Do Drought Management Plans really reduce Drought Risk? A Risk Assessment Model for a Mediterranean River Basin

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Abstract

Groundwater resources in arid and drought prone regions with a profitable irrigated agriculture are traditionally overexploited. Depletion of groundwater results from a combination of the physical scarcity of surface sources and the lack of an effective control of use rights from the part of water authorities. This has been the case in the Segura River Basin in Southern Spain. As a result of that drought risk and structural deficits have steadily increased in the last 50 years. The Drought Management Plan recently approved by the Segura River Basin Authorities aims towards more stringent water supply restrictions from surface sources but does not include any explicit policy to tackle illegal groundwater abstraction. By using a stochastic risk assessment model, this paper shows that the implementation of the drought plan will increase the expected irrigation deficits of surface water and can paradoxically lead to a higher drought and aquifer depletion risks than traditional decision rules.

Keywords: Water economics, risk management, drought management , Mediterranean River Basins.

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Do Drought Management Plans really reduce drought risk? A Risk Assessment Model for the Segura River Basin in Spain

1. Introduction

Many semiarid and drought prone regions have significant competitive advantages for irrigated agriculture. Land is abundant and cheap, as not many alternative uses exist, solar radiation is guaranteed and, apart from abundant and cheap labor, many of these areas are located close to the sea and to high demand markets. Anything but water seems to be in place to develop a prosperous agricultural sector. In this context water for irrigation can become the critical production factor determining the viability and the returns of the agricultural sector. This is the case of many European Mediterranean regions where the survival of a competitive and highly productive agriculture depends critically on the ability to satisfy the water demand of a water intensive irrigation system.

In these regions water demand for irrigation is high but water property rights are poorly defined and enforced. Thus under frequent drought events incentives do exist to use more water than the amount provided from public controlled sources. In fact, when current demands cannot be covered by the publicly controlled sources farmers might have powerful incentives to shift towards the more dependable and mostly uncontrolled groundwater sources. Uncertainty, coupled with legacies of past management actions, often leaves decision makers few options other than to reinforce the current trajectory of the system (Anderies et al., 2006). The resulting overexploitation of the aquifers may reduce the robustness/resiliency of the system and its ability to cope with future droughts leading to a vicious circle of increasing risk, vulnerability and water scarcity (Holling, 1973; Perrings, 1989; Ruttan, 2002; Anderies et al., 2004; Anderies, 2005; Anderies et al., 2006).

Some important measures have been recently taken to tackle the structural problem of recurrent droughts in the EU. In what was perceived as an advance towards the replacement of the emergency responses of the past by the apparently more appropriate planned and anticipated risk management response, several river basin authorities from Spain, UK, Portugal, Holland and Belgium have recently approved their respective Drought Management Plans (DMP) (EC, 2007). Basically, for the case of drought events these plans set up more stringent constraints to the access of the publicly provided water at the same time that priority uses such as drinking water are guaranteed and minimum environmental services are ensured. As a result the declaration of a drought event will automatically reduce in a predictable amount the quantity of water delivered to the irrigation system from publicly controlled water sources. The DMP defines the precise thresholds of possible drought situations and sets the water constraints that will enter into force in each one of these cases (EC, 2007). For example, in the Segura River Basin in Spain, a four stage classification system is used (normality, pre-alert, alert and emergency): in the case of an emergency, an optimistic[1] 50% of planned

[1] During past drought events, observed irrigation resources conceded have reached in many cases levels well under 50% of initially planned irrigation resources. This was the case of the last 2005-2008 drought, when irrigation resources conceded were under 25% of initially planned for the whole period (CHS, 2010 and 2011).

irrigation resources will be conceded, trying to guarantee in the first place the survival of the ligneous crops (although water distribution can be revised by the local authorities). Less stringent water constraints are established for alert (75%) and pre-alert levels (90%) (CHS, 2010).

The Plans reduce *de jure* water supply during drought events. However neither the DMP nor the water authorities introduce any instrument to tackle groundwater illegal abstraction[2], which is not only one of the main causes of the increased scarcity and drought risk in arid and semiarid catchments but also one important limit to the ability of the water authority to reduce water use during droughts. In fact, the imperfect enforcement of property rights over groundwater use in several European Mediterranean basins raises some important doubts about the effectiveness of the DMP. Reductions in water supply from controlled sources, while proved to be efficient over surface water, are more difficult to enforce over legal and illegal groundwater sources (Llamas, 2007; CHS, 2010). As has happened in the past farmers may try to use informal and more reliable groundwater to compensate for the lack of formal surface water. Under the existing drought management rules aquifers can be considered as an insurance against drought[3] making drought risk equivalent to groundwater depletion risk.

