DESERTIFICATION MITIGATION AND REMEDIATION OF LAND – A GLOBAL APPROACH FOR LOCAL SOLUTIONS

Addendum Report to Deliverable 5.3.1

Additional model outputs for the Spanish hotspot site to identify the likely environmental, environmental and social effects of proposed remediation strategies

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Summary

This report summarizes the findings of in-depth modelling tools applied within WB5 to the Spanish study site. It is an addendum report to deliverable 5.3.1 where the general WB5 modelling results, applied to all study areas are presented. The report is kept brief and primarily aims to point the interested reader to the PhD thesis of Doan Nainggolan where tools are explained in considerably more depth, as well as to a series of papers that have come out of this work. The report exemplifies how modelling tools can be employed to study the dynamics and consequences of land use change under drivers of desertification, here with particular reference to unsustainable water use. The modelling undertaken makes use of land use change analysis, agent-based modelling and input-output analysis.

Scenario analysis to predict land use and land management decisions relies on availability of a time series of aerial photographs and satellite images to construct land cover maps, as well as on the implementation of a resource-intensive land user survey. To estimate the regional effects of land managers' decisions on the regional economy requires the availability of detailed statistical information at the regional level; as a regional input-output table was not available for Murcia, we give some pointers as to how to create one.

1. Introduction[1]

Mediterranean landscapes have seen significant land use alterations involving intensification on the one end of the continuum and land abandonment on the other with profound effects on water and land resources (Hill et al., 2008; Serra et al., 2008). Land use change in the Mediterranean environments is not a recently emerging issue as it is heavily associated with the historical land use especially for agricultural purposes involving land clearing, use of machineries, and overgrazing (Geist and Lambin, 2004; Grove and Rackham 2001; Wainwright and Thornes, 2004). In Mediterranean agro-ecosystems where agricultural activities form the major land use and thus exert the greatest effects on the system, a specific set of driving forces interact to shape land use change in the system. Important drivers are physical (mainly associated with farm characteristics and management regimes imposed on the farm), environmental (i.e. all biophysical elements essential to support crop growth), and socio-economic (e.g. market, subsidy schemes, and land tenure) (UNCCD, 1994; Kosmas and Valsamis, 2001; Garcia-Ruiz, 2010).

Mediterranean environments are unique in that the role of natural forces and anthropogenic influences on land use change and land degradation has been evident for a long time (Brandt and Thornes, 1996). In this particular ecosystem, scarce water availability limits natural recovery process and constrains land productivity (Kosmas et al., 1999; FAO, 2006a; ESA, 2003; and ICIS, 2000). What is more, flood and fire incidences impose more destructive impacts upon these environments (Geist and Lambin, 2004). Conditioned by persistent dry climate with long dry season and periodic droughts, this situation apparently exacerbates the human-driven land degradation problems in these environments (ESA, 2003 and ICIS, 2000).

There is a growing consensus that land degradation results from a combination of causes (Turner et al., 1995; Puigdefabregas, 1998). It involves both natural and human-induced forces, although to isolate one from another poses its own challenge (Baartman et al., 2007). Turner et al. (1995) highlighted that the scales at which key forces (socio-economic and biophysical forces with agents and processes connecting the two which drive land use and land cover change) operate might not necessarily manifest effects at the same scale as of these drivers. Various processes such as overgrazing, unsustainable water use and failed water governance for agriculture, political agendas, urbanization and climatic variability have been identified as drivers of land degradation in Mediterranean environments (Baartman et al., 2007). A consensus has been implicitly established on the fact that the underlying cause of degradation cannot be associated with one particular factor in isolation such as population growth or poverty (UNEP, 1997; Lambin et al., 2001). It is indeed a consequence of sometimes multi-directional, reciprocal interactions between diverse biophysical and socio-economic driving forces. However, different land systems may respond differently to these combined pressures depending upon their biophysical characteristics, historical climatic and human intervention regimes, and their inherent shock absorbing and recovery capacities following perturbations.

In this report, we summarize work undertaken in the framework of WB5 in the Spanish study site in order to analyse processes and consequences of land use change. We report on land use change analysis in the period 1956-2004, and scenario modelling of how the heterogeneity of farmers might affect future land uses under the influence of water resources scarcity – one of the manifestations of land degradation. The latter work consists of an agent-based model to show the likelihood of land use change in a spatially-explicit way, as well as an attempt to investigate the regional economic consequences of land use change.

[1] This section is based on a part of the literature analysis as reported in Nainggolan (2012).

2. Trajectories of land-use change in the Torrealvilla catchment

2.1. Study area[2]

Guadalentin in general has been selected as one of the study sites for DESIRE due to its severity of desertification problem while at the same time the project can build on the documentation of previous EU-scale projects in this area (de Vente and Sole, 2008; Baartman et al., 2007). Rambla de Torreallvilla (Figure 1) has been chosen as the site for this study because it is representative of the multidimensional characteristics of land degradation throughout the Guadalentin basin. Most parts of the sub-catchment are managed for agriculture; hence hereafter it is referred to as the agro-ecosystem. Both dryland and irrigated farming practices are found in this area. The study area in particular makes an interesting site for studying land use change in Mediterranean dryland agro-ecosystems because land use in the area has been changing and human interventions have historically influenced the landscape in various directions. As in other parts of the Guadalentin basin, soil erosion and water scarcity are among the key environmental challenges with strong linkages to land use change dynamics (Lopez-Bermudez et al. 2002; Martinez-Fernandez and Esteve, 2005; Garcia-Ruiz, 2010; Garcia-Ruiz and Lana-Renault, 2011). The biophysical characteristics of the area are inherently susceptible to soil erosion. The Torrealvilla is characterised by a meseta-like plain and an undulating landscape with long pediments and strongly incised river terraces; soils are formed dominantly in highly erodible lithologies (marls and limestones). Dominant soil types include Gypsisols, Fluvisols, and Cambisols (FAO, 2006b). The local climatic conditions are characterised by dry summers and heavy rains in spring and autumn which aggravate the soil erosion problem (Lopez Bermudez et al., 1998; 2002). The mean annual precipitation is between less than 300 to more than 500 mm. Droughts, centred during summers, commonly lasting for more than 4-5 months. The monthly temperature ranges from 12 to almost 17°C with an average of 15°C. Annual potential evapotranspiration rates larger than 1000mm are common in large parts of the basin. The aridity index (UNESCO, 1979) of the basin is dominantly between 0.2 and 0.5 as such the study area is considered to be semiarid. Most recent land uses in the study area consist of rainfed cereals, almond/olive orchards, intensively irrigated horticulture (vegetables), grapes, pig/animal farming, shrubs, and forest. Stipa tenacissima, Rosmarinus officinalis and Anthyllis cytisoides are among the most commonly found semi-natural vegetation in the shrubland. The forests are mainly covered by Pinus halepensis. Administratively, most parts of Rambla de Torrealvilla belong to Lorca municipality. The rest of the study area is shared among three other municipalities: Aledo, Totana and Mula. Within the study area there are three main population settlements namely Torrealvilla, Zarzadilla de Totana and Aledo with totals of population in 2011 of 94, 519, and 1044 respectively. Although figure on employment at village level for the study area is not available, statistics for municipality level for 2011 indicate that agricultural sector is the second most important employment sector in the area.

