1. Annex 1: Prospective Model for Household Water Demand (HWD)

This model is used to simulate future scenarios of water demand based on data on economic growth (current and future trends), population growth (current and future trends at a local – municipality – level), water prices, income per capita, price/income elasticity, water use coefficients, etc. The model can also be used as a financial tool to estimate the effects over tax revenue and water demand of different cost-recovery policies, based on the investment and maintenance costs of water infrastructures.

The model assumes that the increase/decrease in household water demand is a consequence of the number of users (*scale effect*) adjusted by the effects that prices and income may have on individual water demand. This basic idea reveals the relationship that exists between the water demand growth rate and the set of independent variables that determine water demand (at a municipality level):

$$g_{AFi} = \left[(1 + g_{Ni})\left(1 + \epsilon_p g_{pi} + \epsilon_y g_{yi}\right) - 1\right] \qquad [1]$$

Where:

g_{AFi} is the water demand growth rate (billed water) in the municipality *i*.
g_{yi} is the income growth rate in the municipality *i*.
g_{pi} is the price increase in the municipality *i*.
g_{Ni} is the population growth rate in the municipality *i*.
ϵ_p is the price elasticity of household water demand in the municipality *i*.
ϵ_y is the income elasticity of household water demand in the municipality *i*.

$1 + g_{Ni}$ is the scale effect and it determines the final effect of water price and income growth rates on water demand. For example, should water demand be independent from water prices and income, it would vary at a constant proportion to population growth. This is the over-simplistic scenario behind traditional water demand forecasts that is still used by some holistic models; consequently, this assumption is commonly found in several river basin management plans across the EU. However, it has been shown that water demand increases with higher income, while it falls when water prices are higher (Martínez-Espineira, 2002, 2003a and 2003b; Martínez-Espineira and Nauges, 2004; Hoffman et al., 2006; Gaudin, 2006). As a result, any valid economic forecast needs to take into account these two variables as well. Understanding and estimating this relationship is of paramount importance for the water planner. For example, it would allow limiting the negative effects of higher income/population growth rates over water demand through higher prices.

This relationship can also be expressed using the number of households instead of the number of inhabitants, as follows:

$$g_{AFi} = \left[(1 + g_{Vi} + g_{\theta i})(1 + \epsilon_p g_{pi} + \epsilon_y g_{yi}) - 1\right] \quad [2]$$

where:

g_{Vi} is the growth rate of the number of primary houses in the municipality *i*.

$g_{\theta i}$ is the growth rate of the average household members in the municipality *i*.

This function is preferred to the previous one, as it is usually observed that there are economies of scale in water usage per person in larger households (Höglund, 1999).

In addition, should one want to account for water leakages due to the inefficiencies in the water transportation and distribution network, one could use the following formula:

$$g_{ADi} = \left[(1 + g_{Vi} + g_{\theta i})(1 + \epsilon_p g_{pi} + \epsilon_y g_{yi}) - 1\right] - g_{fdi} \quad [3]$$

where:

g_{ADi} is the growth rate of the total amount of water distributed in the municipality i.

g_{fdi} is the growth rate of the efficiency rate in the water transportation and distribution network.

In this last equation we show the whole set of policies that the water planner has at hand: water pricing and efficiency improvements in the transportation and distribution network. There are other variables that are exogenous but nonetheless affect water demand: namely, population and income.

Water demand relationships above depend on factors that are highly volatile throughout time and space, and therefore need to be obtained at a municipality level. Accordingly, to develop proper forecasts of water demand we combine the observed values at a municipality level with the economic and population forecasts available (usually at a national level). The software developed by IMDEA based on this methodology provides water demand forecasts for 2015, 2021, and 2027. Obviously, the accuracy of these forecasts will be lower the larger is the time span considered. Results are available at a municipality, province (NUTS 3) and basin level, displaying:

- Water demand (i.e. billed water) in the baseline, 2015, 2021, and 2027.
- Total amount of water delivered in the baseline, 2015, 2021 and 2027.
- Finally, using some coefficients, these values can be used to estimate the total amount of pollutants that are spilled over the river (baseline, 2015, 2021, and 2027).

1.1 References

Gaudin, S., 2006. Effect of price information on residential water demand. Applied Economics 38, 383–393.

Hoffman, M., Worthington, A.C. and Higgs, H., 2006. Urban water demand with fixed volumetric charging in a large municipality: the case of Brisbane, Australia. Australian Journal of Agricultural and Resource Economics 50, 347–359.

Höglund, L., 1999. Household demand for water in Sweden with implications of a potential tax on water use. Water Resources Research, 35, 12, 3853-3863.

Martínez-Espiñeira, R., 2002. Residential water demand in the northwest of Spain. Environmental and Resource Economics, 21, 161–187.

Martínez-Espiñeira, R., 2003a. Estimating water demand under increasing-block tariffs using aggregate data and proportions of users per block. Environmental and Resource Economics, 26, 5–23.

Martínez-Espiñeira, R., 2003b. An estimation of residential water demand using cointegration and error correction techniques, Working Papers, St Francis Xavier University, Canada. Available at: http://www.stfx.ca/ [Last accessed, 10/06/2013].

Martínez-Espiñeira, R. and Nauges, C., 2004. Is really all domestic water consumption sensitive to price control? Applied Economics 36, 1697–1703.

2. Annex 2: Revealed Preference Model (RPM)

This annex presents a revealed preference model that uses basic microeconomic theory to calibrate and simulate farmers' preferences and decisions. This model allows for the assessment of several policies of different sign and it can be implemented in different areas and contexts. This model is based upon the works by Gutiérrez and Gómez (2011) and Gutiérrez *et al.* (2013).

2.1 The empirical model

In our model farmers decide on cropland areas trying to maximize their welfare, which is a function of a set of relevant attributes that may contain expected profit, risk avoidance, managing complexities and/or others. This decision is constrained by technical, economic, policy, and environmental variables. It is assumed that the outcome stemming from this optimization problem results from an underlying utility function that can therefore be calibrated provided all relevant variables are measurable and known. These include water prices, irrigation costs, water availability, irrigation efficiency as well as other relevant economic, agronomic and environmental variables.

According to all this the following decision problem is formulated:

$$\underset{x}{\mathrm{Max}}\, U(x) = U(z_1(x);\ z_2(x); z_3(x) \dots\ z_m(x)) \qquad [1]$$

$$\text{s.t.:} \quad 0 \leq x_i \leq 1 \qquad [2]$$

$$\sum_{k=1}^{n} x_k = 1 \qquad [3]$$

$$X \in F(x) \qquad [4]$$

$$z = z(x) \in R^m \qquad [5]$$

Where $x \in R^n$ is the decision profile or the crop portfolio showing one way to distribute land among crops and each x_i measures the share of land devoted to crop *i*, including a reservation option (x_n) consisting of rainfed agriculture. Each crop has its own water demand, which may either be satisfied or not according to water availability and irrigation efficiency, thus generating a predictable yield/profit with an attached risk, management complexities, etc. (or the set of attributes, z).

Farmers have preferences over attributes of the decision profile (z(x)). For example, farmers might prefer decisions with high-expected profits, highly predictable yields and prices and not too many managing actions besides planting and harvesting.

Finally, F(x) represents the space of feasible decision profiles, given the resource, policy, economic, and balance constraints.

The first problem one needs to deal with to reveal farmers' preferences is to know which ones among potentially relevant attributes are relevant to explain the observed decision. Our method to answer this question consists of stating that the relevant set of attributes is the one to which the observed decision is closest to the attribute possibility frontier. In real situations this efficiency frontier cannot be analytically defined with a closed mathematical function and the only way to represent it is via numerical methods. One practical solution consists in plotting a line from the origin, going through the observed decision attributes and extending them as far as possible in the space of feasible attributes. This way we can measure the distance from the observed attributes to the efficiency frontier attributes. This procedure can then be repeated for any set of potentially relevant attributes and the best candidate to reveal farmers' preferences will be the one which is closest to its associated efficiency frontier.

The solution to this problem will be an application assigning a distance φ_l ($l = 1, \dots, 2^m$) to each member of the power set P(z)[1]. The relevant set of attributes will be the one with the lower distance to the efficiency frontier measured by the parameter $(\varphi - 1)$. In synthesis the preference-eliciting problem can thus be presented as:

$$\underset{\tau}{\mathrm{Min}}\ \varphi_l - 1 \qquad [6]$$

Where:

$$\varphi_l = \mathrm{ArgMax}\left[(\varphi)\ \mathrm{s.t.}\ \tau(x) = \varphi\big(\tau_o(x)\big);\ 0 \leq x_i \leq 1;\ \textstyle\sum_{k=1}^{n} x_k = 1;\ X \in F(x); \text{for all }\ \tau \epsilon P(z)\right] \qquad [7]$$

$$l = (1 \dots . 2^m) \qquad [8]$$

By solving this problem the set (τ^*) of attributes that better explains current farmers' decision is obtained. Among the many factors that might be of relevance in farmers' preferences, this set of attributes is the one that takes the observed decision closer to the attribute efficiency frontier. If this calibration procedure takes us close enough to the efficiency frontier we can obtain the implicit value of all the attributes over the efficiency frontier by analysing how attributes change in the surroundings of this reference point, and this information is everything that is needed to integrate a utility function representing farmers' preferences[2].

Using basic economic principles and knowing the efficiency frontier in the surroundings of the observed decision allows one to integrate such a utility function. Rational decisions imply that, in equilibrium, farmers' marginal willingness to pay in order to improve one attribute with respect to any other is equal to the marginal opportunity cost of this attribute with respect to the other. In other words, the marginal transformation relationship between any pair of attributes over the efficiency frontier

---

[1] A power set P(Z) is the set of all the 2^m subsets of the set Z and the power set $P_0(Z)$ is the set formed by the 2^m subsets of the numerical set of observed attributes.

[2] The optimal solution of φ and the reference point in the efficiency frontier provide all the information to measure the calibration error in the atributes space.

(MTR_{kp}) is equal (in equilibrium) to the marginal substitution relationship between the same pair of attributes over the indifference curve tangent to the observed decision (MSR_{kp}):

$$\beta_{kp} = MTR_{kp} = MSR_{kp} = -\frac{\partial U / \partial z_p}{\partial U / z_q}; p, q \in (1,..l); p \neq q \qquad [9]$$

This information for the reference point over the efficiency frontier is enough to integrate a utility function leading to the observed decision as the optimal decision given the existing resource, economic, balance and policy constraints. For example, if we assume a constant-returns-of-scale Cobb-Douglas utility function of the kind:

$$U(\tau) = \prod_{r=1}^{l} z_r^{\alpha_r}; \quad \sum_{r=1}^{l} \alpha_r = 1 \qquad [10]$$

The marginal substitution relationship among any pair of attributes is:

$$-\frac{\partial U / \partial z_p}{\partial U / z_q} = -\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p} \qquad [11]$$

And the parameters of the Cobb-Douglas utility function are obtained from the following system:

$$-\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p} = \beta_{kp} \qquad [12]$$

$$\sum_{r=1}^{l} \alpha_r = 1 \qquad [13]$$

In the results section we use this type of function, which offers the advantage of having a unique solution. The problem is then solved using microeconomic data at an agricultural district level (the smallest agricultural administrative division in Spain).