Controlling property rights is a necessary condition to cope with the collective challenge of dealing with water scarcity and drought risk. The main hypothesis in this paper is that when water use property rights are not perfectly enforced, making formal water supply contingent to drought levels can paradoxically worsen both water deficits and drought risk. To test that in this paper we develop a methodology to compare and assess the water supply deficits resulting from two alternative drought responses: i) The baseline response results from the traditional decision rules historically applied in the basin; ii) The counterfactual response stems from the decision rules of the recently approved DMP[4].

The basic conclusion is that if not complemented with a proper enforcement of water use rights the new decision rules would lead to increased water deficits and would reinforce the existing incentives to increase the depletion of the largely uncontrolled groundwater resources.

The paper is structured as follows: section 2 introduces the area where the case study is applied, the Campo de Cartagena agricultural district in the Segura River Basin (Spain). Section 3 presents the risk assessment model. Section 4 shows and discusses the results obtained under the two alternative decision rules and section 5 concludes.

2. Background to the case study: Campo de Cartagena, Segura River Basin (Spain)

[2] On the contrary, river basin authorities have explicitly postponed the compliance of Environmental European quality and state Standards for aquifers further than the initially planned deadline of 2015 (EC, 2003; CHS, 2010 and 2011)

[3] Traditional response against illegal water abstraction has been more infrastructure and concession of additional irrigation rights (Gómez, 2009). This partly explains why irrigated land in CHS has grown more than 275% from 1990.

[4] No drought has been declared since its implementation, however, as a result of a succession of relatively rain abundant years (CHS, 2011).

As most of the variables involved are site or crop specific -such as rainfall, water demand, water supply and risk exposure- we illustrate each step of the model with the results for the particular case of the ligneous crops of the Campo de Cartagena Agricultural district in the Segura River Basin (SRB)[5].

The SRB is an example of a semi-arid water scarce basin exposed to an increased drought risk and with an imperfect enforcement of water use rights. For example in 2008, according to the rainfall-runoff models used by the water authority average household, manufacturing industry and agriculture demand was estimated in 1.9 billion cubic meters per year (85% from irrigated agriculture) while average renewable resources only amount to 0.75 billion (CHS, 2010 and 2011), indicating a Water Exploitation Index higher than 2.5[6]. Indeed, apart from the transfer of water from the Tagus river basin that has never covered more that 20% of the Segura water demand[7], strong evidence (CHS, 2010 and 2011 and WWF, 2006) shows that the existing deficit of water supply in the last decades has been effectively covered by the use of the mostly uncontrolled groundwater sources [8] [9]. Instead of enforcing property rights by closing illegal mills, traditional response has consisted in tolerating offenders[10] (CHS, 2010; Llamas, 2007). Not surprisingly drought risk has increased with water scarcity, and, as the evidence presented below shows, under the current water supply and demand a drought might occur in one out of every six years.

Campo de Cartagena, in the SRB, is an agricultural district with about 13,000 ha of irrigated ligneous crops (28.9% of total irrigated land) that demand around 58 million cubic meters (hm^3) for irrigation in a normal hydrological year, of which about 16.7 hm^3/year come from already overexploited aquifers (CHS, 2010; MARM, 2007). In spite of suffering from severe water scarcity, Campo de Cartagena is one of the largest and most profitable irrigated areas of

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[5] Campo de Cartagena is at the same time one of the more overexploited and profitable Agricultural districts in Spain (CHS, 2010).

[6] The *Water Exploitation Index* (WEI) is calculated as the ratio of total freshwater abstraction over the total renewable resources. According to the European Environment Agency (2009), this index was 1.27 in 2003, indicating a meaningful trend towards a higher water scarcity in the last 20 years. Previous studies (Martínez et al., 2002) estimated that water consumption was already 2.25 times larger than available renewable resources almost a decade ago.

[7] Tajo-Segura Water Transfer was intended to provide an average of 55% of total water resources in SRB and 35.78% of irrigation resources during the period 2005-2010 (CHS, 2010).

[8] SRB accumulated groundwater overexploitation amounts to 7,000 hm^3 (CHS, 2010), including aquifers whose resources have been exhausted to such a level that even in the absence of more abstractions it would take more than a century to recover them completely. This is the case of the Alcoy-Sopalmo aquifer, where during some hydrological years it has been pumped out twenty times its renewable resources (CHS, 2010).

[9] All this happens in spite that the granting of new concessions in the Segura river basin is forbidden since 1986 due to the significant water scarcity. Nevertheless irrigated areas grew between 1990 and 2000 at a rate of 6,500 ha/year (MMA, 2005); for example, in Campo de Dalias (Almería) the number of hectares farmed under plastic has tripled from 1980 to 2005, even though drilling new wells is prohibited. Only in the Segura River Basin about 100,000 ha were irrigated with water illegally abstracted in 2005 (IDRUICM, 2005). See WWF(2006).

