very Wet

| Year | Water Year Type |
|---|---|
| 2000 | Normal |
| 2001 | Dry |
| 2002 | Dry |
| 2003 | Dry |
| 2004 | Normal |
| 2005 | Normal |
| 2006 | Normal |
| 2007 | Dry |
| 2008 | Dry |
| 2009 | Dry |
| 2010 | Normal |
| 2011 | Normal |
| 2012 | Normal |
| 2013 | Dry |
| 2014 | Dry |
| 2015 | Dry |
| 2016 | Normal |
| 2017 | Normal |
| 2018 | Normal |
| 2019 | Dry |
| 2020 | Dry |
| 2021 | Dry |
| 2022 | Normal |
| 2023 | Normal |
| 2024 | Normal |
| 2025 | Dry |
| 2026 | Dry |
| 2027 | Dry |

☑ Allow dragging of values

Behind each model elements lies the associated user-defined data that drives the water balance calculations, such as population, agricultural area, water use rates, groundwater recharge, streamflow, and reservoir capacity. Time dependencies of variables or other relational dependencies between variables are defined here also. For example, in this study, the area-dependent demand nodes of future purchase of water use rights, of the legalization of illegal wells and the closing of illegal bores. On the supply side, streamflow and groundwater recharge expectations are important variables to consider in this analysis of the ability of certain agricultural policies to mitigate groundwater decline in the basin. For future climate

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[2] A more detail description of the Guadiana Basin WEAP model can be found in previous works by the authors, not cited here to maintain anonymity.

conditions, we derived two sequences. For the first climate sequence, based on year 2000 streamflow, precipitation, lateral inflows/outflows, and riverbed infiltration were used to represent 2027 climate expectations. For the second climate sequence we analyzed the river headflow data set (1946-1997) to define very dry, dry, wet and very wet conditions relative to normal. These factors could then be applied to the starting year (2000) river headflow and groundwater recharge to generate a simple future climatic sequence with user-defined interannual variability.

Integration of the economic and hydrology models is done by means of mapping the selected farm types on the specific geographical sites of the Water Users Associations located in the aquifer boundaries and by simulating the same policy scenarios in both models. The farm-based results of the economic model (cultivated area, crop mix, water use) were entered into the demand nodes of the WEAP model that permits the up-scaling to the basin's level of all water parameters resulting from the policy simulations. It is possible then to assess the aquifer's water storage for different climate scenarios and hence its recharge capacity in each of the short-term and long-term policy scenarios. This allows to know how these will be able to comply with the WFD requirements along the established time horizon of 2027.

The integration of economic and hydrology models allows to grasp the overall complexity of the economic, social and environmental interactions in the aquifer, given that both models are a stylized mathematical replica of the social and water systems. Hydro-economic modelling has been used to tackle complex multi-level water management issues in a number of basin locations worldwide (Rosegrant *et al.*, 2002; Jenkins *et al.*, 2004; Mainuddin *et al.*, 2007; Brouwer and Hofkes 2008). In Spain it has been applied to address the complexity and multi-facet management endeavours in water-scarce basins that have to comply with the UE WFD (Andreu *et al.*, 2006; Heinz *et al.*, 2007).

## 3. Results and discussion

The simulation results of the economic model are summarized in Tables 4 and 5 below, showing respectively, the short term and the long term analyses. In the short term analysis the CAP scenario corresponds to the partial decoupling scheme currently in force. For the long term analysis we have assumed that the CAP programs will evolve into a full decoupling structure. Water policies have been analyzed for both types of agricultural policy settings selecting the current programs in force in each period.