2.2 Calibration errors

The revealed preference model above provides three types of calibration errors which gives an idea of the accuracy of the model's adjustment:

-The distance between the observed attributes and the attribute efficiency frontier:

$$e_f = (\varphi - 1) \qquad [14]$$

-The distance between the observed attributes and the calibrated ones:

$$e_\tau = \frac{1}{l}\sum_{r=1}^{l}\left(\frac{\left(z_r^{0\,2} - \tau_r^{*\,2}\right)^{1/2}}{z_r^0}\right) \qquad [15]$$

-The relative distance between the observed crop pattern and the optimal one:

$$e_x = \frac{1}{n}\sum_{k=1}^{n}\left(\frac{\left({x_k^o}^2 - {x_k^*}^2\right)^{1/2}}{x_k^o}\right) \qquad [16]$$

And the mean calibration error is defined as follows:

$$e \frac{\sqrt{e_x + e_\tau + e_f}}{3} \qquad [17]$$

2.3 References

Gutiérrez-Martín, C. and Gómez, C. M., 2011. Assessing Irrigation Efficiency Improvements by Using a Preference Revelation Model. Spanish Journal of Agricultural Research. 9, 4, 1009-1020.

Gutiérrez-Martín, C., Pérez-Blanco, C.D., Gómez, D.M., Berbel, J., 2013. Price Volatility and Water Demand in Agriculture. A Case Study of the Guadalquivir River Basin (Spain). In Economics of Water Management in Agriculture (in press).

3. Annex 3: Risk Assessment Model (RAM)

The fair risk premium is the key element in the design of any commercial insurance and is estimated as the ratio between the expected indemnity (a function of the expected losses) and the expected production in a reference year (in this case, a normal or average hydrological year). The expected indemnity and the expected production are estimated from the assessment of the historical evolution of the insured good, in this case water availability. The following methodology allows for the calculation of these values and the resulting fair risk premium through the development of a risk-production model which depends on three stochastic variables (rainfall, runoff and stock) and a set of institutional decision rules. The model is a five-tiered one:

i) The first tier calculates the amount of water available in different scenarios and its associated probability, which is assumed to be a function of three stochastic variables: rainwater, runoff and stored water (SRBA, 2008).

ii) The second tier estimates the amount of water delivered to the irrigation system in accordance with a set of decision rules (SRBA, 2013).

iii) The third tier obtains in first place the expected evapotranspiration. This value and the results in i) and ii) are used to calculate the percentage of evapotranspiration satisfied and the water demand in excess of available resources (irrigation deficit), as well as the incentive to engage in illegal abstractions.

iv) The fourth tier develops a deterministic agronomic model which estimates the yield of every crop as a function of the percentage of evapotranspiration satisfied obtained in iii).

v) Finally the fair risk premium is estimated as the ratio of the expected drought indemnity to the expected production value.

3.1 First Stage: Water availability

In Campo de Cartagena, which belongs to the Sistema Cuenca sub-basin, the water authority allocates scant irrigation resources according to water availability in the reservoirs and the annual runoff in the whole SRB. Consequently, water availability in Campo de Cartagena is a function of the local rainfall and of annual runoff and water stock in reservoirs in the basin. Local rainfall is scarce and has a negligible incidence over runoff or water stock in the SRB due to the downstream location of Campo de Cartagena. In addition, water stock not only depends on annual runoff, but also on the runoff of precedent years. As a result, we treat rainfall, runoff and stock as independent variables. In the following sections we obtain the probability density function (PDF) of the three variables in order to determine the probability associated to every level of water availability.

3.1.1 Rainfall

Rainfall is a stochastic variable that can be adjusted to a PDF. This allows assigning a probability ($y = z(p)$) to each rainfall level (p). This function is obtained as the best-fit gamma function of the following type (Gómez and Pérez, 2012):

$$y = z(p|a,b) = \frac{1}{b^a \Gamma(a)} p^{a-1} \exp(\frac{-p}{b}) \quad [1]$$

where a and b are, respectively, the scale and the shape parameters. Table 1 presents the maximum likelihood estimators (MLEs) of this function's parameters. Data used corresponds to the period 1941-2008 (MARM, 2011).

Table 1: Rainfall Gamma function. The dependent variable is mm of rainfall.

Variable	Coefficient
a (scale)	16.358[a]
	(2.821)
b (shape)	22.9964[a]
	(2.286)
No. of observations	68

Estimated by maximum likelihood. Standard errors in parentheses.

a: significant at 1 the per cent level.

Source: Authors' elaboration from MARM, 2011

Rainfall satisfies plants' water needs in Campo de Cartagena through the effective rainfall directly captured by crops.

3.1.2 Runoff

Annual runoff is measured as a percentage over the storage capacity of the reservoirs in the river basin. Following Gómez and Pérez (2012), we adjust the runoff to a gamma PDF.[3] This allows assigning a probability (q) to each runoff level (r). The Gamma function can be represented as follows:

$$q = f(r|a,b) = \frac{1}{b^a \Gamma(a)} r^{a-1} \exp(\frac{-r}{b}) \quad [2]$$

Table 2 shows the best-fit parameters for the runoff function. Data used corresponds to the period 1941-2008 (MARM, 2008).

3 Runoff values range from 0% to 225% over the river basin dam storage capacity.

Table 2: Runoff gamma function. The dependent variable is the percentage of runoff over the total surface water storage capacity.

Variable	Coefficient
a (scale)	6.1813[a]
	(1.088)
b (shape)	0.1143[a]
	(0.012)
No. of observations	68

Estimated by maximum likelihood. Standard errors in parentheses.
a: significant at the 1 per cent level.
Source: Authors' elaboration from MARM, 2008

3.1.3 Water stock in reservoirs

Following Gómez and Pérez (2012) we adjust the PDF of the level of available stored surface water by using the Weibull function. This function allows for assigning a probability (w) to each amount of water stored (s), measured as a percentage of the storage capacity. The Weibull function can be represented as follows:

$$w = j(s|a,b) = \frac{b}{a}\left(\frac{a}{b}\right)^{b-1} \exp\left(-\left(\frac{s}{a}\right)^{b}\right) \quad [3]$$

Table 3 shows the MLEs of the parameters in the function above. Data used corresponds to the period 1941-2008 (MARM, 2008):

Table 3: Surface water stored: Weibull function

The dependent variable is the percentage of dam stored water over dam storage capacity.

Variable	Coefficient
a (scale)	0.3411[a]
	(0.063)
b (shape)	4.1286[a]
	(0.497)
No. of observations	68

Estimated maximum likelihood. Standard errors in parentheses.
a: significant at the 1 per cent level.
Source: Authors' elaboration from MARM, 2008.

3.2 Decision rules

At the onset of every irrigation season, the water authority estimates the amount of water required for irrigation (TIR)[4] according to the crops available in the sub-basin and their historical evapotranspiration data. Then, the water authority assesses annual runoff and water availability in the reservoirs and determines the amount of water to be delivered to agriculture.

Traditionally, the percentage of TIR effectively met followed discretional decision rules. This situation changed with the approval of the DMPs, which clearly establish a set of drought thresholds with specific restrictions associated. Nonetheless, DMPs still offer the possibility to follow discretional criteria during exceptional junctures (e. g., during extreme droughts or after a lasting drought to speed up the recovery) (SRBA, 2008), so actually both decision rules are in force.

3.2.1 Traditional decision rules to determine water delivery for irrigation

Unlike the situation created by the recently approved drought plans, the decision rules followed thus far have been the result of a combination of social agreements, opinions of expert judges and discretion with no written rules to be applied in any case, depending on the water available for the crop season. To formalize these decisions, we use the available data on the amount of water effectively delivered to farmers measured as a percentage of TIR satisfied. Available data span a range of 15 years (1992 to 2007) (SRBA, 2013). We found that the only relevant variable explaining the percentage of TIR satisfied in the past has been the runoff (r)[5]. The relationship between the percentage of TIR satisfied ($h(r)$) and runoff is linear (Gómez Ramos et al., 2001). The parameters of the function are estimated using ordinary least squares[6].

[4] Spanish river basins estimate TIR as the amount of water required to cover the 80th percentile of annual historical evapotranspiration with a global efficiency of the water provisioning system of 60%.

[5] Stored water (s) was not found to be statistically correlated with the percentage of TIR satisfied, which could be a consequence of the small storage capacity of the Segura River Basin. The ratio of reservoir storage capacity (1,141 hm^3) over average yearly water use (1,905 hm^3) is only 60% in the SRB, far lower than that of the drought-prone Guadalquivir River Basin (238%) and the rainfall-abundant Ebro River Basin (90%).

[6] For values of TIR over 100%, the function is truncated and equals 1.

Table 4: Irrigation resources estimation under the traditional decision. The dependent variable is a percentage of TIR conceded in the SRB.

Variable	Coefficient
r	1.351[a]
	(.131)
R2	0.89
Adjusted R2	0.88
No. of observations	15

Estimated by maximum likelihood. Standard errors in parentheses.
a: significant at 1 the per cent level.
Source: Authors' elaboration from SRBA (2010b)

3.2.2 DMP decision rules over water for irrigation

The recently approved DMP for the SRB quantifies the particular situation at hand and the harshness of the problem by using an objective and publicly observable drought index dependent on the values of the annual runoff and stock ($I_e(r,s)$). The drought index is calculated as follows (SRBA, 2008):

$$I_e = \begin{cases} \frac{1}{2}\left(1 + \frac{B_i - B_{med}}{B_{max} - B_{min}}\right), if\ B_i \geq B_{med} \\ \frac{1}{2}\left(\frac{B_i - B_{min}}{B_{med} - B_{min}}\right), if\ B_i < B_{med} \end{cases} \quad [4]$$

where B_i is an indicator that is unique for each sub-basin. In *Sistema Cuenca*, which is Campo de Cartagena's corresponding sub-basin, B_i is obtained as follows:

$$B_i = \frac{2*DSC*r + DSC*s}{3} \quad [5]$$

where r is the runoff as a percentage of the total dam storage capacity (DSC) and s is the water stock in reservoirs as a percentage of the total DSC. Using r and s maximum, minimum and average values during the reference period, we obtain B_{max}, B_{min} and B_{med}, respectively.

The DMP establishes the following four drought thresholds: i) when water stored levels are regarded as *normal* ($I_e > 0.5$), there are no explicit restrictions, and thus water delivery is the same as in the baseline or traditional decision rules scenario; ii) water for irrigation is reduced by 10% ($h = 0.9$) when available water falls below the pre-alert threshold ($0.35 < I_e \leq 0.5$); iii) if the alert limits are exceeded ($0.2 < I_e \leq 0.35$), water for irrigation is reduced by at least 25% ($h = 0.75$); and iv) in emergency situations ($I_e \leq 0.2$), water for irrigation is halved ($h = 0.5$) (SRBA, 2013).