[10] The concession of new water use rights is legally forbidden in the Segura River basin since 2005 when aquifers were declared overexploited. Nevertheless agricultural use increased by a 5% every year since 2005 and 2010 (CHS, 2010 and 2011). This is possible because of lack of control over irrigation water demand: only 155,313 hectares out of the 225,356 ha irrigated in Murcia (71.4% of total irrigated land in SRB) are officially registered by the water authority.

Spain (CHS, 2010), with production levels well over 20,000 kg/ha in some fruit trees (such as lemon tree, mandarin tree, orange tree and peach tree) (Pérez et al., 2011), so incentives for aquifer overexploitation are high even in the presence of high abstraction costs. Main ligneous crops there are citrus fruits (CHS, 2011).

There are three aquifers in the Campo de Cartagena agricultural district: Carrascoy, Victorias and Campo de Cartagena. These resources are overexploited even in non-drought periods. In a normal hydrological year Irrigation resources coming from these aquifers cover 29% of the irrigation demand, 36% of which being non-renewable ground water (CHS, 2010). This is exacerbated by the low technical efficiency of the abstraction, distribution and irrigation system (25.5% according to CHS, 2010), implying that only one fourth of the water abstracted effectively contributes to satisfy the agronomic water requirements.

3. The risk assessment model

To analyze the alternative drought management rules we use a two stage risk assessment method. The first stage consists in representing both the water required and the water available for a given set of ligneous crops in any moment of time as stochastic variables. In the second stage we use these stochastic variables to determine the resulting water supply deficit associated with each decision rule. We can describe the two stages as follows:

- The first stage uses a standard method to obtain water requirements for each ligneous crop. We compare the evapotranspiration requirements with the amount of water available which results from the following five sources: three stochastic sources (rainwater, runoff and stored water), the existing stock of groundwater and a variable but deterministic amount of non-conventional sources (wastewater reuse and desalinated water).

- The second stage allows us to determine the amount of water delivered to the irrigation system in accordance with the two alternative decision rules (traditional vs. drought contingency rules) and serves to measure the resulting excess demand for water (and the moral hazard incentive to engage in illegal abstractions). The alternative decisions are obtained as follows:
    - i) In the *Baseline* (or the traditional case) the water authority decides the amount of surface water to be delivered to the irrigation system using the same discretionary rules that can be deduced from past decisions, which basically depends on the amount of runoff observed in any moment of time.
    - ii) In the alternative case, the water authority follows the decision rule approved as part of the DMP. When the natural supply of water is "normal" (stored water and/or runoff may provide enough water) the decision is the same as in the traditional rule, but in the case of a drought emergency, alert and pre-alert (which occurs with a probability of 14% in our model) the amount of water delivered needs to be adjusted to the specific predetermined thresholds.

3.1. First Stage. The decision context: water requirements and water availability.

Following MMA standard method[11] the amount of water required by a single crop, or its Evapotranspiration (ET), is measured by using the evapotranspiration registered in the period 1941-2009[12]. In the case of irrigated crops, these water requirements are partially covered by the Effective Rainfall (ER) received from nature, which is a function of rainfall (a stochastic variable in the model). Thus the amount of water needed from the irrigation system or the Agronomic Water Required (WR) by a particular crop is equivalent to the difference between crop's Evapotranspiration (ET) and the Effective Rainfall (ER). Agronomic Water Requirements can be satisfied or not depending on the region's natural capital (stochastic runoff) and human capital (surface water stored).

The effective coverage of the agronomic water requirements depends on three stochastic variables: rainfall, runoff and surface water stored. The next subsections consider the Probability Density Function (PDF) of these three factors determining the water supply at any moment of time.

3.1.1. *Effective Rainfall*

Effective Rainfall (ER) is the amount of rainfall in mm (p) that effectively contributes to satisfy evapotranspiration[13]:

$$ER = g(p) \quad [1]$$

To represent ER_i under every possible state of nature observed data were adjusted to a Probability Density Function (PDF)[14] which allows assigning a probability ($y = h(p)$) to each rainfall level (p). This function is obtained as the best fit Gamma function[15] of the following kind (McWorther et al., 1966; Martin et al., 2001):

$$y = z(p|a,b) = \frac{1}{b^a \Gamma(a)} p^{a-1} \exp(\frac{-p}{b}) \quad [2]$$

Where *a* and *b* are respectively the scale and the shape parameters. Table 1 presents the Maximum Likelihood Estimators (MLE) of this function's parameters. As Figure 1 shows the

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[11] MMA methodology follows the Hargreaves method (Hargreaves et al., 1985; Samani, 2000; and Allen et al., 2006), which can be summarized as follows:
ET0 = 0,0023 (Tm + 17,8) (Tmax – Tmin) 0.5 Ra
ET = ET0 · Kc
Where ER stands for Effective Rainfall, T_m for average temperature (degree centigrade), T_{max} for maximum temperature, T_{min} for minimum Temperature and R_a for solar radiation. K_c are crop coefficients, which vary with region. ET is measured in l/m^2 or mm.