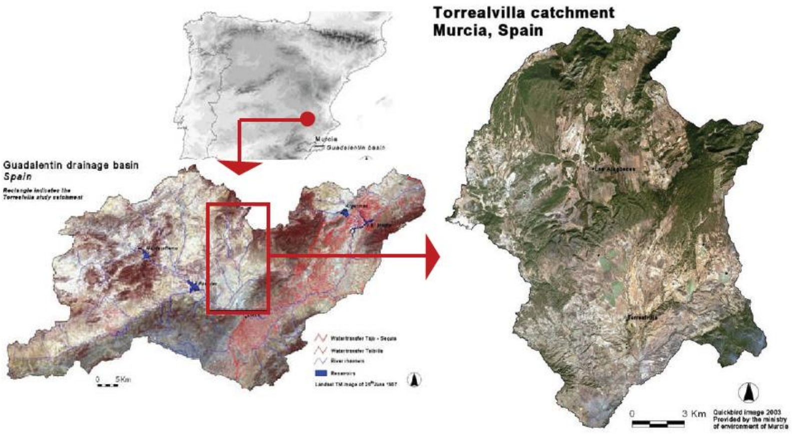

Figure 1. Study site location.

[2] The study area description is taken from Nainggolan (2012).

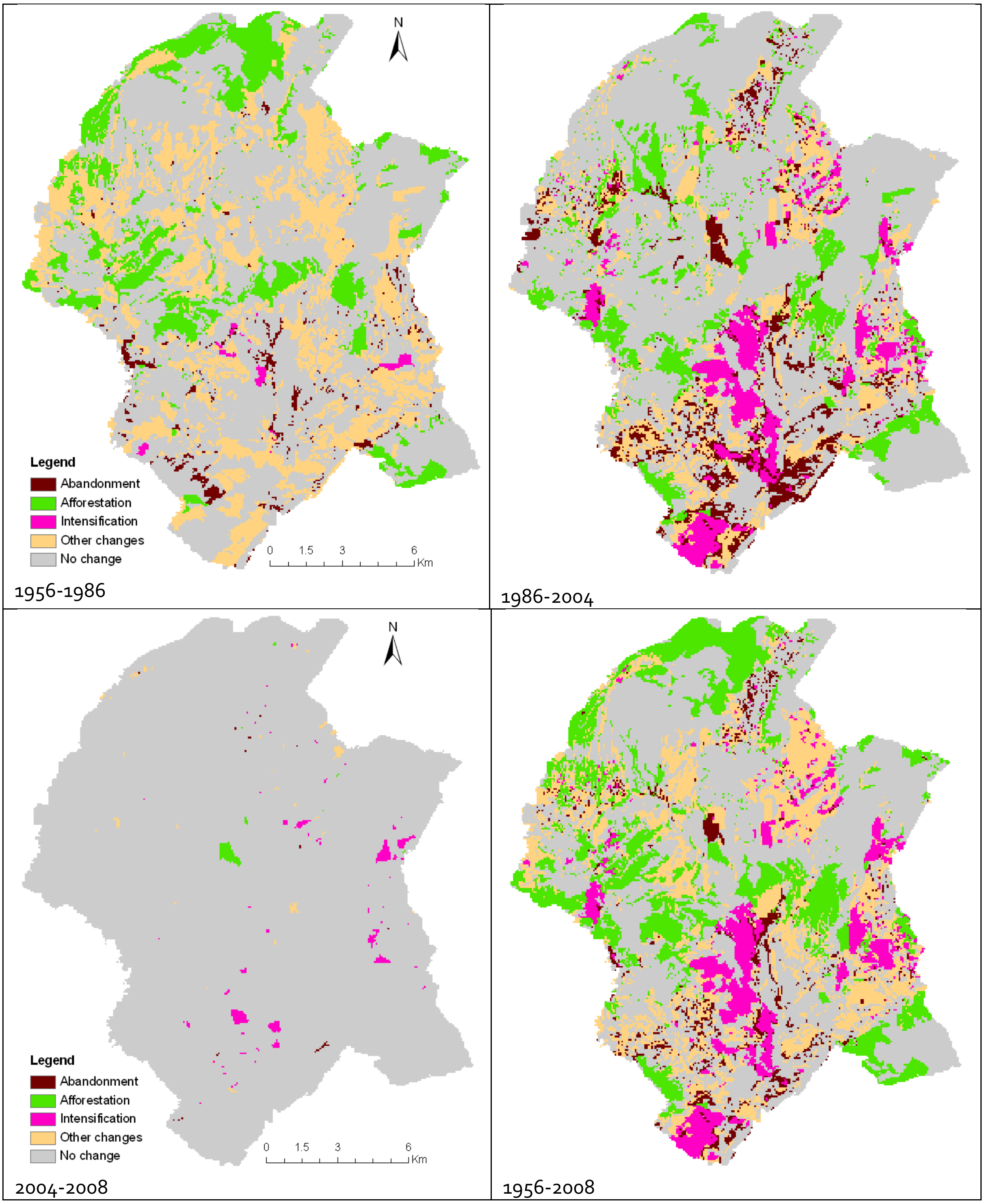

Figure 2. Key land use change trajectories at different periods.

2.2. Land use change analysis[3]

Between 1956 and 2008 Torrealvilla catchment has seen important land use changes involving the expansion of forest patches, abandonment of rainfed farming, and intensification process (Figure 2). The detected land use changes have important implications for landscape fragmentation. The observed changes were

[3] Full details are available in Nainggolan et al. (in press - a).

attributable to various interacting biophysical and socioeconomic drivers. Traditional rainfed agriculture has suffered abandonment due to persistently unattractive market. This abandonment process mainly occurred in areas of greater slope away from road access and settlements. On the contrary, in response to market and to some extent subsidies, intensification process has thriven in flattest parts of the landscape on fertile soils close to road access. It is also important to highlight the increasing prominence of solar panel fields over the recent years which will likely continue especially if the future market for vegetable farming becomes less attractive, water resources are more reduced, and subsidy schemes for solar energy are maintained. Finally, afforestation has also occurred extensively on non productive soil in higher parts of the catchment situated on greater slope gradient. This process may have been favoured by past policies that encouraged reforestation and as a result of vegetation succession from shrubland and abandoned farmlands. Overall, the study shows that even within a locality very contrasting land use trajectories could emerge as a manifestation of local responses to multiple drivers. The findings of this study are relevant for other semi-arid Mediterranean agro-ecosystems elsewhere where multidirectional land use trajectories are inevitable as a result of the interaction of variable biophysical determinants and socioeconomic forces. For a sustainable future management of these vulnerable agro-ecosystems, policy instruments must therefore fully consider the local spatial and socioeconomic heterogeneity, the diversity of potential local responses of farmers managing different land use types to combined effects of market forces and policy packages, and the potential (both positive and negative) feedbacks to the ecosystem. These carefully devised instruments are crucial for navigating the landscape towards sustainably multifunctional uses and may have to combine both incentive based measures and prescriptive regulations.

2.3. Agent based model[4]

For Torreallvilla catchment – Spain an agent based model was developed. The development of the model was informed by key findings from a farmer typology study undertaken for Torrealvilla (Nainggolan et al, in press - b). Six types of farmers were identified. The identified types of farmers can be discriminated by the characteristics of their households and of their farm management. In particular, types of farmers can be distinguished on the basis of their agricultural water access, land tenure, sources of income, household involvement in both on and off farm activities, the availability of future successors, and the diversity of the farmers' agricultural land use. The second part of the study analyses the link between farmer typology and the farmers' responses to a number of scenarios. The scenarios describe different likely changes to agriculture in the catchment in terms of environmental constraints (irrigation water availability and rainfall pattern) and environmental policy regulation (water taxation and subsidies). This exercise enables us to explore the range of future land use changes that are likely to occur in the study area.