3.2.3 Combined decision rules

We define $l_{r,s}$ as a discrete water restriction variable whose value depends on the drought index (and thus on runoff and stock values):

$$l_{r,s} = \begin{cases} \min(h(r), 0.5), if\ I_e \leq 0.2 \\ \min(h(r), 0.75), if\ 0.2 < I_e \leq 0.35 \\ \min(h(r), 0.9), if\ 0.35 < I_e \leq 0.5 \\ h(r), if\ I_e > 0.5 \end{cases} \quad [6]$$

Water delivered for irrigation is thus a function of runoff and water stock in reservoirs ($TIRr(r,s)$):

$$TIRr(r,s) = l_{r,s} * TIR \quad [7]$$

3.3 Third stage: Evapotranspiration satisfaction, irrigation deficit and illegal abstractions

We measure the expected crop evapotranspiration (ET) for every irrigated ligneous crop in La Campiña according to the Spanish Ministry of the Environment (currently Ministry of Agriculture, Food and the Environment) standard method, using data for the period 1941 to 2009 (MARM, 2011)[7]. The evapotranspiration thus obtained is partially covered by effective rainfall. Effective rainfall (ER) is a function of stochastic rainfall, whose PDF was obtained in [1], and a series of parameters that can be safely assumed constant (Cuenca, 1989)[8]:

$$ER = g(p) \quad [8]$$

The part of evapotranspiration (ET) that is not covered by effective rainfall is the irrigation water requirement (WR):

$$WR = ET - g(p) \quad [9]$$

WR can either be satisfied from irrigation or left uncovered, depending on the available water resources and on the prevailing decision rules. The total amount of water delivered for irrigation was estimated in the previous section ($TIRr(r,s)$). Nonetheless,

[7] MARM methodology follows a combination of the Thornthwaite and Penman-Monteith Methods (see, for example, Allen et al., 2006).

[8] Effective rainfall (ER) is estimated using the Soil Conservation Service–USDA methodology for Spain (Cuenca, 1989), and it is a function of humidity deficit (f(D)), rainfall (p) and evapotranspiration (ET). It is measured in annual mm:

$ER = g(p) = f(D) \cdot [\,1{,}25\ p^{0{,}824} - 2{,}93] \cdot 10^{\,0{,}000955 \cdot ET}$

only a share of the $TIRr(r,s)$ effectively contributes to satisfy evapotranspiration due to water losses during the abstraction, transportation and irrigation stages. The effective irrigation resources ($EIR(r,s)$), or the part of the irrigation resources that effectively satisfy evapotranspiration, is a function of $TIRr(r,s)$ and the overall efficiency of the irrigation system (e_{sys}), around 87% in Campo de Cartagena (SRBA, 2013):

$$EIR(r,s) = TIRr(r,s) * e_{sys} \quad [10]$$

The percentage of the evapotranspiration satisfied ($\%ET$) can now be obtained from the previous equations, as follows:

$$\%ET_{r,s,p} = \frac{g(p)+EIR(r,s)}{ET} \quad [11]$$

Each $\%ET$ has an associated probability ($u(r,s,p)$), which depends on stock, (s), runoff (r) and rainfall (p) values. Using expressions [1], [2] and [3] this probability can be expressed as follows:

$$u(r,s,p) = f(r) * z(p) * j(s) \quad [12]$$

The expected evapotranspiration satisfaction (E_{ET}) and the resulting expected irrigation deficit (ID) and potential groundwater depletion are defined as follows:

$$E_{ET} = \int_{r=0}^{225} \int_{p=0}^{1300} \int_{s=0}^{100} [z(p) * g(p) + f(r) * j(s) * EIR(r,s)] \quad [13]$$

$$ID = ET - E_{ET} \quad [14]$$

$$PotGW = \frac{ID}{e_{gw}} \quad [15]$$

where e_{gw} is the efficiency of illegal groundwater abstractions in the SRB, estimated at 25% (SRBA, 2008).

3.4 Fourth stage. Agronomic production functions and production value

The agronomic production of a given crop largely depends on available water, either from rainfall or irrigation. However, making the production function of a crop dependent only on the evapotranspiration satisfied implies that other variables that may affect the production function (soil type, fertilizers and pesticides, climatic variables, etc.) are excluded. On other hand if we consider this set of variables constant it is still possible to develop sound and rigorous agronomic production functions which provide results close to observed values (SCRATS, 2005; Pérez et al., 2011). Thus we obtain the agronomic production in kg ($Q_{p,s}$):

$$Q_{r,s,p} = f(\%ET_{r,s,p}, k) \quad [16]$$

The reference agronomic production functions for the crops considered are obtained after a comprehensive literature survey. Then these functions are adapted to the characteristics of the area of the case study, if there are not site-specific production functions (MARM, 2010; SCRATS, 2005). To do so it is assumed that the local features have fixed effects that shift the reference agronomic production functions but maintain their elasticity and marginal productivity. Resulting production functions are quadratic:

$$Q_{r,s,p} = a * \%ET_{r,s,p}{}^{2} + b * \%ET_{r,s,p} + c \quad [17]$$

Then we obtain the value of output, which is the result of agronomic production ($Q_{r,s,p}$) times the updated average prices of the last 10 years (P) (MARM, 2007).

$$V_{r,s,p} = Q_{r,s,p} * P \quad [19]$$

The reason to assume constant prices is that neither revenue insurance (price, yield and costs) nor income insurance (price and yield) do exist in the European Union, where yield insurance prevails (Bielza et al., 2008a and b). As a result price variability is not considered in our model.

3.5 Fifth stage. Fair risk premium

The key element of any insurance market is the estimation of the fair risk premium that, given the likelihood of a catastrophic event, does guarantee a certain level of coverage for the insured with no losses for the insurer in the medium-long term. The indemnity conceded by drought insurance in case of drought losses in the EU is subject to two requisites: i) losses must be institutionally acknowledged; and ii) losses have to be larger than a minimum threshold predetermined by the insurance company, usually as a percentage of the expected production value (Bielsa et al., 2008b).

i) For any drought losses to be institutionally acknowledged as such the Basin Authority has to formally declare that irrigation restrictions are going to be implemented (that is to say, DMP comes into play). In the case of the SRB a hydrological system is considered to suffer a drought when it is under an emergency, alert or prealert state (i.e., $I_e \leq 0.5$). We generate a dichotomous variable, $a_{r,s}$, to include this condition in our model.

$$\begin{cases} a(r,s) = 1, if\ I_e \leq 0.5 \\ a(r,s) = 0, if\ I_e > 0.5 \end{cases} \quad [20]$$

ii) Additionally, insurance systems only cover at most a percentage of the expected production value in a normal hydrological year (V_{exp}). This threshold aims to reduce the moral hazard problem (Miranda, 1991) and in Spain is 70% (Bielsa, 2008b). Indemnity in every possible scenario ($IND(r,s,p)$) is then defined as follows:

$$IND(r,s,p) = \begin{cases} \mu * V_{r,s,p}\ , if\ V_{r,s,p} < 0 \\ \mu * V_{exp} - V_{r,s,p}, if\ 0 \leq V_{r,s,p} < \mu * V_{exp} \\ 0\ , if\ V_{r,s,p} \geq \mu * V_{exp} \end{cases} \quad [21]$$

As a result the expected Indemnity (IE) for each crop is obtained from the following equation:

$$IE = \int_{r=0}^{225} \int_{p=0}^{1300} \int_{s=0}^{100} [z(p) * f(r) * j(s) * a(r,s) * IND(r,s,p)] \quad [22]$$

Finally the risk basic premium (BRP) is obtained as a percentage of expected value of production in a normal hydrological year:

$$BRP = \frac{IE}{V_{exp}} \quad [23]$$

3.6 References

Bielza Diaz-Caneja, M., Conte, C.G., Dittmann, C., Gallego Pinilla, F.J., Stroblmair, J., 2008a. Agricultural Insurance Schemes I. European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra, Italy.

Bielza Diaz-Caneja, M., Conte, C.G., Catenaro, R., Gallego Pinilla, F.J., 2008b. Agricultural Insurance Schemes II. Index Insurance. European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra, Italy.

Cuenca, R., 1989. Irrigation system design: an engineering approach, Prentice Hall. Englewood Cliffs.

Gómez-Ramos, A., Iglesias, E., Garrido, A., 2001. Evaluación de la garantía de suministro de agua en la agricultura. Una aplicación a la cuenca del Guadalquivir. Ingeniería del Agua, 3, 9, 279-294.

Gómez, C. M., Pérez, C. D., 2012. Do Drought Management Plans really reduce drought risk? A Risk Assessment Model for a Mediterranean River Basin. Ecological Economics, 76, 42-48.

Ministerio de Medio Ambiente y Medio Rural y Marino (MARM), 2007. Informes Técnicos de Sistemas de Explotación Agraria. Madrid.

Ministerio de Medio Ambiente y Medio Rural y Marino (MARM), 2008. Anuario de Aforos 2007-2008. http.//hercules.cedex.es/anuarioaforos/default.asp. Last accessed 14/02/2013Last accessed 30/06/2013.

Ministerio de Medio Ambiente y Medio Rural y Marino (MARM), 2010. Encuesta sobre Superficies y Rendimientos de Cultivos 2009. Madrid.

Ministerio de Medio Ambiente y Medio Rural y Marino (MARM), 2011. Sistema Integrado de Información del Agua (SIA). http://www.mma.es/portal/secciones/acm/aguas_continent_zonas_asoc/sia/Descripcion.htm. Last accessed 14/02/2013Last accessed 30/06/2013.

Sindicato Central de Regantes del Acueducto Tajo-Segura (SCRATS), 2005. Informe sobre las repercusiones de la sequía 2004-2005, Murcia.

Segura River Basin Authority (SRBA), 2013. Propuesta de Proyecto de Plan Hidrológico de la Cuenca del Segura. http://www.chsegura.es/chs/planificacionydma/planificacion/. Last accessed 30/06/2013.

Segura River Basin Authority (SRBA), 2008. Plan especial ante situaciones de alerta y eventual sequía de la cuenca del Segura. http.//www.chsegura.es/chs/cuenca/sequias/gestion/. Last accessed 30/06/2013.