**Table 4.** Results of policy analysis in the Partial Decoupling Scenario (PD) (short term)

| AGGREGATE RESULTS | POLICY OPTION | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ref. policy (PD) | WAP[a] | AEP[b] | | Purchase of water rights | | |
| | | | $AEP_1$= 50% Red. | $AEP_2$= 100% Red. | $P_1$= 3.000 €/ha | $P_2$= 6.000 €/ha | $P_3$= 10.000 €/ha |
| **Farm Income** | | | | | | | |
| Total (€/ha) | 917 | 769 | 769 | 691 | 421 | 641 | 936 |
| % | 100 | 84 | 84 | 75 | 46 | 70 | 102 |
| **Water Consumption** | | | | | | | |
| Total (m3/ha) | 3304 | 2495 | 1247 | 0 | 0 | 0 | 0 |
| % | 100 | 75 | 38 | 0 | 0 | 0 | 0 |
| **Public Expenditure** | | | | | | | |
| Total (€/ha) | 127 | 130 | 328 | 612 | 343 | 563 | 858 |
| % | 100 | 103 | 258 | 482 | 270 | 443 | 675 |
| **Water Shadow Price** | | | | | | | |
| Total (€/m3) | 0,006 | 0,061 | 0,082 | 0,973 | 0,973 | 0,973 | 0,973 |
| % | 100 | 76 | 39 | 0 | 0 | 0 | 0 |
| **Water Costs** | | | | | | | |
| Total (€/m3) | 0,061 | 0,061 | 0,063 | 0 | 0 | 0 | 0 |
| **Inc. compensation AEP** | | | | | | | |
| Total (€/m3) | - | - | 0,159 | 0,197 | - | - | - |

*Notes*: “a” Water Abstraction Plan, “b” Agri-environmental Programs.

**Table 5.** Results of policy analysis in the Full Decoupling Scenario (FD) (long term)

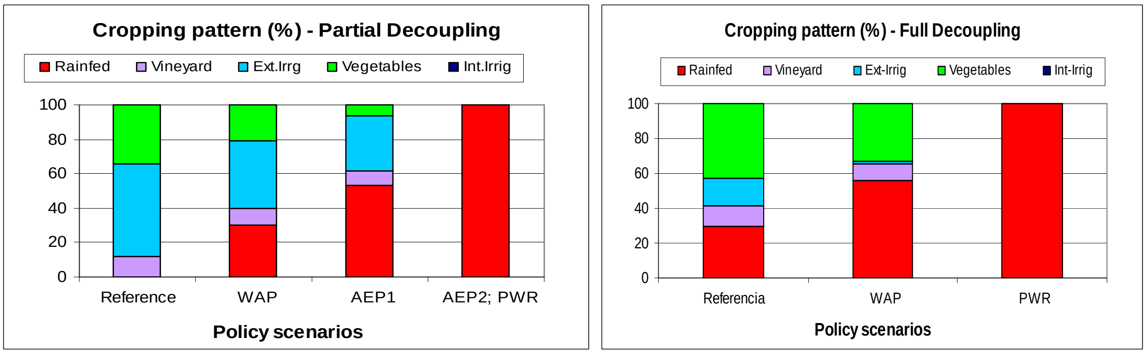
| AGGREGATE RESULTS | POLICY OPTION | | | | |
|---|---|---|---|---|---|
| | Ref. policy (FD) | WAP[a] | Purchase of water rights | | |
| | | | $P_1$= 3.000 €/ha | $P_2$= 6.000 €/ha | $P_3$= 10.000 €/ha |
| **Farm Income** | | | | | |
| Total (€/ha) | 958 | 921 | 434 | 655 | 949 |
| % | 100 | 96 | 45 | 68 | 99 |
| **Water Consumption** | | | | | |
| Total (m3/ha) | 3261 | 2495 | 0 | 0 | 0 |
| % | 100 | 76 | 0 | 0 | 0 |
| **Public Expenditure** | | | | | |
| Total (€/ha) | 130 | 130 | 343 | 563 | 858 |
| % | 100 | 100 | 263 | 432 | 657 |
| **Water Shadow Price** | | | | | |
| Total (€/m3) | 0,004 | 0,067 | 0,973 | 0,973 | 0,973 |
| % | 100 | 77 | 0 | 0 | 0 |
| **Water Costs** | | | | | |
| Total (€/m3) | 0,061 | 0,061 | 0 | 0 | 0 |

*Notes*: “a” Water Abstraction Plan.

### 3.1. The agronomy: Water consumption and cropping patterns

Results from the economic model show that in the short term partial decoupling scenario, water use reductions to reach the aquifer’s recharge target are met for the WAP and the AEP programs. This level is also attained in the longer term analysis, although AEP programs disappear and in its place, the SPUG is applied for the three levels of water rates as established in the program (Table 4 and 5). This result does not mean that the recharge target will be met in the overall sub-basin, as evidenced in the hydrology analysis (see next section). In Figure 4, we can see that farming extensification takes place when the WAP is enforced, that is, rain fed farming appears and intensive irrigation crops, such as maize, are sharply reduced towards less water demanding crops, such as winter cereals and intensive vegetable productions are also diminished. In the full decoupling scheme of the long term analysis, extensification starts even in the reference situation, and this trend is reinforced in the more water-scarce WAP, evidencing a clear synergy of CAP programs with water conservation targets. In fact, full decoupling shows a polarization of cropping trends. Intensive cereals are clearly penalized in the FD scenario (due to the lost of its comparative advantage of the production-based aids received in the previous programs) and are being substituted bywater-intensive horticulture crops and by rainfed crops. This may contradict the biodiversity targets of the CAP.