The main objective of the agent based modelling is essentially to upscale the findings on the typology of farmers and the potential responses to various scenarios from the sampled farmers to the whole catchment in a spatially explicit way. This modelling approach allows an assessment of the aggregate implication across the landscape of individual farmers' land use decisions. To implement the modelling we ideally need a complete cadastral map of land parcels in Torrealvilla and detailed information regarding the farmers and their farming management characteristics for each individual land parcel. The detailed information is crucial for systematically assigning the typology of farmers for each land parcel. However, we had access only to the cadastral map but no further information regarding individual parcels were accessible. As an alternative we assign farmer characteristics using the distribution of characteristics derived from the agricultural statistics at the municipality level. Thus the set of variables that could be drawn were constrained by available statistics. As the study area lies across four municipalities (Lorca, Aledo, Totana, and Mula), the study area was accordingly split into four zones. Using this stochastic approach we were able to generate demographic and farm management parameters for every agricultural land parcel within the study area. Specifically the approach enabled us to assign age, tenure, household labour for farming, and non household labour for farming. These variables along with the number of agricultural land uses managed by a farmer were found among the key determinants of farmer typology based on the farmer survey mentioned at the beginning of this section.

The next step involves assigning farmer agent type to each individual land parcel. To achieve this, we first estimated a multinomial logit model to establish the relationship between the different farmer and farm

[4] Full details are available in Nainggolan et al. (submitted) and Nainggolan (2012).

management characteristics and the types of farmers. It is important to note that at this stage we worked with five types of farmers instead of the original six considering the limitation of data that could be drawn stochastically following distribution patterns that were available from the agricultural statistics. Nonetheless, the estimates from the multinomial logit model were then used to calculate the probabilities of each individual land parcel belonging to one of the five agent types. Subsequently, an agent type was then allocated by selecting the one with the highest probability. All five agent types were successfully distributed spatially across the study area. The output of the agent type allocation shows interesting clustering patterns for example neighbouring land parcels tend to be managed by similar farmer agent types (Figure 3). The land occupation for the different types of agents across the total agricultural area in the study area is as follows: 26.7% occupied by agent type 1, 7 % by agent type 2, 8 % by agent type 3, 12 % by agent type 4, and 46% by agent type 5. In future, a further examination of the observed agent clustering patterns may be useful to verify the robustness of the agent typology approach that has been developed and used.

Having successfully assigned farmer agent type for all the agricultural land parcels across Torrealvilla catchment, we then simulated the estimated aggregate effect of farmers' reactions to future scenarios in a spatially explicit manner. The farmer agent decisions in the simulation were informed by the probabilities of responses recorded in the farmer survey (Nainggolan et al, in press - b). In the survey we recorded farmer responses as: 1) farming continuation, 2) partial abandonment, 3) land use conversion, and 4) total abandonment.

As an illustration of the output of the simulation, in this report we present the probability of agricultural abandonment under water taxation scenario considering the fact that overexploitation of groundwater is among the pressing land degradation problems in the area. The water taxation scenario specifically explored how farmers would respond to groundwater taxation imposed by the government which would result in increased water costs. The scenario was presented relative to the farmers' current water costs and their individual maximum threshold beyond which the maintenance of present farming activity would be perceived by the farmers as being no longer viable. This scenario assessed the potential effectiveness of monetary based instruments that may be used by the government to regulate groundwater use. The simulation output shows that the introduction of groundwater tax higher than farmer's maximum threshold for affordable water cost can drastically result in more than half of the irrigated agricultural lands in the catchment being at high risk of abandonment (probability of 0.5 – 1). For comparison at similar probability level, only 18% of these irrigated areas are prone to abandonment in the case of groundwater taxation at a level resulting in a water price of up to the individual farmer's maximum threshold for affordable water cost (Figure 4).

Box 1. A brief description of the five agent types of farmers in Torrealvilla, Spain

Agent type 1 consists of older (>55 years old), low income landowners who are mainly managing rain-fed agriculture. ***Agent type 2*** is a group of younger tenant farmers (none > 55 years old). None of the farmers in this group own the land they manage and the contract period for the land rental is definite (fixed term tenancies). Farmers within this cluster are relatively new to farming and the majority are full-time irrigated agriculture farmers. ***Agent type 3*** is associated with relatively young farmers who mostly own the land they work on. They are mainly involved in managing irrigated agriculture. The farmers in this category are highly specialised on one particular land use. ***Agent type* 4,** in many respects, has the characteristics similar to those of agent type 3. The key differentiating features between the two are the age and education level of the farmers; farmers belonging to this group are older and the majority only have primary education. The proportion of agent type 4 farmers managing land for diverse agricultural products is low. One of the key characteristics of farmers belonging to ***agent type 5*** is that they financially benefit from managing multiple agricultural land uses and from subsidy scheme participation. Their intensive production is supported both by their own family labour and externally sourced labours. On average, they have been working in agriculture for many years (mean 37 years).

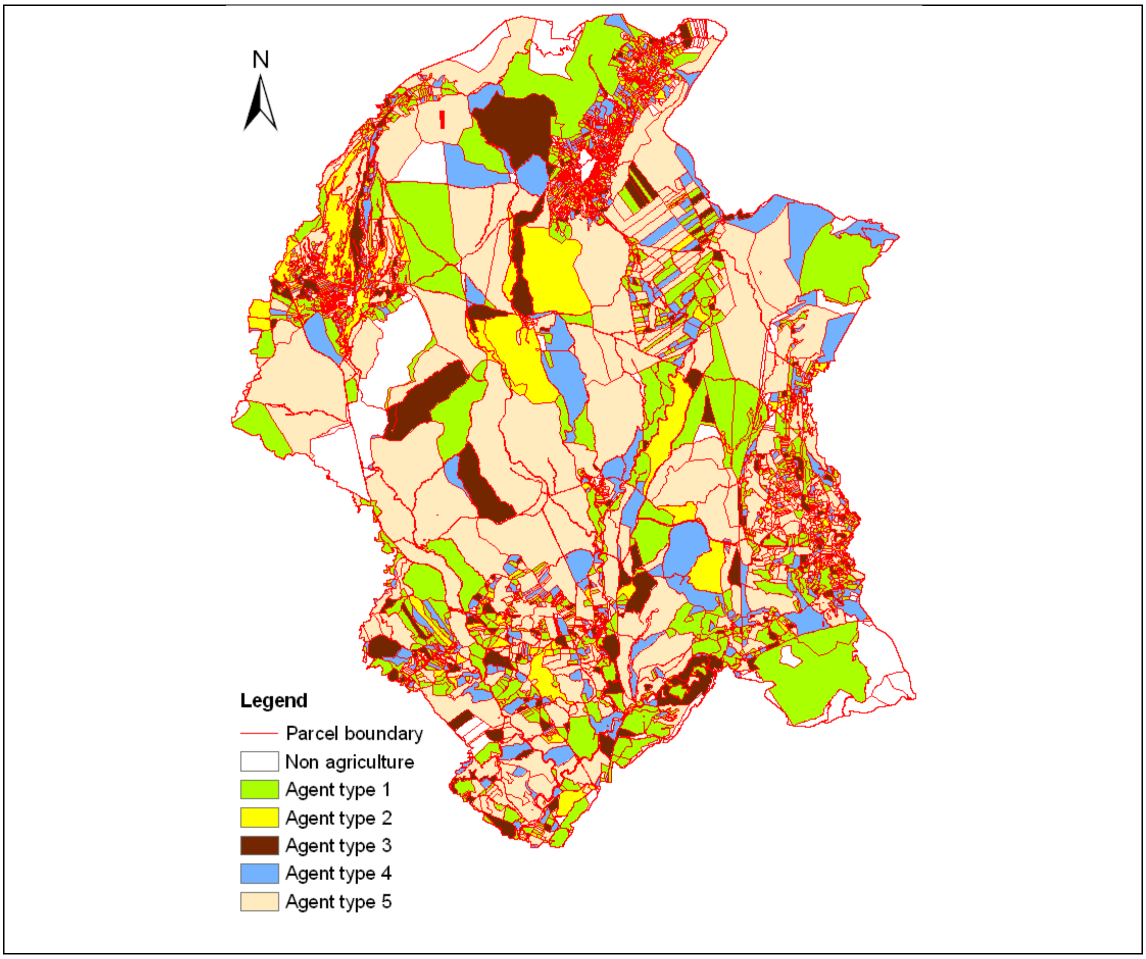

Figure 3. Spatial distribution of different types of farmers in Rambla de Torrealvilla catchment, Spain.