[12] Data is obtained from *Sistema de Información del Agua* (SIA), MARM, 2009.

[13] 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:
$ER = f(D) \cdot [1{,}25\, p^{0{,}824} - 2{,}93] \cdot 10^{0{,}000955 \cdot ET}$

[14] Data on cumulative annual rainfall is obtained from the *Sistema Integrado de Información del Agua* (SIA) (MARM, 2009), and it covers from 1941 to 2009.

[15] The Gamma function is defined by a scale parameter (a) and a shape parameter (b). It is consistent with rainfall measures as negative values are not allowed. The function reaches a maximum for intermediate values, decreases according to its scale parameter and converges to a normal distribution function as the shape parameter increases.

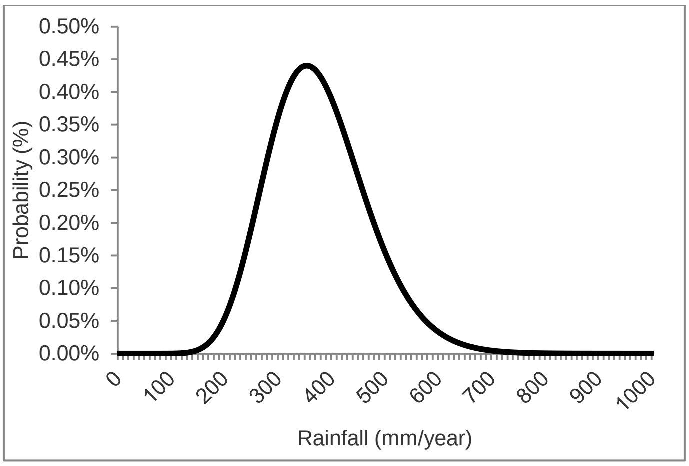
higher probabilities correspond to rainfall levels that are low or even very low for a region supporting a highly productive and water dependent agriculture[16]:

Table 1: Rainfall Gamma function. 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

a: significant at 1 per cent level. *Source: SIA, Own elaboration.*

Figure 1: Rainfall Probability Density Function, SRB, 1941-2008



Source: Own elaboration

The water deficit (WR) representing the part of evapotranspiration (ET) that is not covered by effective rainfall (ER) is also a stochastic variable that can be defined as:

$$WR = ET - g(p) \quad [3]$$

3.1.2. Runoff

The amount of water available to cover the agronomic water requirements is estimated using two proxy variables measured in percentage units: i) the percentage of annual cumulative runoff over the river basin surface water storage capacity (r) and ii) the percentage of water stored over the river basin surface water storage capacity at the beginning of the crop season (s) (CHS, 2010; Gómez Ramos et al., 2001). Both are stochastic variables.

Following Martin et al. (2001) we adjust the runoff probability distribution function to a Gamma function[17]. This allows assigning a probability (q) to each runoff level (r):

[16] The Segura river basin (SRB) is exposed to the higher meteorological drought risk in Spain. Average Evapotranspiration is similar to that of the Guadalquivir river basin but the time distribution is concentrated in low values (90% of rainfall values are between 400-800 mm while for example they are above 500 mm with a 92% probability in the Ebro river basin).

$$q = f(r|a,b) = \frac{1}{b^a \Gamma(a)} r^{a-1} \exp(\frac{-r}{b}) \quad [4]$$

Table 2 and Figure 2 shows the best fir parameters for the runoff function:

Table 2: Runoff Gamma function. Dependent variable is % of runoff over total surface water storage capacity

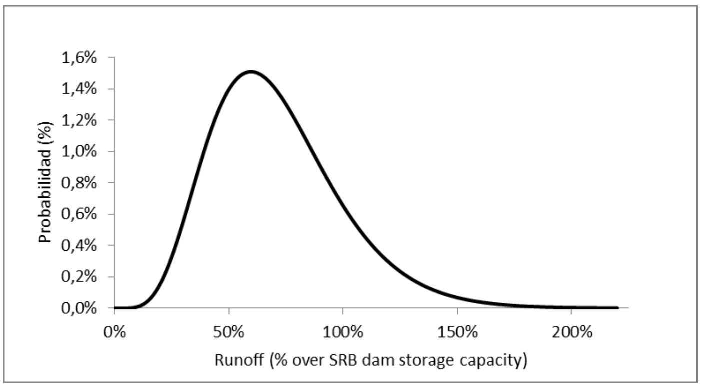
Variable	Coefficient
a (scale)	6.1813[a]
	(1.088)
b (shape)	0.1143[a]
	(0.012)
No. of observations	68

Estimated by maximum likelihood. Standard errors in parentheses.

a: significant at 1 per cent level.