**Figure 4.** Crop distribution by policy scenarios in partial and full decoupling

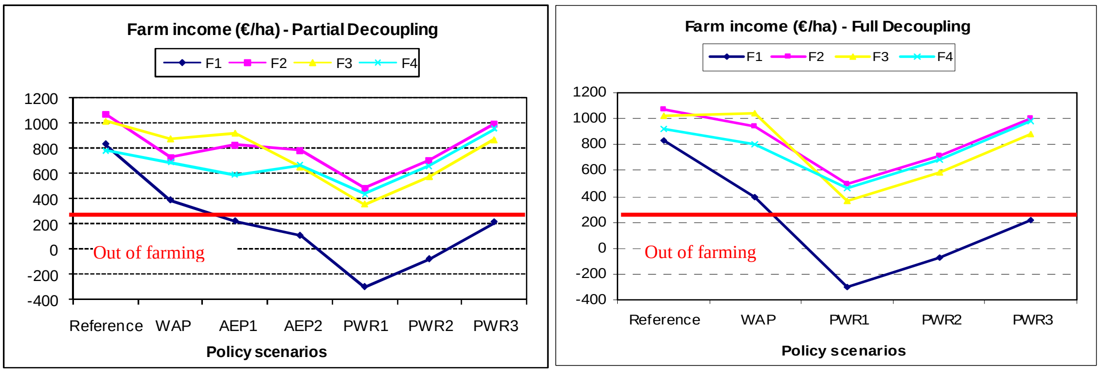


### 3.2 Farm income and purchase of water rights

In the aggregate farm type (tables 4 and 5) farm income is reduced by 20% when the WAP quotas are applied in the short term partial decoupling scenario. This tendency is mitigated in the long term FD, evidencing that a full decoupled subsidy scheme acts as a risk shelter for irrigated farming. However, when farmers sell their water rights within the SPUG program, both scenarios produce equivalent farm income reductions and the original level of income gain is only attained when water rights are compensated to the highest price rate of 10,000 € per ha.

When comparing the different types of farms (Figure 5), results show that income is reduced less drastically as water availability diminishes across scenarios when subsidies are decoupled from production (FD scenarios). Again, for all farms, the fully decoupled program is less risky for farming than the precedent production-based program.

**Figure 5.** Farm income variations by policy program and farm type



However, willingness to sell the entitled water rights varies across farm types and irrigators' attitudes and it is dependent on the cropping pattern chosen in each scenario. Prices offered by the RBA in the Water rights exchange center, range from 3000-10000 € per ha for herbaceous annual crops and form 3000-6000 € per ha for permanent crops (vineyards). Based on these data, Table 6 shows the maximum and minimum revenue collected by the farmers when they sell their water rights. An irrigator will be willing to sell his water rights when the price perceived will compensate his lost income when passing from irrigation farming (in the WAP situation) to rain fed farming. As water rights are sold on a permanent basis, the annual compensation payment is calculated by the annuity of the perceived income flow over a period of 20 years along which water rights will hold (interest rate is set at a real rate of 4%). Table 7 shows the willingness to sell of the different types of farms. We can see that only F2 and F4 farm types will be willing to sell their water rights if water prices reach the upper level.

**Table 6.** Farmers' willingness to sell water rights.

| Price of water rights (€/ha) | Representative farms type | | | |
|---|---|---|---|---|
| | F1 | F2 | F3 | F4 |
| Maximum | 6000 | 10000 | 8800 | 10000 |
| Minimum | 3000 | 3000 | 3000 | 3000 |