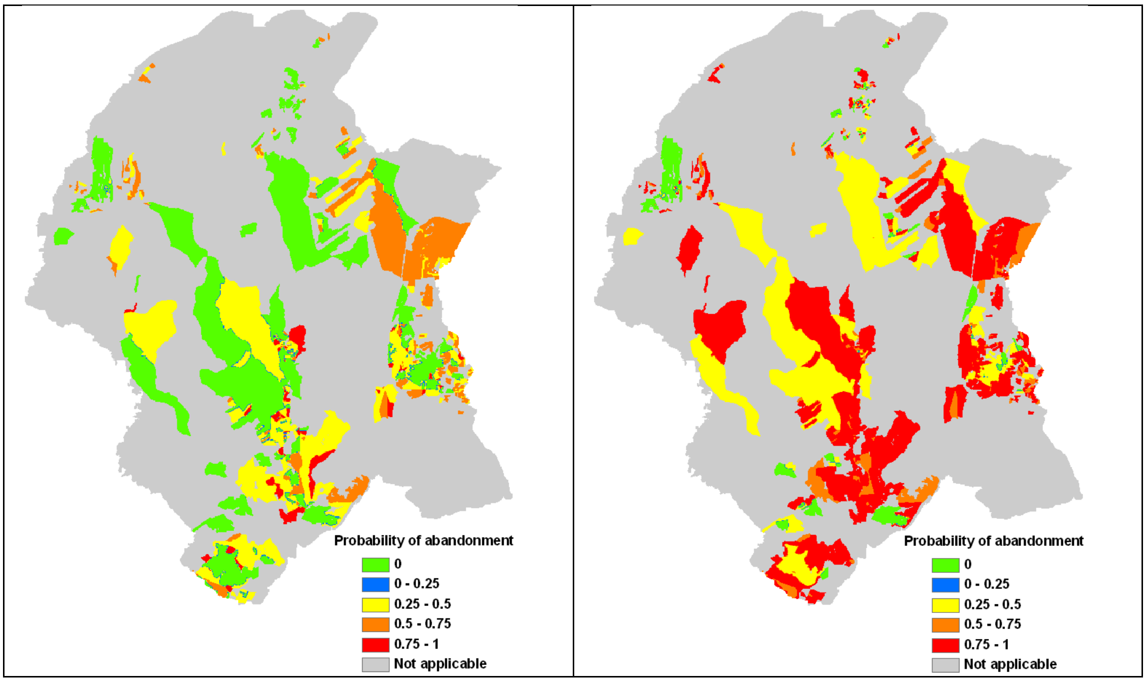

Figure 4. Simulating the likelihood of agricultural abandonment as different types of farmers responding to water taxation scenarios of government imposes tax on groundwater abstraction resulting in a water price of 1) up to the individual farmer's maximum threshold for affordable water cost (left map); and 2) higher than the threshold (right map).

3. Input-output model application to water resources management in Murcia[5]

3.1. Introduction

The Region of Murcia, despite being hot and dry, has witnessed remarkable agricultural development over the last decades. However, its agricultural sector is premised on heavy overexploitation of groundwater resources and reliance on the Tagus–Segura inter-basin water transfer (IBWT) scheme, which was inaugurated in 1979 (Garrido et al., 2006; Grindlay et al., 2011). The region has become known as a major producer of fruits and vegetables. This is reflected in the importance of agriculture in the economy (8.3% of regional employment and 5.8% of regional gross added value against 4.5% and 2.6% at the national level, respectively), but most significantly by the fact that agricultural exports make up 35.4% of Murcia's total exports (CREM, 2010). For the past thirty years, regional water demand in the Segura basin has surpassed availability as a combined effect of increased irrigation and rapid urbanization (Grindlay et al., 2011). As a result, ironically, the IBWT scheme has only further aggravated the region's chronic water shortage. The water thirst of the region is stressed by many authors, with Garrido et al. (2006, p.347) classifying the Segura basin as 'one of the most interesting cases of water conflicts in Spain, and perhaps worldwide'. Ambitious but highly contested plans for a further Ebro–Segura IBWT scheme have for the time being been put on hold. Simultaneously, the European Water Framework Directive (WFD) prescribes that water should be priced at full-cost recovery and water resources and fluxes should be systematically monitored. The WFD further stresses institutionalising environmental water demands at par with societal and economic water demands. As a consequence, the Tagus–Segura IBWT may be limited by allocating more water within the conceding basin (Martínez-Santos et al., 2008), and prices of groundwater extraction would also rise (Garrido et al., 2006). In this context, water users generally have great uncertainty over water availability and regulations governing its use.

3.2. Methodology

As the agricultural sector is embedded in the regional economy, shifts in competitiveness of land uses can have important knock-on effects on other sectors. We combine discrete choice based interviews (DCI) with an input-output model to assess not only the direct aggregate effects of individual land use decisions, but also of indirect effects on the regional economy and associated water use. Setting up the I/O model requires several intermediate steps (only very briefly explained here). The DCI were obtained from a farm survey among farmers in the Torrealvilla catchment. The effects of the DCI-elicited land use change scenarios can be assessed with the I/O model. We also triangulate the DCI responses by using virtual water multipliers in the I/O framework.

3.2.1. Input-Output model

I/O analysis, initially developed by Wassily Leontief (1936) and still widely used today, is a method to analyse interrelations between sectors of an economy. To perform I/O analysis, one needs to construct an I/O matrix (usually provided by national statistical offices) which represents the intersectoral flows of products (usually in monetary terms and for a specific time period – i.e. a year) from each of the sectors (producer) to each of the sectors (purchaser) (Miller and Blair, 2009). These intersectoral flows are relatively stable: e.g. to produce a unit worth of margarine a more or less fixed quantity of oilseeds is needed. The stability of unitary intersectoral flows, which have become known as inter-industry technical coefficients, is a fundamental assumption of the I/O model. Once an I/O matrix is constructed, I/O modelling entails the analysis of changes in final demand, inter-industry coefficients or value added through a system of linear equations. A symmetrical set of I/O tables containing 73 x 73 sectors is available for Spain for 2005, produced by the National Statistics Institute (INE, 2009). I/O tables have been constructed for many Spanish autonomous regions, but not for Murcia. Therefore we needed to construct a regional I/O table based on the national one. A well-known problem in constructing regional I/O tables is that inter-industry technical coefficients are prone to be

[5] Based on Fleskens et al. (2012). The text as included here was presented at the field excursion of the final DESIRE project meeting in Almeria, Spain.

exaggerated as the propensity of sectors to import is inversely related to the size of the economy considered (Boomsma and Oosterhaven, 1992; Harris and Liu, 1998; Flegg and Tohmo, in press). We applied the method described by Flegg and Tohmo (in press), building on earlier work by the same author(s), which takes this issue into account. We subsequently tested the method by comparing the output multipliers from non-survey I/O tables based on various location quotient approaches with those from survey-based I/O tables which are available for the neighbouring autonomous regions Valencia and Andalucía.

3.2.2. Disaggregating the agricultural sector of the regional I/O table

We are interested in the effects of agricultural land use changes and therefore need to subdivide the single agricultural sector into a series of agricultural subsectors. These are defined based on importance of land use, extent of recent changes and differences in water use and economic dissimilarity: 1) grains and other annual field crops; 2) horticulture and fruit trees; 3) grapes; 4) olives and almonds; and 5) livestock. Various regional agricultural statistics were used to achieve this.

