Abstract

A key guideline of the European Water Framework Directive (WFD) asks to cover water costs in a way to encourage the efficient use of the resource, therefore its protection, but minimizing possible adverse environmental, social and economic impacts of cost recovery. We use a Mathematical Programming model of an Italian, Mediterranean agricultural area where a Reclamation and Irrigation Board (RIB) manages collective irrigation facilities, to simulate the impact of replacing the existing pricing system with several alternatives, at different degrees of water cost recovery. We estimate the water distribution cost (WDC) of the RIB with a *Translog* cost function, and consider the cost incurred by the Sardinian water agency (ENAS) for maintaining regional dams and primary water infrastructures. We also consider that a Regional subsidy pays part of the RIBs and ENAS energy cost for water lifting, and that ENAS rates are modulated among end-users to reduce agricultural fee by increasing the charge on industrial uses. We simulate the impact of alternative pricing under four scenarios of cost recovery: (i) current partial recovery of WDC, with no ENAS charge; (ii) current recovery of WDC, plus ENAS cost at modulated agricultural rates; (iii) full coverage of WDC, i.e. absence of the Regional aid, plus ENAS cost at modulated agricultural rates; (iv) full coverage of WDC, plus unmodulated ENAS rate. Solely changing the water pricing system, at current cost recovery level, generates limited total impacts, but substantial income redistributive effects among farm types whose magnitude grows increasing the level of recovery. The full cost recovery scenarios generate remarkable global impacts and drops of income in the single farm types, particularly when applying ENAS undiscounted rate. Major consequences also emerge for the use of water and other productive factors, and labour employment.

Keywords

Water Framework Directive, pricing irrigation water, water distribution cost function, mathematical programming

1. Introduction

One of the key guidelines of the Water Framework Directive (WFD) is to combine economic principles and tools (*polluter pays*, and *pricing*) to achieve environmental goals, while ensuring *full cost recovery* (FCR) of water services, and adequate incentives to efficiently use water (European Commission, 2000; Massarutto, 2007; Martin-Ortega et al, 2015). The European guidance document on the Directive précises how to plan and organise the economic analysis in implementing the water policy (WATECO, 2003). Besides, Article 9 of WFD recognizes that applying efficient water pricing may raise social and redistributive concerns, and establishes that Member States may consider social, environmental impacts and economic in planning the mode and level of cost recovery. This aspect is important. On it, Reynaud (2016) shows that increasing water payments for domestic use could mainly affect the most vulnerable social groups. From the agricultural perspective, Venot (2008) stresses that raising taxes on the water taken from farms wells does not involve significant savings of that resource, and can further reduce the profitability of extensive crops or low income. In the case of irrigation water supplied by collective facilities, Dono et al. (2010) stress that if the latter are underused, FCR rates could be based on average costs that are much higher than the marginal costs: uncontrolled extractions of groundwater may result where this resource is available, or negative impacts on incomes where not. Definitely, pursuing FCR by increasing water payments might generate a vicious circle favouring the use of sources difficult to protect, appreciably affecting low income users and reducing the use of collective services (Azevedo and Baltar, 2005; Reynaud, 2016).

According to a recent report of the European Commission, not all Member States apply transparent water pricing, and Greece and Italy are particularly lagging behind in adapting (European Commission, 2015)[1]: a solicitation arises for many national and local water authorities, to recover the delay. Our analysis takes its cue from this commitment, and assesses the possible impact of various pricing

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[1] A key factor of delay is considered the lack of adequate metering systems, a precondition to present users the water costs.

methods in an irrigated Mediterranean area of Sardinia (Italy) where a *Reclamation and Irrigation Board* (RIB) distributes water to farms[2]. Our goal is twofold. First, assess the impact of replacing the current pricing with alternative systems, including *volumetric*, often regarded as the most effective in promoting efficient use of water. Second, evaluate the effect of including all the costs of water in the irrigation rates, and, indirectly, assess the choice of Regional Authorities to limit this transfer to farms. The next section, *Background*, illustrates aspects of the scientific debate that are relevant to our study. Section *Materials and Methods* describes the study area, the approach for assessing the impacts of water pricing and cost recovery, with simulated pricing systems, and the estimation of water costs. The *Results* section reports the economic, and some environmental and social impacts of the simulations. The *Discussion* section assesses the impacts of the pricing systems, and the *Conclusions* follow.