EPI WATER

Evaluating Economic Policy Instruments for Sustainable Water Management in Europe

Research Task 4.2 Output 13

(Annex 4 to the final report)

EPI4Drought: an agent based model for assessing water trading between Spanish Irrigation Communities during a drought event

15/06/2013

Grant Agreement no. 265212

COOPERATION

Deliverable Title	T4.2–Output 13
Filename	**EPI4Drought: an agent based model for assessing water trading between Spanish Irrigation Communities during a drought event**
Authors	Christophe Viavattene (FHRC – Middlesex University) Carlos Dionisio Pérez Blanco (IMDEA Water)
Date	23/07/2013

Prepared under contract from the European Commission
Grant Agreement no. 265213
FP7 Environment (including Climate Change)

Start of the project:	01/01/2011
Duration:	36 months
Project coordinator organisation:	FEEM

Deliverable title:	NA
Deliverable no. :	NA

Due date of deliverable:	NA
Actual submission date:	NA

Dissemination level

☐	PU	Public
☐	PP	Restricted to other programme participants (including the Commission Services)
☐	RE	Restricted to a group specified by the consortium (including the Commission Services)
☐	CO	Confidential, only for members of the consortium (including the Commission Services)

Deliverable status version control

Version	data	Author
1.0	June 2013	Viavattene C., Perez Blanco C.D.
1.1	July 2013	Viavattene C., Perez Blanco C.D.

4. Research Task 4.2 Output 13 (Annex 4 to the final report): EPI4Drought, an agent based model for assessing water trading between Spanish Irrigation Communities during a drought event

4.1 Introduction

Water scarcity is the most pressing environmental issue in many southern European regions. This situation is to a great extent attributable to agriculture. Consequently, policy makers in drought prone areas have called for measures in this sector to alleviate water scarcity. These measures have consisted so far on supply oriented policies, such as the construction of major infrastructures or the modernization of irrigation devices, and on the enactment of restrictive laws, whereas water demand policies have been excluded from the policy mix. Paradoxically, this scheme has ended up increasing water demand, reducing water availability and undermining the robustness and resiliency of the system and its ability to cope with future droughts (Gómez and Pérez, 2012).

More recently the literature has encouraged the implementation of economic instruments and in particular of water markets as an inexpensive and efficient way of reallocating water among users (Ranjan and Shogren, 2006; Cave, 2009; Rey et al., 2011). Actually, the economic and environmental outcomes of this instrument differ a lot from one region to other: while the Australian and Chilean experiences indicate that a market based on nominal rights and transfers may not be sustainable or equitable, the *principle of effective use* characteristic of the US (and the EU) in which water remains a public resource subject to forfeiture if not used may provide under certain preconditions a Pareto improvement.

In the frame of the EPI-Water project, MU and IMDEA have designed an Agent Based Model (ABM) to assess the potential of water markets to attain a better allocation in the particular case of the Tagus and Segura interconnected river basins in Central and South-Eastern Spain. Agent-based simulation aims at portraying social entities', behaviour and relationship in order to study the global behaviour of their population and to simulate emerging organisations. It is based on a bottom-up rule-based mechanism. A multi-agent system is typically composed of an environment (a space), a set of situated objects, an assembly of agents (active entities), a number of relations between different objects, a set of agents' capacities (perceiving, communicating, behaviour, interaction with other objects…) and a set of defined rules (universe laws) (Ferber, 1997). ABM results from the convergence of two aspects. The first aspect is the idea that the behaviour of large groups can be understood on the basis of very simple interaction rules, so that individuals act essentially as automata responding to a few key stimuli in their environment (Ball, 2004). The second aspect is the past development in DIA (Distributed Intelligence Artificial), of which the objective is to reproduce the knowledge and reasoning of several heterogeneous agents that need to coordinate to jointly solve planning problems (Bousquet and Le Page, 2004). ABM has already been successfully used in various contexts from physical modelling, ecological modelling and social behaviour modelling to more complex modelling such as CHAN (Coupled Human And Natural systems) or environmental modelling (Tweedale et al., 2007; An, 2001; Bithell et al.,2008).

In this research project the economic model, called EPI4Drought, (Figure 1) has been developed on the netlogo platform (http://ccl.northwestern.edu/netlogo/). The software is free of charge and open-source. This report presents the modelling context (i.e. the Tagus-Segura Inter-basin water trading scheme), the model principles and rules and the results obtained under different type of trading schemes.

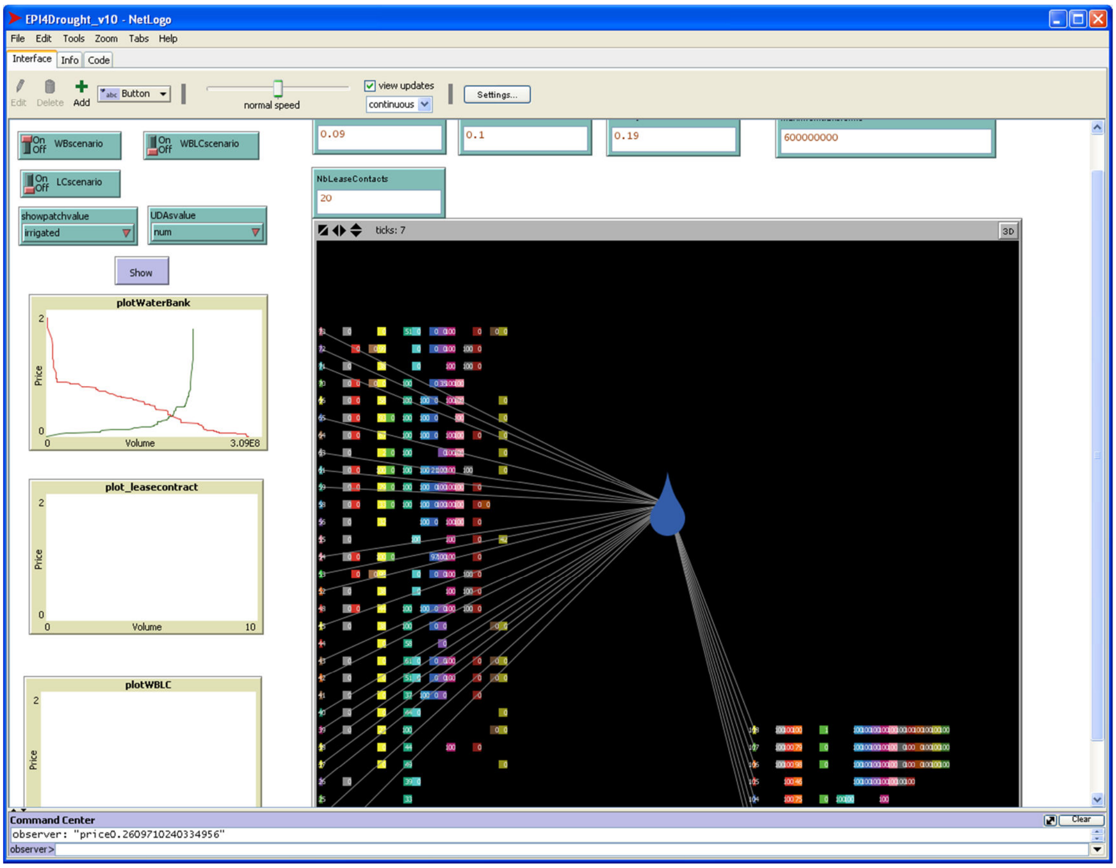


Figure 1: The EPI4Drought ABM interface

4.2 The Tagus-Segura Inter-basin water trading scheme

Water demand in the Segura River Basin (SRB) amounts to 1 900 million m³ per annum while average renewable resources are estimated to be only 760 million cubic meters per annum, making the SRB the most overexploited river basin in Europe (EEA, 2009). Shortage of renewable resources is partially compensated by an inter-basin water transfer from the Tagus River Basin (TRB) (circa 330 million m^3/year) that, nevertheless, since its opening in 1985 has been always below the maximum capacity of the transfer of 600 million m^3/year[9]. The resulting deficit is mostly covered by the overexploitation of aquifers and has resulted in a significant environmental deterioration (SRBA, 2008).

In contrast to that, water demand in the Tagus River Basin (TRB) amounts to 2 600 million m^3 over an average resource availability of 12 000 million m^3. The TRB is the largest of the Iberian Peninsula (its Spanish section covers 55 750 km^2), and despite momentary local scarcity problems and the high variability in water resources, drought vulnerability is still moderate in the river basin (TRBA, 2010).

Figure 2: Tagus (Orange) and Segura (Green) Interconnected River Basins

The informal nature of an increasing share of water abstractions in the SRB, especially during drought events, is both the result of the water scarcity and the socioeconomic relevance of irrigation for an area which has one of the most productive agricultural sectors in Europe, on which the economy relies strongly (Pérez et al., 2011). The Segura River Basin Authority has recognized the importance of this sector and the need to guarantee its viability in the years to come, thus transforming the informal rights into *de facto* rights (SRBA, 1998; SRBA, 2008; SRBA, 2010). Contrary to this, after the approval of the EU Water Framework Directive (EC, 2000) a more prominent role has been given to the environmental and urban uses to the detriment of other productive

[9]The actual capacity of the TSWT is 1 000 million cubic meters per year, but it has been limited to 600 million cubic meters per year by law (SRBA, 2013).

uses, including agriculture, the basin's most relevant water user (85% of total water demand) (SRBA, 2008). For example, the recently approved Drought Management Plans (DMPs) (SRBA, 2010; TRBA, 2007) introduce clear restrictions to water allocation in agriculture during drought events. The new regulatory framework also makes possible the implementation of economic policy instruments with the potential to meet both the economic and environmental objectives at stake, such as water markets (EC, 2000; Water Act 29/1985, Act 46/1999, RD 1/2001, Water Act 63/2003).

In the new Water Law two main different procedures for inter-basin water trading were allowed for, both requiring approval from the corresponding River Basin Authority (Calatrava and Garrido, 2005):

1. Lease Contracts ("Contratos de cesión"): Direct trading among concession holders who privately agree on the conditions for the temporary lease of public water concessions;
2. Water Banks ("Centros de intercambio") that are publicly-run water banks: Aim to speed water transfers during periods of scarcity and to disseminate information about volumes exchanged and prices paid.

Water use tradable rights in Spain are only granted when a set of prerequisites are met (see Rey et al., 2011). In the case of inter-basin water markets using previously existing infrastructures, such as the Tagus-Segura water transfer, a specific legal framework has to be in place in the form of a Royal Decree (RD 15/2005).

The inter-regional conflicts arising from water transfers in Spain have been so far an important limit for the development of these markets, with Royal Decrees being approved only under emergency junctures. In spite of this barrier, inter-basin water markets have been the most successful reallocation instrument in terms of volume traded (Rey et al., 2011). For example, water trade from the TRB to the SRB only in 2006 surpassed that of all the water exchanges approved before within the SRB, when farmers from the Upper Tagus Basin (Comunidad de Regantes de Estremera) agreed to transfer 31.5 million cubic meters annually during three years to farmers in the Segura Basin through a particular type of lease contract supervised by the authorities (though this may be arguable, since illegal intra-basin water transfers are not accounted for in the statistics; see for example Hernández-Mora and De Stefano, 2013).

4.2.1 The Agricultural Demand Units

The model aims at representing the behaviour of the irrigation communities. But as no information is available at such scale, the UDAs (Unidades de Demanda Agraria or Agricultural Demand Units) have been used as representing of a group of irrigation communities (Figure 3). Given the high complexity of the political framework surrounding the Tagus-Segura water transfer, only the UDAs in the TRB headwaters (8

UDAs) and the UDAs of the SRB (21 UDAs) which have formal water allocations over the resources from the transfer are represented in the model.