3.2.3. Estimating regional final demand and sector output

Most required final demand data for Murcia were obtained from CREM (2010). National sector final demand scaled down using employment data was used to fill regional data gaps. Good regional data on exports were available. As expected, the regional and national level data bear little relation, both in overall size (regional exports were 20 times larger than the scaled national data) and structure (r^2=0.07). After deciding on the location quotient method to employ, the regional total final demand vector was substituted in the IO accounting equation to estimate total regional output. Agricultural sector output data was available from CREM (2010) and was used in further analyses together with simulated output for industrial and service sectors.

3.2.4. Creating water I/O table

Regional water statistics (CREM, 2010) were available as a basis to calculate sectoral water use for agriculture (data relating to year 2005) and industry (year 1999), but not for services. Data for 2007 from the piped water distribution network used in economic sectors and the available statistics were used together with equivalent data from Andalucía (Consejería de Medio Ambiente, 1996) and Spain (INE, 2010) to calculate Direct Water Consumption (DWC) and to harmonise sectoral water consumption (Table 1). Agricultural water productivity in Murcia is high in comparison with Andalucía and Spain. In the case of Murcia, grains and olives and almonds are hardly irrigated. The bulk of water is used in producing high value fruit and vegetable crops. The high DWC in Andalucía may stem from significant water use in low value crops (grains) and relatively wasteful irrigation techniques: 45% of irrigation is by gravity (Dietzenbacher and Velázquez, 2007). In contrast, in Murcia 85% of water is supplied to crops by drip irrigation (CREM, 2010). Backward linkages water multipliers represent how much water is used indirectly in a given sector by considering the water consumption for its intermediate consumption in relation to direct water use. Forward linkages water multipliers represent the ratio of additional water use in purchasing sectors relative to the direct water consumption 'embedded' in output from the supplying sector considered.

3.2.5. Water scarcity scenarios and farmers' land use responses in Torrealvilla catchment

Interviews were administered with farmers within the Torrealvilla catchment (266 km^2 of which 140 km^2 qualifies as Usable Agricultural Area (UAA) of the Guadalentin Basin in Murcia. In total 99 valid interviews were carried out. Sampling was done using the snowball method, making sure all land uses (see Table 2) were covered. The final number of respondents was 7 for grains, 24 for almonds and olives, 32 for grapes, 24 for horticulture and fruits and 12 for livestock. In part, the interviews were intended to capture farmers' responses to hypothetical scenarios that reflect future uncertainty of water availability. The scenarios were developed based on insights gained through discussions with farmers in the area during preliminary site visits. Different scenarios were presented to farmers who currently have access to water and those who do not. The former group of farmers was asked how the following will affect the future of their current principal land use:

- Scenario A – No access to water for agricultural use (total water depletion or deterioration);
- Scenario B – Government imposes tax on groundwater abstraction resulting in a water price higher than

maximum willingness to pay for water[6]; and

- Scenario C – Government imposes tax on groundwater abstraction resulting in a water price of up to the individual farmer's maximum WTP.

Farmers' responses were: 1) no change; 2) conversion to other agricultural land uses; and 3) stop farming/abandonment.

In contrast, farmers who currently do not have access to water were asked how their principal agricultural land use may alter if water became available, e.g. through IBWT. This led to a fourth scenario (D):

- Scenario D1 – Water becomes available to previously non-irrigable areas.
- Scenario D2 – as Scenario D1, but for the grain farmers we adopted weights of conversion to irrigated farming as elicited from olive and almond farmers (i.e. increasing propensity of grain farmers to change).

The responses registered in Scenarios D1 and D2 were: 1) no change; 2) increase production (expansion); and 3) conversion to irrigated agriculture. For the purposes of expansion we assumed only the 140 km^2 of UAA in Torrealvilla catchment to be available.

Table 1. Direct water consumption of selected sectors.

Sectors	Water consumption calculated with available data			Harmonized water consumption data	
	Murcia*	Andalucía*	Spain*	Murcia	
	DWC (litre €$^{-1}$)			DWC (litre €$^{-1}$)	DWC (10^3 m^3)
Agriculture	274	-	395	274	563,096
Grains	190	1833	-	190	6,979
Horticulture and fruits	345	683	-	345	468,832
Grapes	505	695	-	505	52,440
Olives and almonds	179	655	-	179	17,836
Livestock	37	15	-	37	17,009
Fisheries	0	0	0	0	0
Industry	2.4	-	0.7	2.1	21,770
Agro-food industries	3.5	3.3	0.9	3.3	9,242
Paper, printing and publishing	0.3	38.3	0.4	0.2	90
Chemical industry	8.1	25.0	1.3	4.5	6,374
Rubber and plastics	3.6	2.0	2.1	4.7	1,038
Metallurgy	2.4	3.6	0.5	2.6	1,692
Construction	-	2.4	0.2	0.2	208
Services	1.5	-	0.7	1.5	31,209
Hotels and restaurants	10.4	18.3	-	3.8	8,358
Education	-	5.0	-	2.0	2,018
Health and social services	-	5.0	-	2.0	3,173
Public administration	2.0	4.7	-	2.0	3,288
Other community and personal services	-	13.3	-	2.8	4,188

* Sources: Murcia – authors' calculations based on available statistics (CARM, 2010); years of estimates vary: 2005 for agriculture, 1999 for industry, and 2007 for services. Andalucía – based on Consejería de Medio Ambiente (1996), using a conversion rate of 1 EUR = 166 ESP. Spain – based on INE (2010).

3.2.6. Upscaling local scenario responses to the Murcia region

As all interviews were conducted within the Torrealvilla catchment area, we must take into account the relative shares of each land use when upscaling to the Region of Murcia. We thereby assume that there are no differences in the agricultural production structure of subsectors between the local and regional area. Regional effects of the DCI-elicited responses to water uncertainty scenarios can now be assessed with the I/O tables. Total regional effects are defined as the sum of direct effects and the combined backward and forward indirect effects (Grêt-Regamey and Kytzia, 2007). An analogous procedure is followed to assess the direct and indirect effects of the changed total sector water demands.

3.2.7. Effect of increased water cost on sector unitary output prices

With the preceding steps, we can now simulate the impact of increased water costs on sector unitary output prices. We will assume that increased costs for water only apply to agricultural water use, assuming that other

[6] WTP individual farmers: lowest €0.20 m^{-3}; highest €0.60 m^{-3}; average €0.31 m^{-3}; standard deviation €0.08 m^{-3}

sectors already pay more for water (e.g. twice as much in neighbouring Almería province – Downward and Taylor, 2008). A so-called virtual water multiplier (VWM) can be used to calculate product price increase as a result of water price increase (the VWM itself representing a price increase of €1). We will present the effects of a price increase of €0.10 m^{-3} – equal to the average incremental WTP (€0.04 m^{-3}) plus one standard deviation (€0.06 m^{-3}) to account for possible understatement (the range of incremental WTP was €0.00–0.25 m^{-3}). The cumulative effects of the water price increase, through water input-output relations, on product prices can help to understand farmer responses to the discrete choice scenarios.

Table 2. Current and future land use (area percentage) in Torrealvilla and Murcia under different scenarios.