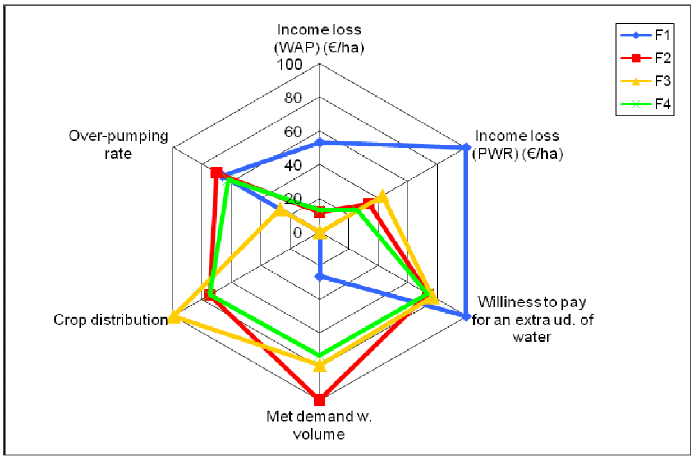
**Table 7.** Selling of water rights faces different water price level (PD Scenario, short term).

| Representative farms type | Income loss (€/ha) | | Sale of water rights (€/ha) | | |
|---|---|---|---|---|---|
| | PD | FD | $P_1$= 3,000 | $P_2$= 6,000 | $P_3$= 10,000 |
| F1 | 16601 | 16601 | NO | NO | NO |
| F2 | 8545 | 12312 | NO | NO | YES |
| F3 | 13575 | 16353 | NO | NO | NO |
| F4 | 8614 | 10175 | NO | NO | YES |

### 3.3 Farms' vulnerability

Assessing farms' vulnerability is complex and has been discussed extensively in the literature (Downing *et al.*, 2001; Alwang *et al.*, 2001; Downing *et al.*, 2006; among others). In our study, it has been analyzed using a varied set of indicators (see Figure 6). These are income loss when the WAP reduced volumes are applied or the purchase of water rights are established (water price level of 6000 €/ha), the willingness to pay for an extra water volume, the water volume that satisfies water demand in the farms, the cropping mix variation potential of the farms and the over-pumping rate. We can see that farms have different responses to these indicators, showing distinct adaptive capacity to water use limitations. The diversified larger and medium-size farms F4 and F2 respectively are more adapted to water stress conditions. They lose a smaller proportion of farm income when both WAP and water rights are sold, and water demand requirements are met at lower water volumes when compared to the other farm types. This result evidences that economies of scale as well as cropping mix potential play an important role in the adjustment process towards water scarcity in this region. In this sense, Reidsma and Ewert (2008) suggest that the diversity of farm sizes, cropping potential and intensive cultivation possibilities of the Mediterranean regions reduces vulnerability to climate variability and droughts. Hence, this regional diversity can be a source to climate adaptation strategies.