For each UDA information may be obtained on the percentage of area for different crops categories, the water requirement for each crop category and the irrigation efficiency and price (TRBA, 2013; SRBA, 2013). The crops categories considered in the model are: almond tree, winter cereals, spring cereals, summer cereals, citrus trees, industrial crops, fruit tree (stone-pit), fruit tree (pip), horticulture (bulb), horticulture (cauliflower, artichoke), horticulture (fruit), horticulture (leaf), horticulture (green house), horticulture (root), horticulture (tubercular), leguminous plant, olive grove, vineyard (fruit), vineyard (wine). However the database does not provide information on the irrigated net marginal value and the rain fed net marginal value. Average values were obtained from regional statistics (MARM, 2012) by averaging the associated parameters of specific crops into UDAs group categories. The parameters considered are the yield value, direct costs, machinery cost, labour cost, water costs and subsidies. A white noise is also estimated to take into account any source of variability in the final yield value (excluding droughts[10]).

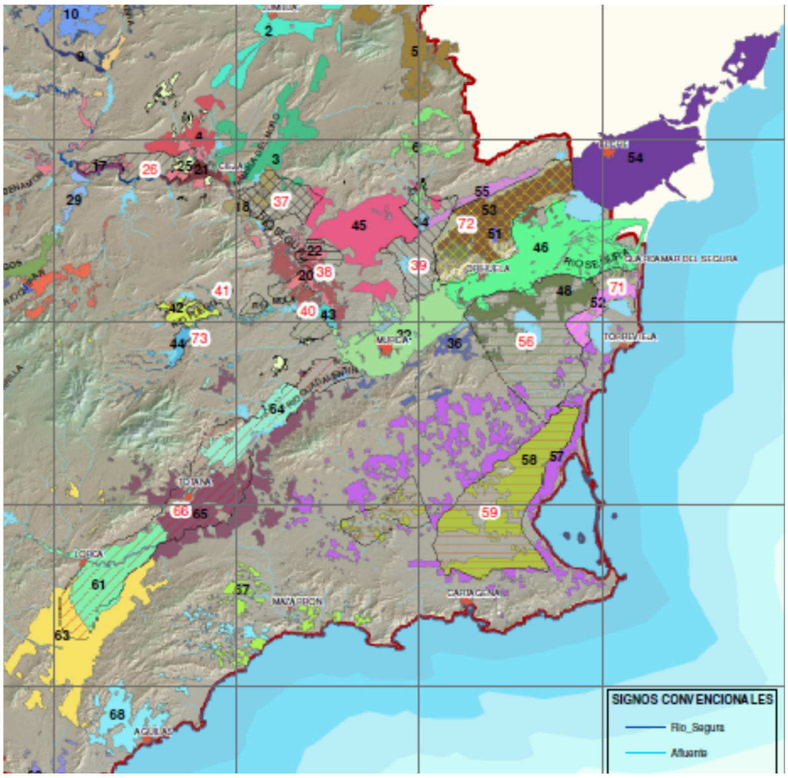


Figure 3: UDAs on the Segura catchment (http://www.chsegura.es)

[10] Therefore, this white noise was obtained from the years where no drought was declared.

4.3 Model Principles

The aim of the model is to assess if irrigation communities from different catchments may benefit from inter-basin water trading in a drought situation. The model has been developed to fit the Tagus-Segura River Basin case study. However, the theoretical framework of the model, the methodology and the expected outcomes could be used on other catchments with similar information available.

4.3.1 The Environment: Drought Stochastic approach

The model simulates yearly events independently. Each early event represents the same year but with different conditions. No learning process or no past experience is therefore considered in the current model. The trigger effect in the model is the announcement of a drought. In Drought Management Plans (DMPs), four levels of severities are considered per catchment: normality, pre-alert, alert and emergency (TRBA, 2007; SRBA, 2008). For each level of severity the level of water allocation is reduced. In a normal situation it is considered that the agronomic water requirements (i.e. evapotranspiration) are satisfied. The methodology used at this stage is based on the work by Gómez and Pérez (2012).

The methodology adjusts a Probability Density Function (PDF) for the relevant variables in the drought index of the sub-basins implied in inter-basin trade. This way the probability of every possible drought event is obtained using two types of functions: the Gamma function is used to adjust the rainfall, runoff and the piezometric level PDFs (Gómez and Pérez, 2012; Pérez et al., 2011; Martin et al., 2001; McWorther et al., 1966), while the Weibull function is used for the water stock in reservoirs (Gómez-Ramos et al., 2002).

The Gamma PDF is a function of a scale (a) and a shape (b) parameters and ascribes a probability p_i $(i = 1, \dots, 3)$ to every value of the variable x_i $(i = 1, \dots, 3)$:

$$p_i = z(x_i|a,b) = \frac{1}{b^a \Gamma(a)} {x_i}^{a-1} \exp(\frac{-x_i}{b})$$

where x_1 stands for the rainfall, x_2 for the piezometric levels and x_3 for the runoff. p_1, p_2 and p_3 are the corresponding probabilities.

The Weibull PDF is a function of a scale (c) and a shape (d) parameters. The Weibull PDF ascribes a probability (p_4) to every value of the water stock in reservoirs (x_4):

$$p_4 = j(x_4|c,d) = \frac{d}{c}\left(\frac{c}{d}\right)^{d-1} \exp\left(-\left(\frac{x_4}{c}\right)^d\right)$$

From the PDF's estimated parameters, the value and the likelihood of every drought index, as well as its associated water restrictions, can be estimated. Drought indexes can be obtained from a single variable or from the combination of up to four of them, weighted by a coefficient predetermined in the corresponding DMP, b_i. The drought index is thus obtained as follows:

$$I_e = \sum_{i=1}^{4} b_i * I_{e,x_i}$$

with:

$$I_{e,x_i} = \begin{cases} \left[\dfrac{x_{i_j} - x_{i_{min}}}{2\left(x_{i_{med}} - x_{i_{min}}\right)}\right], if\, x_{i_j} < x_{i_{med}} \\ \dfrac{1}{2}\left[1 + \dfrac{x_{i_j} - x_{i_{med}}}{x_{i_{max}} - x_{i_{med}}}\right], if\ x_{i_j} \geq x_{i_{med}} \end{cases}$$

where x_{i_j} is the observed value, and $x_{i_{med}}$, $x_{i_{max}}$ and $x_{i_{min}}$ are the average, maximum and minimum historic values, respectively.

Finally, the ascribed probability is obtained as:

$$p_e = \prod_{i=1}^{4} h(p_i)$$

where:

$$h(p_i) = \begin{cases} 1, if\ \ b_i = 0 \\ p_i, if\ b_i > 0 \end{cases}$$

It is also possible to obtain the probability of every drought stage in both the Segura and Tagus River Basins by aggregating the probability of all the drought indexes that fall within each threshold. The following dummy variables are defined:

$$N_{I_e} = \begin{cases} 1, if\ I_e > I_{e,z} \\ 0, if\ I_e \leq I_{e,z} \end{cases}$$

$$P_{I_e} = \begin{cases} 1, if\ I_{e,a} < I_e \leq I_{e,z} \\ 0, otherwise \end{cases}$$

$$A_{I_e} = \begin{cases} 1, if\ I_{e,e} < I_e \leq I_{e,a} \\ 0, otherwise \end{cases}$$

$$E_{I_e} = \begin{cases} 1, if\ I_e \leq I_{e,e} \\ 0, if\ I_e > I_{e,e} \end{cases}$$

where $I_{e,z}$, $I_{e,a}$ and $I_{e,e}$ are the pre-alert, alert and emergency thresholds, respectively. The probability of every drought threshold (normality, q_N; pre-alert, q_P; alert, q_A; and emergency, q_E) is obtained as follows:

$$q_N = \int_{x_1=0}^{max_{x_1}} \int_{x_2=0}^{max_{x_2}} \int_{x_3=0}^{max_{x_3}} \int_{x_4=0}^{max_{x_4}} \left(N_{I_e} * \prod_{i=1}^{4} h(p_i) \right)$$

$$q_P = \int_{x_1=0}^{max_{x_1}} \int_{x_2=0}^{max_{x_2}} \int_{x_3=0}^{max_{x_3}} \int_{x_4=0}^{max_{x_4}} \left(P_{I_e} * \prod_{i=1}^{4} h(p_i) \right)$$

$$q_A = \int_{x_1=0}^{max_{x_1}} \int_{x_2=0}^{max_{x_2}} \int_{x_3=0}^{max_{x_3}} \int_{x_4=0}^{max_{x_4}} \left(A_{I_e} * \prod_{i=1}^{4} h(p_i) \right)$$

$$q_E = \int_{x_1=0}^{max_{x_1}} \int_{x_2=0}^{max_{x_2}} \int_{x_3=0}^{max_{x_3}} \int_{x_4=0}^{max_{x_4}} \left(E_{I_e} * \prod_{i=1}^{4} h(p_i) \right)$$

where max_{x_i} is the value of the variable x_i that makes the cumulative density function equal to 1.

Finally, the relative water allocation (w_{I_e}) remains to be defined. During a normal hydrological year, all the agronomic water requirements are satisfied (i.e., water allocation equals the agronomic water requirements, $w_{I_e} = W$). In the event of a drought, DMPs define the water constraints that will come into force for every drought scenario (y). Therefore, the amount of water allocated (w_{I_e}) is obtained as follows:

$$w_{I_e} = y * W$$

For example, in the SRB, water availability during an emergency is reduced by 50% ($y = 0.5$), by 25% in the case of an alert ($y = 0.75$) and by 10% in the case of a pre-alert ($y = 0.9$) (SRBA, 2008).

Table 1:Drought probability and associated water allocation rate

	Segura		Tagus	
Level	Probability (q)	Water allocation rate (y)	Probability (q)	Water allocation rate (y)
Emergency (E)	0.18	0.5	0.19	0.5
Alert (A)	0.31	0.75	0.26	0.77
Pre-alert (P)	0.29	0.9	0.26	0.95
Normal (N)	0.21	1	0.29	1

4.3.2 The Agents

The model represents the behaviour of irrigation communities, the *Unidades de Demanda Agraria* (Agricultural Demand Units or UDAs), which is the basic irrigation unit with available data in Spain. The UDAs comprise exploitations sharing the source of their water resources, administrative characteristics, hydrological characteristics and/or a territory (SRBA, 1998; TRBA, 1998).