	Current	Percentage of total land					Percentage of current land use (=100)				
		A	B	C	D1	D2	A	B	C	D1	D2
Torrealvilla:											
Livestock	1.0	0.0	0.2	0.7	2.0	2.8	0.0	19.7	68.9	196.7	275.4
Vegetables & fruits	10.3	0.0	0.2	4.2	17.1	23.1	0.0	1.9	40.3	164.0	221.5
Grapes	2.7	0.1	0.3	1.1	13.4	13.4	3.6	10.9	40.1	488.0	488.0
Olives & almonds	27.2	12.1	9.9	17.6	15.3	15.3	44.5	36.4	64.7	56.2	56.2
Grains	35.2	36.0	35.6	36.2	31.8	24.9	102.3	101.2	102.9	90.4	70.8
Non-used UAA	23.4	51.8	53.8	40.2	20.5	20.5	221.2	229.8	171.7	87.6	87.6
Murcia:											
Livestock	1.7	0.0	0.3	1.1	2.3	2.5	0.0	17.8	65.1	136.2	148.0
Vegetables & fruits	18.9	0.0	0.4	7.6	23.1	24.9	0.0	2.1	40.2	122.2	131.8
Grapes	5.8	0.2	0.7	2.3	10.9	10.9	3.5	12.1	39.9	188.9	188.9
Olives & almonds	17.5	8.2	6.6	11.6	11.4	11.4	46.7	37.6	66.1	65.0	65.0
Grains	10.2	11.7	11.0	12.0	12.0	10.0	114.3	107.5	117.2	117.2	97.7
Non-used UAA	45.9	79.9	81.1	65.3	40.2	40.2	174.2	176.8	142.4	87.7	87.7

Source: current land use determined from satellite imagery (Torrealvilla) and regional statistics (Murcia); scenario results calculated from discrete choice interviews. See main text for description of scenarios.

3.3. Results

3.3.1. Regional I/O Table for Murcia with disaggregated agricultural sector

The regional I/O table constructed for Murcia was evaluated by applying the same method to neighbouring autonomous regions for which survey-based I/O tables were available: Andalucía and Valencia. This informed the selection of an appropriate LQ to develop a non-survey based regional input-output table for Murcia. Table 3 shows details about the disaggregation of agriculture in five subsectors at the regional scale. All subsectors except livestock occupy sizeable shares of the region's agricultural area (11-36%). However, in terms of output value, grains (2%), grapes (5%) and olives and almonds (5%) contribute only modestly compared with livestock (22%) and especially vegetables and fruits (66%). As a result, productivity per area unit ranges widely. Production structures of the subsectors are therefore also expected to vary considerably. The backward output multipliers of individual subsectors of the disaggregated I/O table varied between 1.22 for vegetables and fruits and 1.86 for livestock (Table 4). The first reflects that relatively little economic activity is generated by producing an Euro worth of horticultural produce, whereas the opposite holds for livestock. Individual agricultural sectors have forward multipliers of 2.11-2.28, which demonstrates that much of their produce is sold to upstream industries. The vegetables and fruits subsector (1.31) is an exception, as produce is not processed in agro-industries but marketed to consumers and – importantly – exported. For all agricultural subsectors, forward linkages are higher than backward linkages. Agro-food industries and construction are sectors with high backward linkages, whereas construction materials and lumber industries have high forward linkages.

3.3.2. Regional I/O Table of water use

Agriculture consumes about 80% of total ('blue') water use in Murcia: households consume about 15%; and other economic sectors together account for only 5%. Not surprisingly, technical coefficients of water use are a fraction of the technical coefficients based on the monetary value of intermediate consumption. The water multipliers (both backward and forward) of the agricultural subsectors are thus low in comparison to output multipliers (Table 4). Livestock is the subsector with the highest backward water multiplier (1.65): its intermediate consumption relies on water-intensive inputs. Grains have the highest forward multiplier (1.28): the sectors grains are supplied to use a considerable amount of water, whereas water needs for grains are relatively low. Similarly, vegetables and fruits have the lowest non-zero forward water multiplier (1.03). Very little additional water is used to produce output in processing sectors (which moreover absorb only a limited part of total vegetables and fruits output). The modest water multipliers for agricultural subsectors contrast with some of the water multipliers in industries and services. Backward multipliers are very high for lumber and cork industries (33.71), agro-food industries (13.60), and paper, printing and publishing (10.74). These sectors thus require water-intensive inputs totalling several times their direct water demand. Machineries and mechanical equipment (23.06) and financial brokerage (18.46) have very high forward water multipliers: their output is produced with relatively low amounts of water, but the output of purchasing sectors requires a multiple factor total water input.

Table 3. Summary data of agricultural subsectors.

	Output (M€)	Area (10^3 ha)	Productivity (€ ha^{-1})	Water use (Mm^3)	(m^3 ha^{-1})	(m^3 €$^{-1}$)
Livestock	455.5	10.0[a]	45550[a]	17.0	1701	0.04
Vegetables & fruits	1357.1	111.9	12129	468.8	4190	0.35
Grapes	103.9	34.2	3041	52.4	1535	0.50
Olives & almonds	99.7	103.9	960	17.8	172	0.18
Grains	36.7	60.6	606	7.0	115	0.19
Total	2052.9	311.1		563.1		

Source: based on various regional statistics (CREM, 2010) and secondary data.
[a] Livestock farming is intensive (i.e. not land-based, two-thirds of output value is pork) and does not appear in regional land use statistics. A nominal area of 10,000 ha has been assumed for this subsector.

Table 4. Output and water multipliers for selected sectors in the regional economy of Murcia.

Sectors	Output multipliers		Water multipliers	
	Forward	Backward	Forward	Backward
Agriculture (current land use configuration)	1.60	1.38	1.09	1.06
Grains	2.28	1.48	1.28	1.17
Horticulture and fruits	1.31	1.22	1.03	1.02
Grapes	2.18	1.36	1.07	1.10
Olives and almonds	2.27	1.41	1.14	1.11
Livestock	2.11	1.86	1.23	1.65
Fisheries	1.15	1.27	1.00	1.00
Industry				
Agro-food industries	1.31	1.80	1.81	13.60
Lumber and cork industries	1.96	1.60	10.40	33.71
Paper, printing and publishing	1.76	1.41	11.50	10.74
Chemical industry	1.50	1.41	2.71	1.26
Machineries and mechanical equipment	1.45	1.34	23.06	4.89
Construction	1.44	1.77	3.13	4.60
Services				
Trade (incl. servicing of vehicles)	1.31	1.41	11.49	3.59
Hotels and restaurants	1.08	1.25	1.05	1.74
Financial brokerage	1.58	1.28	18.46	2.31
Education	1.04	1.12	1.12	1.18
Health and social services	1.07	1.29	1.14	1.36

Source: input-output model results; see main text for procedures and assumptions made.

3.3.3. Discrete choices and land use change scenarios in Torrealvilla

When farmers with current access to water were asked what their strategy would be if water resources would be completely depleted, the vast majority would give up farming (Figure 1, Scenario A). A sizeable minority (43%) of olive and almond farmers would not change land use, a strategy also followed by 3% of vineyard managers. Remaining farmers would resort to rainfed cropping. A similar pattern emerged when the same group of farmers was confronted with high (perceived) water taxation (Scenario B); again the most common response was abandonment. Continuation of the current land use was the preferred strategy of 36% of olive and almond farmers, 17% of livestock farmers, 12% of vineyard managers and only 2% of horticulturalists and fruit growers. Some vineyards and fruit orchards would convert to olive and almond groves and grains, respectively. Under low (perceived) water taxation (Scenario C) the majority (67% and 64%) of livestock and olive and almond farmers would continue current land use. However, 54% of vineyard managers and 52% of horticulturalists and fruit growers would abandon their enterprises whereas 40% would continue. Some 17% of livestock farmers and 8% of horticulturalists and fruit growers would opt for a change to grains, and 5% of vineyard managers would switch to olives and almonds. These three discrete choice scenarios show that water availability and affordability is a crucial factor for all with current access to water, particularly for horticulture and fruit growing, vineyards and livestock farming. Figure 1 also shows scenarios presented to farmers who currently do not have access to water. If a new IBWT project would be realized, some unused land would start to be cultivated to grains (8%) and olives and almonds (5%). Olive and almond groves would see considerable conversion to horticulture and fruit growing (24%) and vineyards (21%). Moreover, 14% of grain fields would be developed to vineyards. Overall, olive and almond farmers demonstrated the most dynamic choices. If the changes above were to occur, land use in the Torrealvilla catchment would change as shown in Table 2.