Source: Own elaboration from Anuario de Aforos 2008 (MARM, 2008)

Figure 2: Runoff Probability Density Function, SRB, 1941-2008



Source: Own elaboration. See Table 2.

3.1.3. Available surface stored water

Following Gómez Ramos et al. (2001) and Pérez et al. (2011) we adjust the probability distribution function of the level of available stored surface water by using a Weibull function[18], which allows assigning a probability (w) to each stored water level (s)[19]:

$$w = j(s|a,b) = \frac{b}{a}\left(\frac{a}{b}\right)^{b-1} \exp\left(-\left(\frac{s}{a}\right)^{b}\right) \quad [5]$$

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

[18] The Weibull distribution is a continuous probability distribution with a scale parameter (a) and a shape parameter (b).

[19] s data series, as percentage of total dam storage capacity, is obtained from *Anuario de Aforos* (MARM, 2008).

Table 3: Surface water stored: Weibull function.

Dependent variable is % of dam stored water over Dam storage capacity

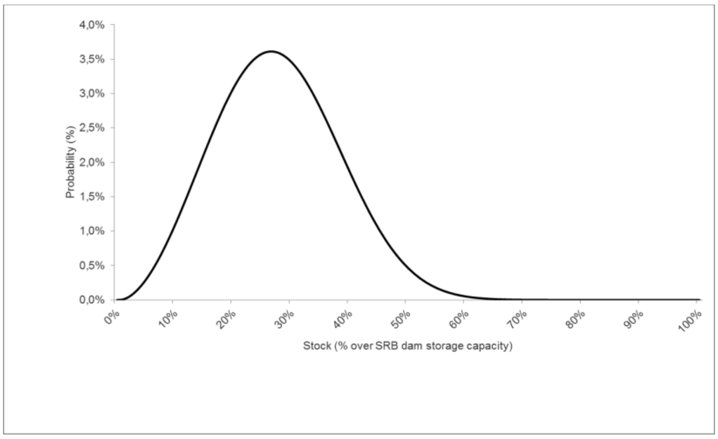
Variable	Coefficient
a (scale)	0.3411[a]
	(0.063)
b (shape)	4.1286[a]
	(0.497)
No. of observations	68

Estimated by maximum likelihood. Standard errors in parentheses.

a: significant at 1 per cent level.

Source: Own elaboration from Anuario de Aforos 2008 (MARM, 2008)

Figure 3: Dam Stored Water Probability Density Function, SRB, 1941-2008



Source: Own elaboration

3.2. Decisions rules:

At the beginning of every crop season the water authority observes the level of water stored in the reservoirs and assess the overall irrigation water required (TIR)[20]. Under this basis and the water authority applies a rule to decide over the amount of water to be delivered to the crop fields[21] The amount of irrigation resources actually delivered each year is a public decision based on the water availability and it might consist in using traditional decision rules (*Baseline*) or in applying the new decision rules of the recently approved DMP. We now analyze the two kinds of decisions separately.

[20] TIR is the maximum amount of irrigation resources that can be conceded in an ideal hydrological year. Spanish river basins estimate TIR as the agronomic water required to cover the 80th percentile of annual historical evapotranspiration (period 1941-2009) with a global efficiency of the water provisioning system of 60% (MARM, 2008). TIR is then higher than %TIR and it is most of the times higher than WR, too.

[21] The irrigation resources actually conceded by the river authority in the Segura cover only a percentage of estimated TIR ($\%TIR$).

3.2.1. *Traditional Decision Rules to decide on water delivery for irrigation*

Different from the situation created by the recently approved drought plans, the decision rules followed so far were the result of a mix of social agreements, expert judges and discretion without 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 . Available data covers a range of 15 years (1992-2007) (CHS, 2010) and, as it is normal in this kind of analysis, the number of observations is lower than the required by a robust estimation of a probability distribution function. In order to cope with the small number of observations problem for the percentage of TIR satisfied, we follow the standard approach of increasing the sample size by representing the percentage of TIR satisfied as a proportion of runoff, r[22] [23] ($h(r)$) by using ordinary least squares (Gómez Ramos et al., 2001)[24]. The function relating $h(r)$ with runoff is the presented in Table 4.