Each agent or UDA is in charge of allocating water to different types of crops in order to maximize their revenues. In most agricultural models, the agents pay attention to one of the following three variables: wealth, income and gain/loss (Hardaker et al., 2004). It could be expected though that the agents incorporate indirectly all these variables in their assessment, as gain/loss is a marginal change in wealth and wealth is the capitalized value of all the present and future incomes. In this approach we use the marginal change in wealth as the argument. Thus, the objective function of each UDA is obtained as follows:

$$Max\ \Pi = \sum_{i=1}^{N} \left(P_i * r_i - \sum_{j=1}^{T} c_{ij} \right) * s_i * \Omega(w_i) + u_i + \left(P_i * r_{i,RF} - \sum_{j=1}^{T} c_{ij,RF} \right) * s_i * (1 - \Omega(w_i)) + u_{i,RF}$$

Subject to:

$$\sum_{i=1}^{N} w_i \leq w$$

$$w \geq w_{min} * s_{ligneous}$$

where $i = 1 \dots N$ are the different crops in the UDA, Π is the revenue, P_i is the price of the crop in EUR per kg, r_i and $r_{i,RF}$ are the average yield (in kg per hectare) for crop I under irrigation and rainfed agriculture[11], respectively, c_{ij} and $c_{ij,RF}$ are the costs involved in production (in EUR per hectare) under irrigation and rainfed agriculture, respectively, s_i is the surface allocated to crop i (in hectares), $\Omega(w_i)$ represents the percentage of the surface of the crop i that can be irrigated (dependent on the total water allocation for that crop, w_i) and u_i and $u_{i,RF}$ are white noises that capture any source of revenue variability apart from water scarcity, such as plagues, hail, floods, price volatility, etc.[12], under irrigation and rainfed agriculture, respectively.

The UDA needs to consider that ligneous crops require a minimum amount of water per hectare in order to secure their survival (w_{min}); therefore, prior to the maximization process each agent delivers that minimum amount of water ($w_{min} * s_{ligneous}$). Since the irrigation of ligneous crops is given a high priority by the law (SRBA, 2008; TRBA, 2007), water resources available need to be at least equal to $w \geq w_{min} * s_{ligneous}$. In any case, the amount of water applied ($\sum_{i=1}^{N} w_i$) cannot exceed the amount of water available (w), where $w = w_{I_e} + m$ is the total amount of water available, being w_{I_e} the allocated water in the drought scenario (obtained in the previous section) and m the water purchased in the water market (in this baseline scenario, $m = 0$).

During a drought event, agents will solve the problem above and irrigate those crops that maximize the objective function. With no market, the remaining crops will be left non-irrigated.

Agents under a water market

In the model one catchment is considered as a potential water seller (Tagus River Basin) and the other one as a buyer (Segura River Basin). In no case the roles are reversed (RD 1/2001).

[11]Traditionally rainfed crops receiving supplementary irrigation may still produce a yield without being irrigated, and this has to be accounted for (e.g., olive groves, vineyard).

[12]This stochastic variable is obtained from the yield and price historic series (MARM, 2012) as the standard deviation of the revenue, excluding the years with drought.

The inter-basin market is activated when the drought index of the "buyer" catchment falls below the emergency threshold and if the "seller" catchment is not in an emergency. In this case, the agents may trade for water and modify their initial irrigation plan to a certain extent in order to increase their revenue. Accordingly, the new objective function of each UDA is defined as follows:

$$Max\,\Pi = \sum_{i=1}^{N}\left[\left(P_i * r_i - \sum_{j=1}^{T} c_{ij}\right) * s_i * \Omega(w_i) + u_i + \left(P_i * r_{i,RF} - \sum_{j=1}^{T} c_{ij,RF}\right) * s_i * (1 - \Omega(w_i)) + u_{i,RF}\right] + P * \left(w_{I_e} - w\right)$$

Subject to:

$$\sum_{i=1}^{N} w_i \leq w$$

$$w \geq w_{min} * s_{ligneous}$$

$$-m \leq w_{I_e}$$

$$|m| \leq M_{UDA}$$

$$\sum_{k} m \leq W_{ATS} - Tr_{ATS}$$

Where P is the market price of water and $w = w_{I_e} + m$is the total amount of water available, being m the water purchased ($m > 0$, SRB) or sold ($m < 0$, TRB) in the water market and w_{I_e} the water allotment in the considered scenario (dependent on the drought index of the previous section, I_e).

Water resources available need to be at least equal to the amount of water resources required by ligneous crops ($w \geq w_{min} * s_{ligneous}$.). The amount of water available ($w = w_{I_e} + m$) has to be at least equal to the total amount of water used by the UDA in the different crops ($\sum_{i=1}^{N} w_i$). Also, water markets are limited by water allocation, as no UDA can sell an amount of water greater than its allocation ($-w_m \leq w_{I_e}$). In addition, water markets are limited by the capacity of the primary and secondary water canals to transport and distribute water (M_{UDA}). Finally, water trade is also limited by the capacity of the Tagus-Segura Water Transfer (W_{ATS}) minus the water transfers outside of the market (T_{ATS}). The maximum capacity of the water transfer equals 1 000 hm³ per year, though it is limited by law to 600 hm³ per year. During a pre-alert event in the TRB, this amount is reduced to 456 hm³ per year, to 276 hm³ per year during an alert and to 0 hm³ per year during an emergency. The water transfers outside the market are variable, though we use historical data to determine an average value (Tr_{ATS}) for every drought event (SRBA, 2013).

4.3.3 The water market

The potential buyers in our model are the UDAs in the SRB with a positive surface of non-irrigated crops. Therefore, the willingness to pay for water depends on the water productivity of these non-irrigated crops. On the other hand, the potential sellers are those UDAs in the TRB with a positive water allocation. The willingness to accept for water depends on the water productivity of the irrigated crops. Accordingly, first of all we need to obtain the productivity of water for every crop (i) and UDA (k) in the irrigated areas (i/Irr) of the TRB (C_{ik}) and in the non-irrigated areas (i/RF)of the SRB (I_{ik}):

I_{ik} = $[(P_{i/Irr,k} * r_{i/Irr,k} - \sum_{j=1}^{T} c_{i/Irr,kj}) - (P_{ik} * r_{ik,RF} - \sum_{j=1}^{T} c_{ijk,RF})]$ / (W_{ik})

C_{ik} = $[(P_{i/RF,k} * r_{i/RF,k} - \sum_{j=1}^{T} c_{i/RF,kj}) - (P_{ik} * r_{ik,RF} - \sum_{j=1}^{T} c_{ijk,RF})]$ / (W_{ik})

where W_{ik} represents the agronomic water requirements in m³/ha of crop i in the UDA k.

Agents in the model will trade until the marginal cost of water equals the marginal productivity of water. In our unilateral market, the marginal productivity of water equals that of the SRB, while the marginal cost equals the marginal productivity of water in the TRB plus other variables including asymmetric information and transportation and environmental costs. In the next sections we assess all these costs and we obtain the theoretical solution to our model.

Basic model with no additional costs

Without asymmetric information and transportation and environmental costs, the marginal cost of water would match the marginal productivity of water in the TRB. In this case, agents would trade until the marginal productivity of water in the SRB matches that of the TRB, i.e., until:

$$P_1 = I_{ik} = C_{ik}$$

where P_1 is the market price that equals the marginal productivity of water in both basins.

UDAs will sell or buy water up to the point where the marginal productivity of water is lower or higher than the market price. Therefore, the amount of water traded (m_1) would be:

$$m_1 = s_i * \left(1 - \Omega(w_i)\right),\ \ s.t.\ I_{ik} \geq\ P_1$$

Or, alternatively:

$$m_1 = s_i * \Omega(w_i),\ \ s.t.\ C_{ik} \leq\ P_1$$

Asymmetric information

In the water exchange there may be some restrictions to access to information. These restrictions may have significant impacts over the marginal productivity/cost as perceived in the market. As a result, the observed price in the water market may not match the "optimum" price obtained in the previous section. These costs are endogenous of each water exchange, and therefore can be represented by a stochastic variable (a white noise e with a standard deviation based on the water prices of previous water markets) (Rey et al, 2011; Calatrava and Gómez-Ramos, 2009). In this case, the water price would be:

$$P_2 = P_1 + e$$

And the amount of water traded in the market would be reduced as compared to the previous section:

$$m_2 = min\left(s_i * \left(1 - \Omega(w_i)\right),\ \ s.t.\ I_{ik} \geq\ P_2;\ s_i * \Omega(w_i),\ \ s.t.\ C_{ik} \leq\ P_2\right)$$

However this asymmetric information has not yet been implemented in the current model (e = 0).

Environmental costs

Water markets may have an impact over the environment, especially in the donor area. In order to prevent environmental deterioration, water authorities may decide that a percentage of the amount of water traded (env) must remain in the TRB in the form of environmental flows. To achieve an environmentally neutral water market, these restrictions should be at least enough to compensate for the return flows generated by agricultural water use in the donor basin. Environmental costs increase the marginal cost of water and the water price in the market, and therefore they reduce the amount of water bought. In addition, they reduce the quantity of water received in the SRB, since part of the water bought will be used to satisfy the environmental flows.

$$P_3 = (P_1 + e)/(1 - env)$$

Of this price, farmers in the TRB will perceive only a fraction, since the remaining cost corresponds to the environment:

$$P_{3,TRB} = (P_1 + e)$$

The amount of water traded will be:

$$m_3 = s_i * (1 - \Omega(w_i)), \ \ s.t. \ I_{ik} \geq \ P_3$$

Or alternatively:

$$m_3 = s_i * \Omega(w_i), \ \ s.t. \ C_{ik} \leq \ P_3$$

However, the amount of water received by the farmers of the SRB, and therefore used for agricultural production in the SRB will be:

$$m_{3,SRB} = m_3 * (1 - env)$$

Transportation costs

The Tagus-Segura Water Transfer covers a distance of 242 km between the Bolarque Dam in the TRB and the Talave Dam in the SRB. Therefore, there are significant transportation costs in the form of transportation fees (f_{TS}) and losses (l_{TS}). This increases the marginal cost of water and the market price:

$$P_4 = \frac{\frac{(P_1 + e)}{1 - env} + f_{TS}}{1 - l_{TS}}$$

And reduces the amount of water traded in the market:

$$m_4 = s_i * (1 - \Omega(w_i)), \ \ s.t. \ I_{ik} \geq \ P_4$$

Or alternatively:

$$m_4 = s_i * \Omega(w_i), \ \ s.t. \ C_{ik} \leq \ P_4$$

Transportation costs further reduce the amount of water that reaches the SRB ($m_{4,SRB}$) as compared to the total amount of water traded (m_4).

$$m_{4,SRB} = m_4 * (1 - env) * (1 - l_{TS})$$

4.4 Market scenarios

The inter-basin market is activated when the drought index of the "buyer" catchment falls below the emergency threshold and if the "seller" catchment is not in an emergency (RD 15/2005). So far water markets have worked through bilateral agreements among agents (lease contracts), though in our model we assess the potential outcome of two more scenarios.

4.4.1 Lease contract

Lease contracts have been the most common legal figure in inter-basin trade. In a lease contract, the potential buyer UDA contacts a potential seller UDA on a *bilateral* basis. Although water authorities can intervene in order to fix a price or to forbid the water transfer (based on third party effects such as impoverished qualitative status of the aquatic ecosystems or environmental flows reduction), in reality this is unlikely and actually public authorities facilitate this type of contracts, for example by offering public subsidies (such as the forfeiture of the transportation fees) (RD 1/2001).