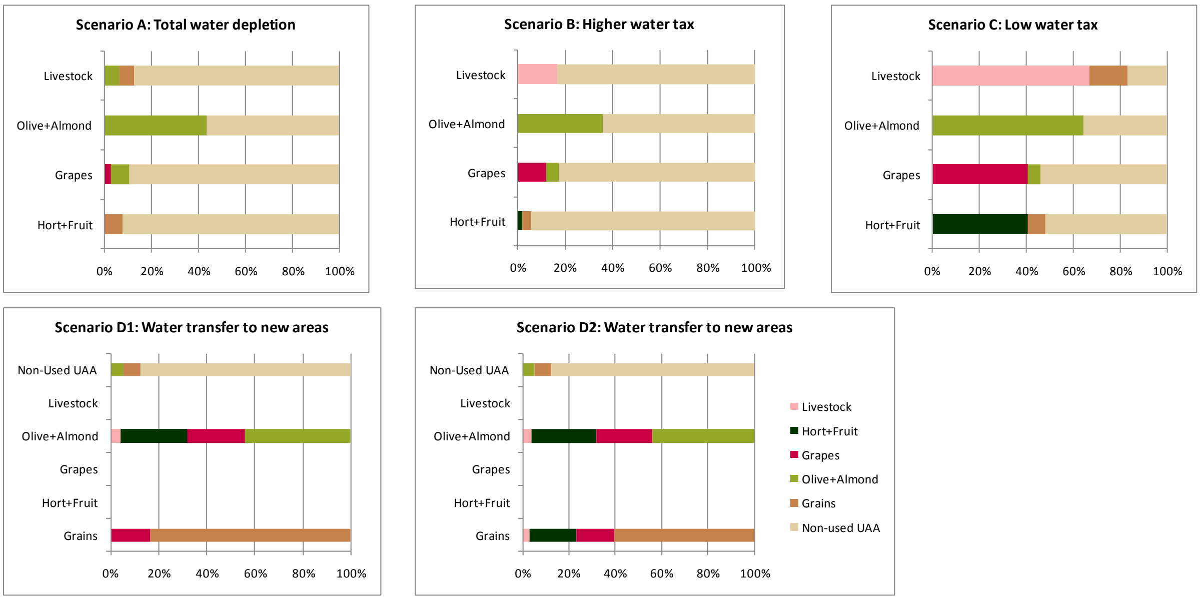

Figure 1. Land use changes under different scenarios in Torrealvilla catchment as recorded from discrete-choice interviews.

3.3.4. Regional effects of land use change scenarios

When we simulate the effects of the discrete choice scenarios in the input-output model, the land use change scenarios driven by uncertainty in water supply result in diverging effects on regional economy and water demand (Figure 2). The total water depletion scenario almost eradicates the agricultural sector, and when taking into account forward and backward linkages leads to a shrinking of the regional economy of 14%. As all irrigated agriculture disappears in this scenario, this scenario reduces the demand for water to about 18% of the current level. A high water tax has just slightly lower impact. A low water tax impacts the regional economic output by 7% while reducing water demand to almost half the current level. A new water transfer may lead to 4-5% economic growth while requiring 23-30% more water compared to current regional demand. The ratio of economic impact to water demand reveals interesting results. When left to abandonment because of a total depletion of water, with the loss of each cubic metre of water output decreases by €5.57. When introducing a high water tax this ratio is reduced to €5.36 per m^3, whereas a low water tax results in a loss of €4.85 per m^3. Increased water availability similarly augments regional economic output by €5.63-5.86 per m^3.

3.3.5. Water price effects

Table 5 shows the effects of 'acceptable' agricultural water price increase on the product price of each sector. Although the horticulture and fruits subsector uses more water, it produces more output per unit of water and hence the effects of water price increases are not as pronounced as for grapes and olives and almonds. The 'acceptable' water price increase represents almost 50% of the currently paid average price and leads to agricultural product price increases between 0.6 and 5.6%, with three out of five subsectors being affected by over 3%. Agro-food (0.4%) and lumber and cork (0.1%) industries are the two non-agriculture sectors where a price effect is notable.

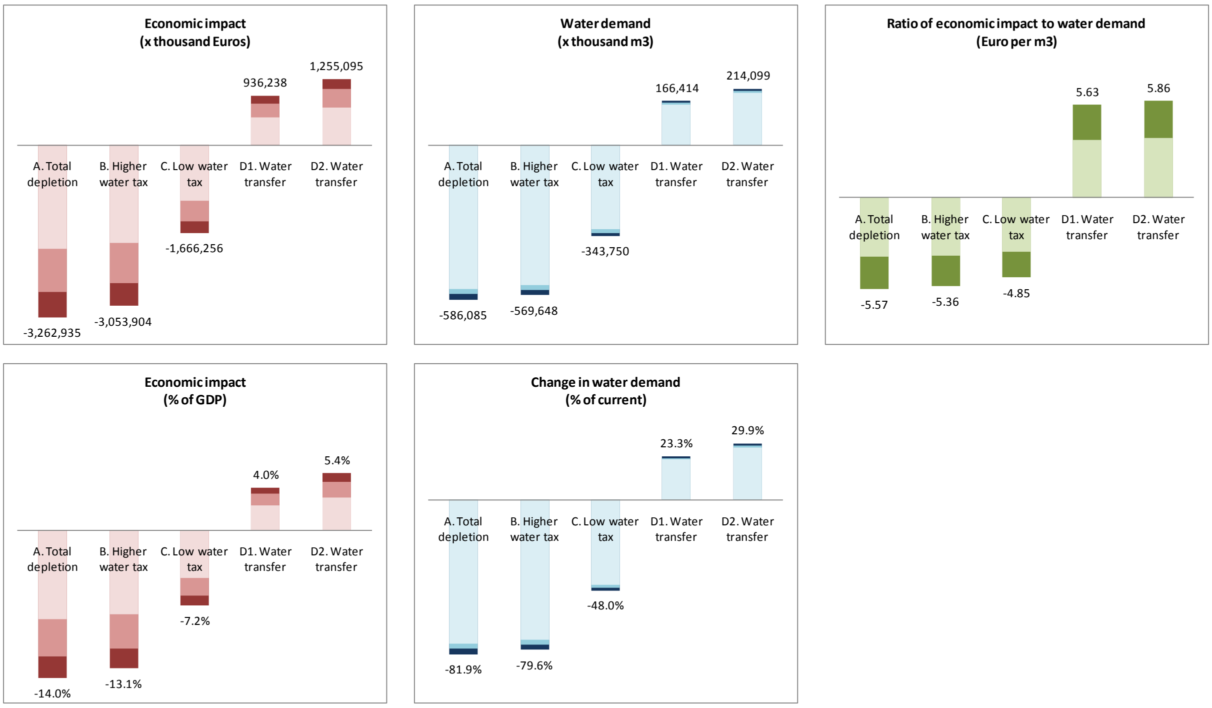

Figure 2. Direct and indirect effects of scenarios on the regional economy and water demand.

Table 5. Impact on output price of selected sectors as a result of price increases for agricultural water use.