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

Variable	Coefficient
Runoff (% over dam storage capacity)	1.351[a] (.131)
R2	89.14
Adjusted R2	88.31
No. of observations	15

[*] Estimated by maximum likelihood. Standard errors in parentheses.

a: significant at 1 per cent level.

Source: Own elaboration

Finally, effective surface irrigation resources ($EIR(r)$), or the part irrigation resources (TIR) that effectively satisfy evapotranspiration, can now be expressed as a function of runoff (trough$g(h)$), and of the overall efficiency of the irrigation system (e_s):

$$EIR(r) = TIR * h(r) * e_{sw} \quad [6]$$

Other water publicly controlled water sources such as the groundwater legally used (gw), treated (tw) and desalinated water (dw) are given to farmers in a proportion of the irrigation resources delivered ($h(r)$)[25] from reservoirs. The amount of water delivered from each one of these sources is also converted into effective irrigation resources by using its own technical

[22] r data as percentage of dam storage capacity were obtained from *Anuario de Aforos* (MARM, 2008).

[23] Stored water (s) was not found statistically correlated with the percentage of TIR satisfied, which might be a consequence of the small storing capacity of the Segura River Basin. The ratio of reservoirs storage capacity (1,141 hm^3) over average yearly water use (1,905 hm^3) is only of 60% in the Segura far lower than the one of the drought prone Guadalquivir (238%) and the rainfall abundant Ebro river basin (90%) (See: CHS, 2011; CHE, 2011; CHG, 2011).

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

[25] In an average hydrological year, Campo de Cartagena irrigation resources come mostly from dam stored water (65.31%, η, 37.6 hm^3 of effective water) and groundwater (29%, 16.92 hm^3 of effective water, λ). Desalinated water (0.39%, θ) and treated water (5.3%, γ) are negligible (3.32 hm^3 of effective water) (MARM, 2007). These percentages are assumed constant in the model.

efficiency index ($e_{gw}$for groundwater, e_{tw} for treated water and e_{dw} for desalinated water)[26], as follow:

$$gw(r) = \frac{\lambda}{\eta} * TIR * h(r) * e_{gw} \quad [7]$$

$$tw(r) = \frac{\gamma}{\eta} * TIR * h(r) * e_{tw} \quad [8]$$

$$dw(r) = \frac{\theta}{\eta} * TIR * h(r) * e_{dw} \quad [9]$$

The percentage of the evapotranspiration satisfied ($\%ET$) can now be obtained from expressions (7) to (10), as follows:

$$\%ET_{p,r} = \frac{g(p)+EIR(r)+gw(r)+tw(r)+dw(r)}{ET} \quad [10]$$

Every $\%ET$ has associated a probability ($prob_{\%ET}$), which depends on runoff (*r*) and rainfall (*p*) values. Using expressions [2] and [4] this probability can be expressed as follows:

$$prob_{\%ET_{p,r}} = f(r) * z(p) \quad [11]$$

The expected level of evapotranspiration coverage ($E_{\%ET0}$) and the resulting expected irrigation deficit (ID) in the traditional rule scenario can be represented as:

$$E_{ET} = \int_{r=0}^{225} \int_{p=0}^{1300} [z(p) * g(p) + f(r) * \left(EIR(r) + gw(r) + tw(r) + dw(r)\right)] \quad [12]$$

$$ID = ET - E_{ET} \quad [13]$$

Illegal groundwater abstraction is a positive function of irrigation deficits. The use of surface water is observable and controlled by the water authority in the limits of the existing legal property rights. Contrary to that access to groundwater is a moral hazard decision taken by the farmer and unobservable for the water authority. When water allowances from publicly controlled water resources fall short with respect to agronomic needs, as the evidence in the Segura river basin shows, farmers will have positive incentives leading them to look for uncontrolled groundwater sources. Illegal groundwater abstraction (GW) is then a positive function of irrigation deficit:

$$GW = c\left(\frac{ID}{e_{gw}}\right) \quad [14]$$

3.2.2. DMP decision rules over water for irrigation

Recently approved DMP for the SRB qualifies the particular situation at hand and the severity of the problem by using an objective and publicly observable drought index, I_e. These plan

[26] Piping and irrigation techniques determine the final amount of effective water applied to satisfy a certain amount of crop's water demand. Global efficiency of the system for the comarca of Campo de Cartagena is about 87% for dam stored water, 60% for desalinated water and reused wastewater and 25% for groundwater (CHS, 2008; MARM, 2007).

establishes four drought thresholds (CHS, 2010): i) When water stored levels are regarded as *normal* ($I_e > 0.5$) there are no additional explicit restrictions, so water delivery ($\%TIR$) is the same as in the baseline or traditional rule scenario; ii) water for irrigation is reduced by 10% ($h = 0.9$) when water available falls below the pre-alert threshold ($0.35 < I_e \leq 0.5$); iii) if the alert limits are overpassed ($0.2 < I_e \leq 0.35$) water for irrigation is reduced by at least 25% ($h = 0.75$); iv) and under emergency ($I_e \leq 0.2$) water for irrigation is halved ($h = 0.5$). According to historical data drought is quite likely in SRB and occurs with a probability of 14%[27].