In this scenario, bargaining is bilateral. Therefore, the market is small (only two UDAs in each exchange, $k = k_1$ in the SRB and$k = k_2$ in the TRB). Transportation costs are included ($l_{ATS} = 0.1$; $f_{ATS} = 10$ Eurocents/m³) (SRBA, 2013), but environmental costs are not ($env = 0$) (Rey et al., 2011; RD 1/2001).

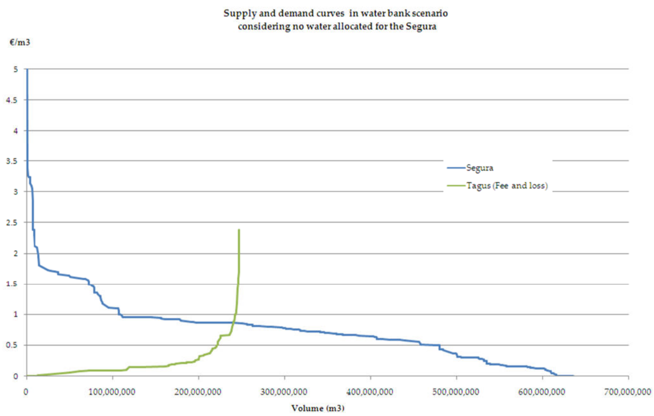
4.4.2 Water banks

Water banks are public exchange centres from which no agent can be excluded. In water banks, the river basin authority organizes the market and sets a fixed price (RD 1/2001). In addition, water banks need to take into account transportation costs ($l_{ATS} = 0.1$; $f_{ATS} = 10$ Eurocents/m³) and third party effects to prevent environmental deterioration. This means that water banks must impose restrictions on the amount of water that can be traded from the TRB to the SRB. These restrictions should be at least enough to compensate for the return flows that would be otherwise lost in a market. Return flows are estimated at 19% in the UDAs of the TRB with access to the water transfer ($env = 0.19$) (SRBA, 2013).

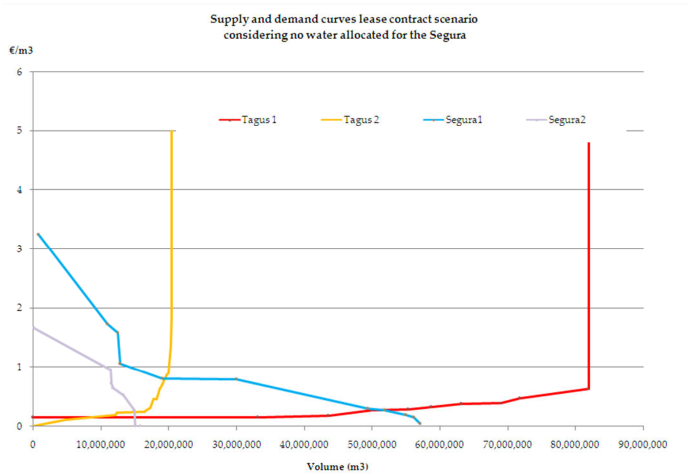
4.4.3 Water banks and lease contracts

In this scenario an institution represents all the irrigation communities from the SRB (buyer). This institution contacts a potential seller (the UDA,$k = k_1$) and they negotiate a price and a volume of water to be exchanged. There are also environmental restrictions and transportation costs.

a- Water bank scenario



b- Lease contract scenario



c- Water bank lease contract scenario

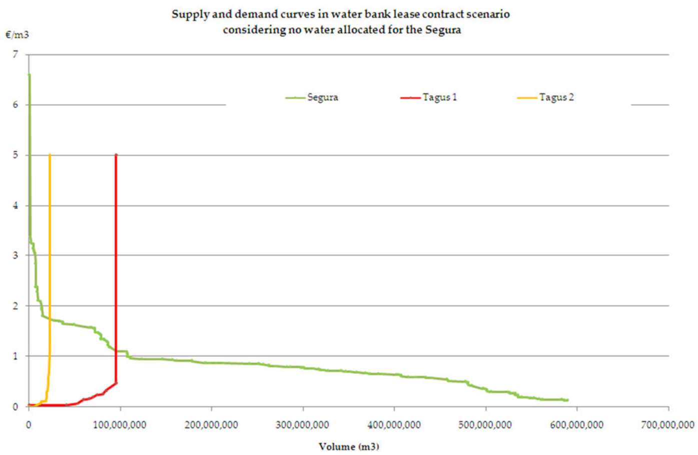


Figure 4: Opportunity for water trading in 3 different scenarios: water bank, lease contract, water bank lease contract

4.4.4 Outputs of the model

For each scenario if relevant the model assesses:

- The revenues in Euros per each UDA and in total
- The volume of water allocated to each UDA
- The surface of crops irrigated and non-irrigated.
- The price per contract

As each event is independent and results of a stochastic approach, expected revenues can also be calculated for each scenario and compared.

4.5 Results

Hundred simulation steps were run with the model to obtain the following results, one simulation step representing a single year with a different Tagus and Segura drought levels obtained by the stochastic approach each time.

Table 2 shows the average revenue obtained in each catchment for the different levels of drought. The revenues are for the baseline scenario, i.e. without any trading market in place. Expected losses for the Segura catchment are higher than in the Tagus catchment. Thus, during an emergency event, loss in revenues due to irrigated water volume restriction are up to 42% of the average normal revenue in the Segura catchment, but only 20% in the Tagus catchment. The differences between both catchments may be explained by the difference in land uses and by the variability in irrigated-rainfed net margins factors.

Table 2: Changes in revenues (€) under baseline scenarios

Segura		Tagus	
Drought	Revenues €	Drought	Revenues €
Normal	490 643 602	Normal	44 410 163
Pre-alert	473 516 114	Pre-alert	43 973 262
Alert	417 062 162	Alert	41 365 707
Emergency	287 783 546	Emergency	36 027 444

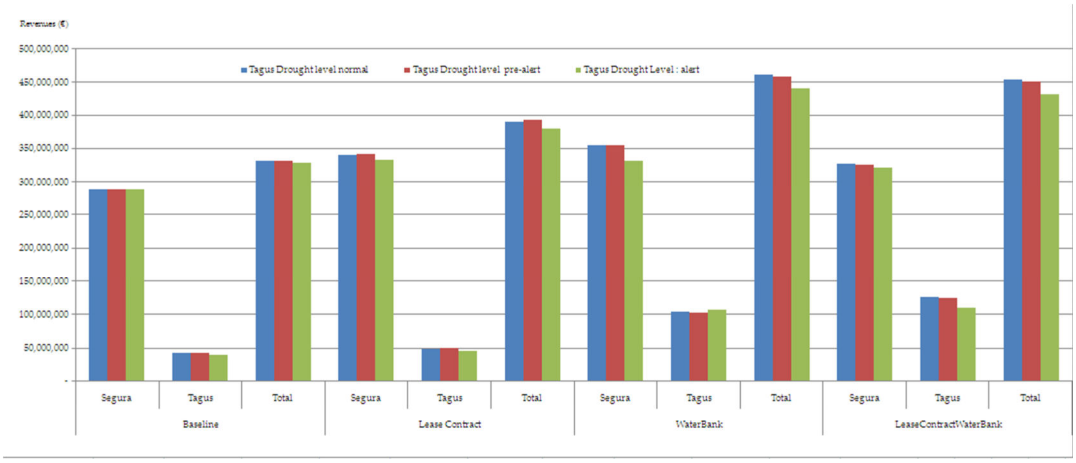


Figure 5: Average changes in revenue for different scenarios in emergency situation

In Figure 5 the expected changes in revenue for the different scenarios (baseline and trading markets) under an emergency event in the SRB are compared. Overall, any type of contract increases total welfare (measured by total income) as compared to the baseline scenario. Yet the reader needs to keep in mind that the consequences in terms of local employment are not considered in the model. The "water bank" option is the most effective one, yet very similar to the "water bank lease contract" option. In the "water bank" scenario the Segura catchment is better off at the disadvantage of the Tagus catchment. For these two scenarios it is important to consider that a hundred per cent participation is assumed in the model. Therefore lower revenues may be expected. For the lease contract 20 contacts were used as a basis. Further research is necessary to explore the participation process and adjust the results of the model on this basis.

The drought level in the Tagus impacts on the increase of revenues in the Segura catchment as less water is available for trading. In addition, the lack of water means that only highly productive water is available for trading, thus increasing the selling price. Interestingly, the Tagus catchment benefits slightly of the emergency situation in the water bank scenario. This can be explained by the rise of the price value in an emergency situation. Indeed for a "water bank" scenario price is set up at 0.49€/m^3 in a normal situation, at 0.5€/m^3 in a pre-alert situation and at 0.64€/m^3 in an alert situation (including transportation fee).

In the "lease contract water bank" scenario the variability of the price value is high with a majority of values around 0.90 €/m^3 (Figure 6). As illustrated on Figure 4c the main reason is in the difference of demand and supply, as all Segura UDAs are grouped and bargain with each Tagus UDA separately. In the lease contract approach prices varies from less than 0.15 €/m^3 to 0.95 €/m^3 with a predominance of low price values.

In both types of contract however asymmetric information and an adaptive strategy during the negotiation process may influence the final price. For instance the fact that all the Segura UDAs are grouped under one institution may allow them to better negotiate and to reduce the price. As stressed in 3.3.2 section adjusting a white noise variable (e) may improve the model results.