Sectors	Virtual Water Multiplier (litre €$^{-1}$)	Impact on product price of a water price increase of €0.10 m^{-3} (%)
Agriculture		
Grains	221.96	2.22
Horticulture and fruits	353.95	3.54
Grapes	558.36	5.58
Olives and almonds	379.69	3.80
Livestock	62.12	0.62
Fisheries	0.43	0.00
Industry		
Agro-food industries	43.50	0.44
Lumber and cork industries	11.81	0.12
Paper, printing and publishing	1.84	0.02
Chemical industry	0.30	0.00
Rubber and plastics	0.97	0.01
Construction	0.20	0.00
Services		
Trade (incl. servicing of vehicles)	0.60	0.01
Hotels and restaurants	2.69	0.03
Health and social services	0.25	0.00
Public administration	0.38	0.00
Other community and personal services	1.01	0.01

Source: input-output model results; see main text for procedures and assumptions made.

3.4. Discussion

- The I/O table for Murcia needed to be constructed first to enable subsequent scenario analyses. Without survey-based I/O tables for neighbouring regions we would probably have run a high risk of substantially overstating impacts of scenarios. The methods for disaggregating the agricultural sector and constructing the water I/O table can, given similar data availability, more confidently be applied in other contexts.
- The ratio of economic impact to water demand (Figure 2) can be interpreted as follows: when confronted with high barriers to water use (total depletion, high water tax), farmers tend to give up farming. In these

cases the economic consequences are high in relation to changes in regional water demand. However, the introduction of a low water tax prompts a significant number of farmers to change land use instead of abandonment. As a consequence, reductions in water use are obtained, resulting in about 10% lower impact on the regional economy per unit of water saved than under a higher water tax scenario. Potential water savings are impressive: a low water tax can reduce total water demand by almost 50% at a 7% cost to the regional economy. Important gains can be achieved in setting the water tax level right: significant water savings can be achieved at relatively low expense to the regional economy by incentivising self-organizing capacity of the agricultural sector. Stronger intervention (through higher taxation) fails to take advantage of this self-organizing capacity and although it may generate higher tax revenues, much of it will be necessary to recover from the inefficiency it created in the first place.

- Given the questionable sustainability of groundwater extraction rates, it is of particular concern that agriculture in Murcia has become so heavily dependent on this finite and dwindling resource. Our results show that without groundwater and IBWT, about two-thirds of the region's agricultural area would be abandoned. Agricultural output would be decimated to less than 5% of its current value. Even the introduction of a low water tax would still lead to about 35% of the agricultural area being abandoned, with an associated loss of more than half of the current output. Whereas our farmer survey using discrete choice scenarios may have led to exaggerated responses, this clearly illustrates how vulnerable respondents feel to uncertainty in water supply. Surprisingly, results of increased water prices (Table 5) have the highest impact on grapes and almonds and olives. This contrasts with the land use decisions elicited from DCI interviews, where horticulture and fruits are the first to be abandoned or switched: perhaps the latter crops are perceived as more sensitive to water shortages.
- Additional water supply through IBWT may lead to a 10% expansion of the agricultural area, with an associated increase in agricultural output of 26-35%. The ratio of economic impact to increased water demand of such an expansion is high (€5.63-5.86 per m^3), suggesting that additional water will be used efficiently and an accelerated growth may result. The economic multiplier is, at 1.75, higher than currently obtained, reflecting the combined effect of water and extra land as production factors. Although this sounds promising, it further increases water-dependency of the regional economy. In addition, the assumption of stable technical coefficients inherent to input-output models might be too optimistic here as land onto which irrigation can be expanded may not be as productive as the currently irrigable area. Strikingly, the farmers' discrete choices may reflect this, with only a minority of grain farmers and slightly over half of olive and almond farmers envisioning land use changes to horticulture and fruits or vineyards.
- The amount of water transferred through the Tagus–Segura IBWT scheme was greatly reduced in 1994/5 and 2005-7 as a consequence of a cap on the transfer if the conceding basin experiences water shortage (Figure 3). In the latter period, the contribution of the IBWT to total irrigation dropped to 8% from 54% in 2002/3. This massive reduction is partly compensated for by increased pumping of groundwater resources. The drop in total irrigation may point at a number of potential issues: a) pumping capacity installed is too low to fully compensate for significant reductions in IBWT water; b) not all areas benefiting from the IBWT can switch to groundwater resources if required; or c) the economic cost of pumping exceeds (€0.12 – €0.54 m^{-3}) by far the price (€0.09 m^{-3}) paid for IBWT water (Tobarra González, 2002). Although a mix of these issues may have occurred, the clear peak of local irrigation clearly suggests that a sizable number of farmers have been willing to pay an additional €0.03 to €0.36 per m^3 water. This is in good agreement with our field data.
- Currently, the economy of Murcia produces €39.26 per m^3 of water used – over 8 times as efficient as would be achieved with new IBWT development. As a consequence, the regional economic output per cubic metre of water would drop below €30. Compare that with the over €90 per m^3 that results from the low water tax and it is clear that better alternatives are available. Admittedly, the first option leads to regional economic growth of 4.4% while the latter to a contraction of 6%, but intermediate solutions should be available that warrant growth while improving water use efficiency.

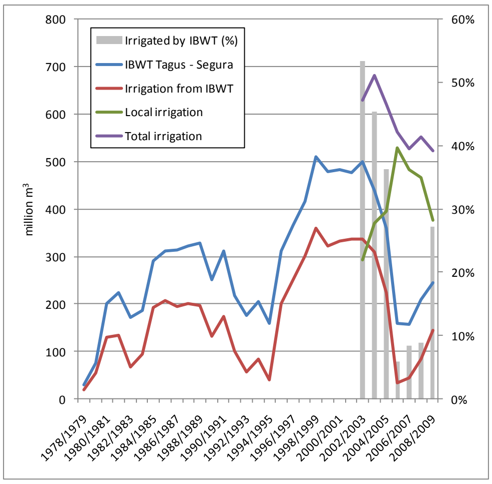

Figure 3. Historical data of water obtained from inter-basin water transfer Tagus–Segura. Source: CREM (2010).

3.5. Conclusion

Agriculture in the Region of Murcia has increasingly become dependent on blue water resources. Current water availability for irrigation is threatened by continuous overexploitation of groundwater resources, increased competition from non-agricultural (and in some cases illegal) uses, and conflicts over inter-basin water transfer – all in the context of global environmental change. The regional government has a tremendous challenge to reduce overexploitation of water resources and reduce vulnerability of the regional economy to water scarcity. At the same time, the region's farmers feel trapped in water-dependent productivity and fear any reform that negatively affects their resource base. We evaluated the effects of farmers' responses to discrete choice scenarios on the regional economy and water demand by means of input-output modelling. Our results confirm that agriculture is heavily dependent on blue water resources, and farmers see no option to continue farming if confronted with complete water depletion (physical water scarcity) or high levels of water taxation (economic water scarcity). These scenarios would lead to very large reductions in water use by agriculture, but also result in a contraction of the regional economy by more than 13%. A low water tax scenario indicated that some farmers may change land use as a result. Although still leading to a contraction of the regional economy by 7%, this scenario showed that the agricultural sector has a self-organizing capacity to deal with some of its water use inefficiency. Any water tax reform should take stock of this capacity and create synergy between incentives for water use efficiency and government intervention. Resolving water scarcity through new IBWT development may lead to regional economic development (4-5%) but only increases the region's dependency on water. By linking survey-based data from individual land users and an input-output model, a regional impact analysis can be performed. In doing so, we were able to show that although water taxation only has relatively minor effects on product prices, it has the potential to lead to dramatic land use changes with considerable economic impact. Likewise, considerable environmental benefits seem within reach as reduced water use in the economy will benefit areas of ecological importance and might replenish some of the depleted groundwater resources, which could be crucial to prepare for future environmental change.

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