In the case of Campo de Cartagena in SRB the drought index (I_e) depends on the observed values of both runoff and stock[28] (CHS, 2010). We therefore define $l_{r,s}$ as a discrete water restriction variable whose value depends on the drought index (and thus on runoff and stock values) and its corresponding h. As empirical data shows that estimated satisfied agronomic crop requirements under new Drought Plan are too optimistic compared to past events, we set $l_{r,s}$ as the minimum between $h(r)$ defined in *Baseline* scenario and SRB's DMP parameters above (h):

$$l_{r,s} = \begin{cases} \min(h(r), 0.5), if\ I_e \leq 0.2 \\ \min(h(r), 0.75), if\ 0.2 < I_e \leq 0.35 \\ \min(h(r), 0.9), if\ 0.35 < I_e \leq 0.5 \\ h(r), if\ I_e > 0.5 \end{cases} \quad [15]$$

In every case the percentage of evapotranspiration satisfied with rainfall and surface water ($\%ET2$) and its associated probability ($prob_{\%ET2}$) can be obtained from:

$$\%ET2_{r,s,p} = \frac{g(p) + \frac{l_{r,s}}{h(r)} * (EIR(r) + gw(r) + tw(r) + dw(r))}{ET} \quad [16]$$

$$prob_{\%ET2_{r,s,p}} = f(r) * z(p) * j(s) \quad [17]$$

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[27] This is a minimum threshold. Historical data underestimate drought risk because it does not take into account that now water sources are in a worse condition than in the past.

[28] I_e is calculated as follows (CHE, 2010):

$$I_e = \frac{1}{2}\left(1 + \frac{V_i - V_{med}}{V_{max} - V_{min}}\right), if\ V_i \geq V_{med}$$

$$I_e = \frac{1}{2}\left(\frac{V_i - V_{min}}{V_{med} - V_{min}}\right), if\ V_i < V_{med}$$

Where V_i is an indicator which is unique for each *Junta de Explotación* (a group of Agricultural districts of comarcas). In *Sistema Cuenca*, Campo de Cartagena corresponding *Junta de Explotación*, V_i is obtained as follows:

$$V_i = \frac{2 * DSC * r + DSC * s}{3}$$

Where r is runoff as a percentage of total Dam Storage Capacity (DSC) and s is dam stored water as a percentage of total DSC. Using r and s maximum, minimum and average observed values during the reference period we get V_{max}, V_{min} and V_{med}, respectively.

We can also obtain expected evapotranspiration satisfaction and expected deficit under *Drought Management Plan* scenario by conditioning evapotranspiration satisfaction to drought threshold indexes impact ($l_{r,s}$):

$$E_{ET} = \int_{r=0}^{225} \int_{p=0}^{1300} \int_{s=0}^{100} \left[z(p) * g(p) + f(r) * \frac{l_{r,s}}{h(r)} * \left(EIR(r) + gw(r) + tw(r) + dw(r) \right) \right]$$

[18]

$$ID = ET - E_{ET} \quad [19]$$

Again, illegal groundwater abstraction would be a positive function of irrigation resources [14]. The whole methodology has to be replied for every crop and every Agricultural district considered[29].

4. Drought decision rules and water deficits

The following table compares the outcome of the two decision frameworks in terms of the expected rates of evapotranspiration covered and of the associated irrigation deficits (both in volume and percent units). The last row the ($PotGW$) shows the expected amount of non-authorized water abstractions that would be needed to fully cover the irrigation deficits in the Campo de Cartagena with the existing technical efficiency of the irrigation system.

Table 5: Expected evapotranspiration satisfaction, Expected Irrigation Deficit and Expected Potential illegal Groundwater abstraction in absolute terms (Hm^3) and as a percentage of ET satisfied ($\%ET$) for all possible states of nature in Campo de Cartagena agricultural district.