**Figure 6.** Farms' profiles (Vulnerability analysis)

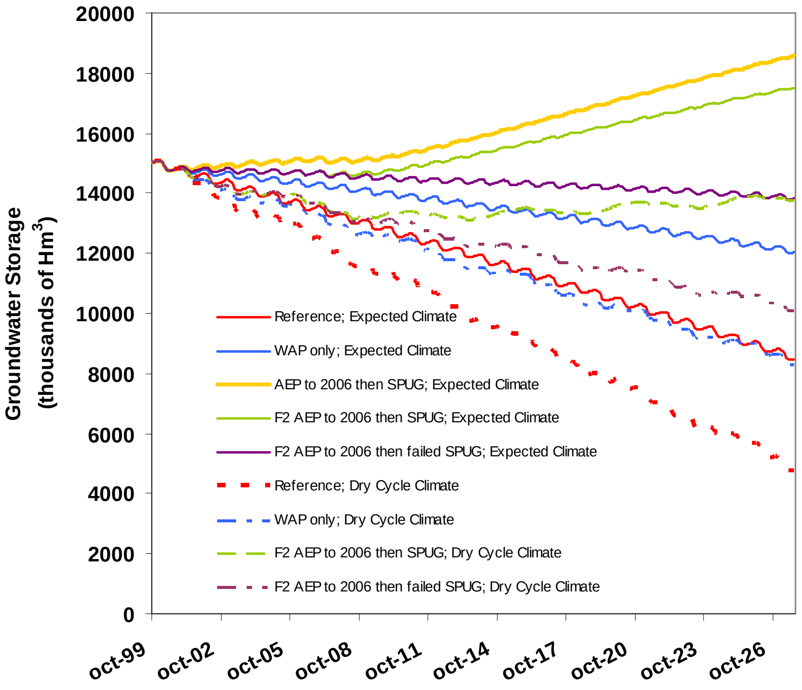


## 3.5 Meeting environmental objectives: aquifer's recharge

Impacts to groundwater storage through 2027 are demonstrated in the results of the WEAP simulations (Figure 7). Under the first climate condition, in which stream flow and natural groundwater recharge decrease by 11% cumulatively over the period, groundwater storage would decrease by approximately 5 bcm beyond current levels if no corrective action were taken ('Reference' in Figure 7), i.e., irrigators use water at rates existing before 2001. If only the WAP policy ('WAP only' in Figure 7) had been implemented in 2001 and continued beyond 2006, storage would fall another 2.3 bcm by 2027. In contrast, a 2.8 bcm increase in storage relative to the 2006 volume is anticipated if one assumes all farm types fully participate in SPUG policy conditions starting in 2007 following a period (2001-2006) in which only F2 farms opted to comply with AEP reductions (at 100% reduction; ‘F2 AEP to 2006 then SPUG; Figure 7). If no farms agree to sell water rights under the SPUG policy implementation, groundwater storage roughly maintains its present volume, losing approximately 900 mcm (‘F2 AEP to 2006 then failed SPUG’; Figure 7).

The situation could be much different if future climate is characterized by cyclic droughts, rather than the gradual decrease in rainfall, streamflow, and groundwater recharge represented by the ‘Reference’ climate. Under the ‘Dry Cycle’ climate, even if all farm types participate fully in SPUG starting in 2007, groundwater storage is simulated to increase by only 76 mcm relative to the 2006 volume (‘F2 AEP to 2006 then SPUG, Dry Cycle climate; Figure 7). If the SPUG policy fails, with no farms selling water rights, aquifer storage decreases by 3.6 bcm through 2027 - a situation worse than if only the WAP policy had been continued through 2027 under a ‘Reference’ climate. Similar results have been obtained using WEAP in the Sacramento Valley in California where climate projections indicate a strong increase in groundwater pumping to irrigate vegetable crops during drought periods The study shows that prolonged drought triggers adaptation strategies among farmers such as the use of more efficient irrigation technologies and cropping changes that favor rainfed farming (Purkey *et al.*, 2008).

**Figure 7.** Potential trends in groundwater storage in the Guadiana basin.



## 4. Conclusions

- The agro-economic and hydrology integrated framework provides an innovative and policy-relevant tool for the analysis of water management policies at different spatial and temporal scales under different climate scenarios. It permits the prediction of different water policy outcomes across farm types (vulnerability and adaptation), at basin's level (aquifer recovery), and along the EU WFD implementation horizon (short and long run).
- In general, short term water conservation policies that are being implemented in the Upper Guadiana basin, can contribute to reduce water consumption in the farms, but will not be able to achieve, in the aggregate, the recuperation of the WLMA. The desired target of the aquifer replenishing will be met only if the new regional water plan (SPUG) is fully implemented and the long-term environmental and social measures for reducing water abstractions are enforced (purchase of water rights, closing up unlicensed wells, legalization of selected illegal wells, reforestation and rainfed farming programs).

However, the recovery objective will be difficult to meet in case of droughts in spite of the high resilience of ground water to climate change impacts.

- The successful implementation of the regional water plan is dependent on the farmers' willingness to sell their water rights at the prices offered. At prevailing prices, farms with permanent crops (vineyard) are less likely to sell their rights due to lower purchase prices and might question the feasibility of the program.
- In general, water conservation polices that apply a strict quota system can achieve water use reductions at low public costs. However, these policies are likely to be opposed strongly by the farmers that bear the full burden and would entail high enforcement costs to the public authorities. Increasing the direct participation of stakeholders and stronger involvement in the decisions as well as social learning activities are strongly needed for the social acceptance of this type of policies.
- Given that the new trends of agricultural policies encourage water-saving farming, a coordinated and integrated implementation of agricultural and water polices is a key element. It would ensure the dual objective of conserving groundwater resources and maintain farm-based livelihoods at tolerable social costs. This will be best attained avoiding contradictions, finding synergies and reinforcing common objectives.
- The design and enforcement of well-balanced region-specific polices is one of the major tasks of policy makers for achieving successful water management policies. The challenge facing the Spanish regional administration is to implement successfully both EU and regional water policies. At present, the environmental and participatory WFD requirements are providing incentives to better enforce water policies with a higher social acceptance, credibility and legitimization.

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