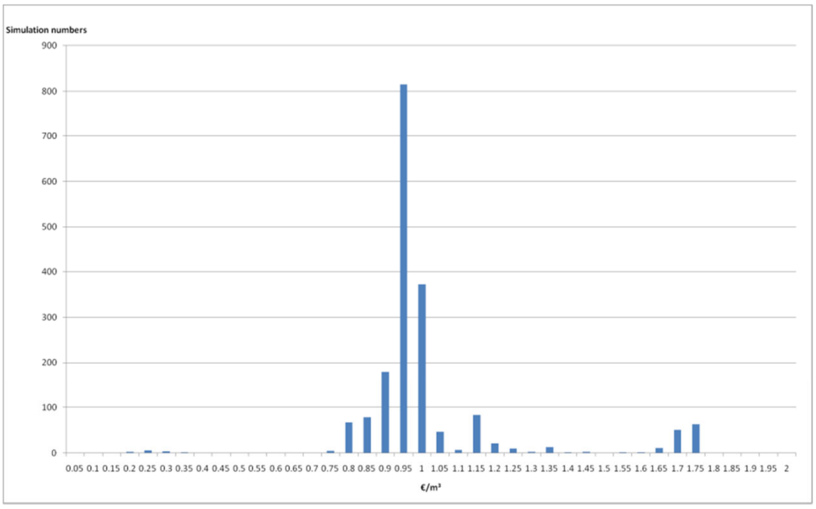


Figure 6: Water Bank Lease Contract Prices (fee included)

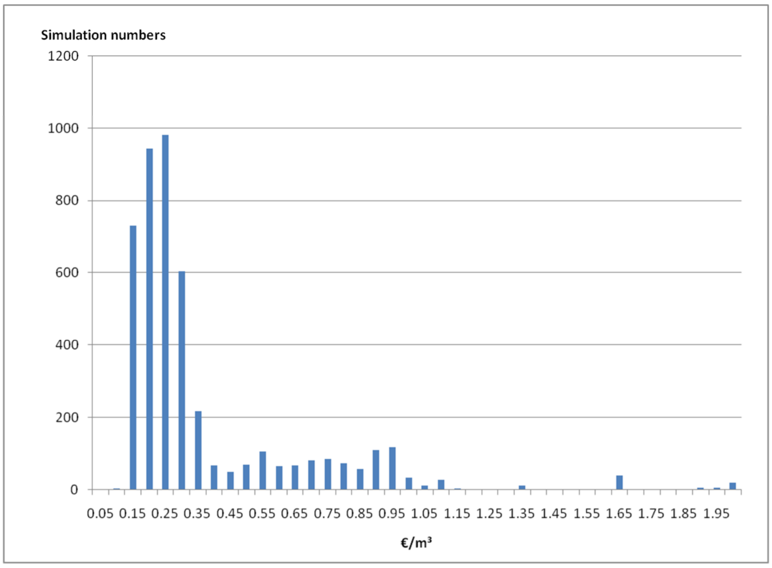


Figure 7: Lease Contract Prices (fee included)

In Figure 8 and 9 the variation in the increase of revenues between UDAs are represented. The opportunity for the UDAs to benefit of the market depends of the surface of crops with high water productivity for the Segura and low water productivity for the Tagus. In the Segura some UDAs such as UDA number 6 cannot participate in any transaction due to its low productivity crops. An UDA is composed of different irrigation communities, modelling at the level of the UDAs may therefore hide further disparity between communities.

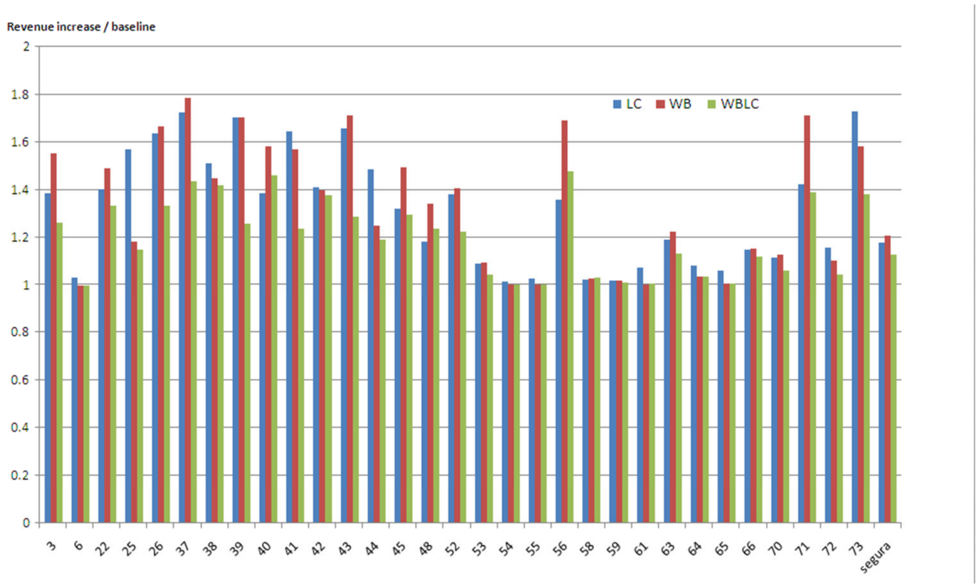


Figure 8: Increase of revenue compared to the baseline per UDA in the Segura

Figure 9: Increase of revenue compared to the baseline per UDA in the Tagus

4.6 Conclusions

The EPI4Drought agent based model has been developed by FHRC (MU) and IMDEA to assess and to compare the potential of water markets to attain a better allocation in the particular case of the Tagus and Segura interconnected river basins in Central and South-Eastern Spain. The allocation of water to the different crops and the market price are mainly ruled using the water productivity concept, defined in this project as the irrigated productivity minus the rainfed productivity divided by the water requirement for different groups of crops. The UDAs (agricultural demand units) entities with available information on both catchments have been used as agents in the model. The model simulates independently annual events, the main stimuli being a change in the drought level defined stochastically on each catchment. The model compares three different types of market to a baseline scenario: water lease contract, water bank scenario and a water bank lease contract. Overall the three options increase the welfare in both catchments as compared to the baseline. The water bank lease contract scenarios and the water bank scenario provide similar total revenues. Defining which of the two scenarios is the preferred option is more elusive as distributional effects differs at inter and intra catchment level. The water prices are dependant of the type of market. Not all the UDAs are benefiting of the market situation.

The model is still at an early stage and further research will aim at improving it including:

- Collecting data at a lower level such as the irrigation communities
- Modelling the potential strategies in the bargaining process
- Indirect impacts of the market on the local economy
- Shorter duration in the model such as monthly steps to better represent the crops water requirement and adaptive behaviour

4.7 References

Act 46/1999 de 13 de diciembre, de modificación de la Ley 29/1985, de 2 de agosto, de Aguas.

An, L. (2011). Modelling human decisions in coupled human and natural systems: Review of agent-based models. Ecological Modelling (in press).

Ball, P. (2004). The physical modelling of human social systems. Complexus, 1:190-206.

Bitherll M., Brasington J., Richards K., (2008). Discrete element, individual-based and agent-based models: tools for interdisciplinary enquiry in geography? Geoforum 39. Pp625-642

Bousquet F., Le Page C. (2004). Multi-agent simulations and ecosystem management: a review. Ecological modelling 176. Pp. 313-332

Calatrava, J., Gómez-Ramos, A. (2009). El papel de los mercados de agua como instrumentode asignación de recursos hídricos en el regadío español [The role of water markets as anallocative instrument of water resources in Spanish irrigation sector]. In: Gómez-Limón,J.A.; Calatrava, J.; Garrido, A.; Sáez, F.J. & Xabadia, A. (eds.), La economía del agua deriego en España [The economics of irrigation water in Spain]. Fundación Cajamar, Almería,Spain: 295–319.

Cave, M. (2009). Independent Review of Competition and Innovation in Water Markets. Final Report, Ofwat, London.

European Commission (EC) (2000). Water Framework Directive. Directive 2000/60/EC, 23 October 2000.

Ferber J., 1997. La modélisation multi-agent : un outil d'aide à l'analyse de phénomènes complexes. Tendances nouvelles en modélisation pour l'environnement – Editions Elsevier. Pp. 113-133.

Calatrava, J., Garrido, A. (2005). Modelling water markets under uncertain water supply.European Review of Agricultural Economics 32 (2), 119-142.

Gómez-Ramos, A., Iglesias, E., Garrido, A.(2002). Evaluación de la garantía de suministrode agua en la agricultura. Una aplicación a la cuenca del Guadalquivir. Ingenieríadel Agua 3 (9), 279–294.

Gómez Gómez, C. M., Pérez Blanco, C. D. (2012). Do drought management plans reduce drought risk ? A risk assessment model for a Mediterranean Basin. Ecological Economics 76 (2012) 42–48.

Hardaker, J.B., Huirne, R.B.M., Anderson, J.R. (2004). Coping with risk in Agriculture.Wallingford, UK. Second Edition. CABI Publishing.

Martin, S., Barnett, B., Coble, K. (2001). Developing and pricing precipitation insurance.Journal of Agricultural and Resource Economics 26 (1), 261–274.

McWhorter, J.C., Matthes Jr., R.K., Brooks Jr., B.P.(1966). Precipitation Probabilities forMississippi. Water Resources Research Institute, Mississippi State University.

Ministerio de Agricultura, Alimentación y Medio Ambiente (MARM) (2012). Encuesta sobre superficies y rendimientos de cultivos (ESYRCE). http://www.magrama.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce/. Last accessed 07/07/2013.

Pérez, C.D., Gómez, C., del Villar, A. (2011). El riesgo de disponibilidad de agua en la agricultura:una aplicación a las cuencas del Guadalquivir y del Segura. Estudios deEconomía Aplicada 29 (1), 1–26.

Ranjan, R., Shogren, J.F. (2006). How probability weighting affects participation in watermarkets. Water Resources Research, 42 W08426.

Rey, L., Calatrava, J., Garrido, A. (2011). Water market scenarios for Spain. Work performed in fulfillment of Work Package 2 Water Cap & Trade. Water marets scenarios for southern Europe : new solutions for coping with increasing water scarcity and drought risk ? IWRM-NET.

Royal Decree (RD) 1/2001, de 20 de julio, por el que se aprueba el texto refundido de la Ley de Aguas.

Royal Decree (RD) 15/2005, de 16 de diciembre, de medidas urgentes para la regulación de las transacciones de derechos al aprovechamiento de agua.

Segura River Basin Authority (SRBA) (1998). Plan Hidrológico de la Cuenca del Segura. http://www.chsegura.es/export/descargas/planificacionydma/plandecuenca/documentoscompletos/docsdescarga/MEMORIA_COMPLETA.pdf.Last accessed 07/07/2013.

Segura River Basin Authority (SRBA) (2008). Plan especial ante situaciones dealerta y eventual sequía de la cuenca del Segura. http.//www.chsegura.es/chs/cuenca/sequias/gestion/ Last accessed 07/07/2013.

Segura River Basin Authority (SRBA) (2007). Esquema provisional detemas importantes. http://www.chsegura.es/export/descargas/planificacionydma/planificacion/docsdescarga/ETI_v6_29julio2008.pdf Last accessed 07/07/2013.

Segura River Basin Authority (SRBA) (2013). Propuesta de Proyecto de Plan Hidrológico de la Cuenca del Segura, available at: http://www.chsegura.es/chs/planificacionydma/planificacion/. Last accessed 07/07/2013.

Tagus River Basin Authority (TRBA) (1998). Plan Hidrológico de la Cuenca del Tajo. http://www.chtajo.es/Informacion%20Ciudadano/Calidad/Documents/Plan%20Hidrol%C3%B3gico%20del%20Tajo.pdf.Last accessed 07/07/2013.

Tagus River Basin Authority (TRBA) (2007). Plan especial ante situaciones dealerta y eventual sequía de la cuenca del Tajo. http://www.chtajo.es/DemarcaTajo/SequiasyAvenidas/Paginas/Pes.aspx.Last accessed 07/07/2013.

Tweedale J., Ichalkaranje N., Sioutis C., Jarvis B., Consoli A., Phillips-Wren G. (2007). Innovations in multi-agent systems. Journal of Network and Computer applications 30. Pp1089-1115.

Water Act 29/1985, de 2 de agosto, de Aguas.

Water Act 62/2003, de 30 de diciembre, de medidas fiscales, administrativas y del orden social.