		Baseline scenario	DMP scenario	Difference
Total Expected Evapotranspiration Satisfaction	E_{ET} (Hm^3) $E_{\%ET}$	43.89 94.73%	43.31 92.32%	-0.59
Expected Irrigation Deficit	ID (Hm^3) $ID_{\%ET}$	1.82 3.99%	2.41 7.68%	0.59
Expected Potential Groundwater Depletion	$PotGW$ (Hm^3)	7.15	9.45	2.3

Source: Own elaboration

In the baseline droughts occur with a 14% probability and the expected deficit amounts to 1.82 Hm^3 of effective water (this deficit is confirmed by the water authority in CHS, 2008) which give the technical efficiency of the irrigation system would require the abstraction of additional 7.28 Hm^3. Implementing the decision rules of the drought plan will increase this expected

[29] Most parameters in the model can be taken at a river basin level, except *K* coefficients and system global efficiency, which are unique for each crop and district, respectively.

deficit in 35% to 2.4 Hm^3. As a result[30] the implementation of the new drought planned decisions will add pressure to the already overexploited aquifers in the area as at least one part of the increased supply deficit will be satisfied with the means of increasing uncontrolled groundwater.

Water deficits and incentives for aquifer overexploitation are particularly high during the drought-emergency events ($I_{e_{t,j}} \leq 0.2$) happening one out of every ten years (with a probability of 9.88% in our model). A drought emergency would now imply a severe cut in water allowances for irrigation that would have a significant impact over evapotranspiration satisfaction and irrigation deficit, decreasing production and income (Pérez et al., 2011). Incentives are then even higher for illegal groundwater abstraction:

Table 6: Expected evapotranspiration satisfaction, Expected Irrigation Deficit and Expected Potential illegal Groundwater abstraction in absolute terms (Hm^3) and as a percentage of ET satisfied ($\%ET$) under emergency in Campo de Cartagena Agricultural district.

		Baseline scenario	DMP scenario	Difference
Total Expected Evapotranspiration Satisfaction	E_{ET} (Hm^3)	37.84	35.82	-2.02
	$E_{\%ET}$	82.76%	78.34%	
Expected Irrigation Deficit	ID (Hm^3)	7.88	9.90	2.02
	$ID_{\%ET}$	17.24%	21.66%	
Expected Potential Groundwater Depletion	$PotGW$(Hm^3)	30.90	38.83	7.92

Source Own Elaboration.

Compared to previous decision rules the expected irrigation deficit will increase from 17% to 22% (see Table 6) and it will need 8 hm^3 more to be covered, meaning higher incentives to use poorly controlled groundwater sources. By trying to reduce water use drought planned responses in the case of the Segura river basin can reinforce the existing moral hazard incentives to groundwater depletion leading to the paradoxical result of lower resilience and high drought risk in the future.

5. Discussion and Conclusions

The results presented above provide relevant insights not only within the ecological economics field, but also in the broader area of drought risk management. The main conclusion is that DMPs must be properly designed taking into account all possible water sources to guarantee that a comprehensive social-ecological water conservation framework is put in place. Otherwise, water demand stemming from their implementation may result in local

[30] Only 12 proceedings for illegal water abstraction have been initiated between 1996 and 2005 in SRB, which gives an idea of the immunity under which offenders operate (WWF, 2006).

overexploitation of illegal water sources such as aquifers, and thus in a loss of resilience and robustness.

This is the case of the SRB in Spain. Irrigated agriculture in this area is among the largest and most profitable of Spain (CHS, 2008; Pérez et al., 2011)), although its sustainability is compromised by the structural water scarcity and recurrent droughts (CHS, 2008 and 2010 and EEA, 2009). The farmers' traditional response of using groundwater as an insurance against drought (Llamas, 2007; WWF, 2006) implies a vicious circle of higher water deficits, lower resilience and more frequent and severe droughts. This dynamic can only be reversed when water use is curved down to match the long term renewable resources of the river basin and this is not possible without the enforcement of existing water property rights (Raffensperger, 2011). The existing data and the risk assessment analysis presented in this paper suggest that the more stringent water constraints over publicly controlled water sources, that are the essence of the recently approved Drought Management Plans, will not be effective to reduce drought risk and, without recovering the control over groundwater resources, these norms will only make water scarcer and more valuable for crops and will result in new incentives for farmers to engage in the moral hazard kind of behavior that now pervades the irrigated agriculture in many Mediterranean areas such as the SRB.

For example, under new Drought Management Plan in the SRB, a likely drought with a rainfall under 400 mm and a drought index below 0.2 would lead to an expected deficit in effective irrigation water of 18.23 hm^3 requiring the abstraction of as much as 71.51 hm^3 of groundwater (more than four times the amount required in a normal hydrological year). This event actually happened during the years 2005-2008, where the drought index remained below the emergency level for almost the whole period. The failure of the emergency responses used at that time was one of the main arguments to design the drought plans approved in 2008. However, emerging decision rules ignore the basic fact that quantitative water constraints can only be successful provided water property rights are properly designed and enforced. In effect according to the above presented results the Drought Management Plan will make future droughts more likely and more severe.

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