2. Background

2.1 Scientific debate on Water Framework Directive

Several aspects of the scientific debate on WFD are relevant to our study. A first issue is identification of the costs to be recovered in agriculture: Garrido and Calatrava (2010) classify monetary costs in three categories. The irrigator pays *private costs* as any other farming cost, such as energy, maintenance and labour. The pricing and water allocation policies can have major impacts on them, leading to change the source of supply, for example encouraging use of groundwater, or the adopted irrigation technologies. Another category is the *costs of the irrigation district*, or *scheme*, for the management and maintenance of water distribution systems to individual farms. RIB*s* manage most of the Italian schemes, and about 63% of irrigation water (Bellini, 2014), and charge specific tariffs to farmers (INEA, 2011), project capital costs are publicly funded. Finally, the *Water Authority costs* pertain to governmental agencies that manage large dams and infrastructures, debiting related costs to end-users and taxpayers: and it is

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[2] The RIBs are non-profit landowners associations with legal status.

interesting to examine the distribution between the two groups (Garrido and Calatrava, 2010). Complex and site-specific analyses are required to estimate and include in the FCR environmental and resource costs. The former consist of *non-use values* associated with obtaining a healthy functioning of aquatic ecosystems, and *use values* of water environment (DG ECO 2, 2004). Resource costs arise when alternative uses of the water generate higher economic value than present use or foreseen future, because of an inefficient water allocation or pollution, over time and across users (EEA, 2013).

Several Authors agree that applying FCR would increase the water users payments, mainly to agriculture that currently pays part of the financial costs (Berbel and Gomez-Limon, 2000; Massarutto, 2007; Berbel et al, 2011; Giannakis, 2016). According to EEA (2013) *volumetric water tariffs* of Italian agriculture are in the range of 0.04–0.25 €/m^3,[3] over 0.002-0.70 €/m^3 in a selected group of European countries; *flat rates* are in the range of 30–150 €/ha, over 30-210 €/ha for those same countries. Arcadis (2012) estimate that those charges generate a 50% financial cost recovery rate, as average of 50-80% in the North, and 20-30% in Southern Italy. Massarutto (2003) mentions analogous levels of partial recovery of the total cost. He also highlights the complexity of this computation, warning that in many facilities the final cost value depends on the joint use in multiple uses, as the hydropower generation in Northern Italy, and public water supply companies in South[4]. The Author also reports that Operation and Maintenance costs are recovered at 70-100% in Northern Italy, and 20-100% in the South.

Related to FCR, another relevant issue concerns the pricing system that can encourage efficient use of water. *Volumetric* is considered as the most suitable pricing for achieving the WFD objectives (Gómez Limón and Riesgo, 2004; Bartolini et al., 2007; Gallego-Ayala, 2012). Yet, many constraints are found to possibly hinder the reaching of efficiency in irrigation water (Johannson et al, 2002). Massarutto (2007) stresses that recovery should only consider costs incurred by an efficient service supplier that pays all

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[3] Arcadis (2012) report 0.03-0.07 €/ m^3 as the prevalent range for *volumetric* pricing in Southern Italy.

[4] Depreciation and capital cost depend on accounting practices, on allocation of assets ownership and economic risk among operators, users, and public authorities (and among types of uses for multipurpose water systems) (EEA, 2013).

inputs at their marginal cost (MC). Furthermore, Dono et al (2013) highlight that MC pricing may not allow FCR when average costs (AC) are decreasing, as in large canal schemes, being MC lower than AC. Other factors, such as scarcity due to climate change, may reduce the use of water at levels where MC of running collective facilities is below AC. In conditions of structurally decreasing irrigation AC, or under-utilized irrigation schemes, FCR pricing would charge farmers for inefficient levels of use that do not depend on their choices.

Finally, and key for this paper, WFD provides that Member States may balance negative effects of FCR on social, environmental and economic issues. Other objectives of national policies can be reconciled in WFD, as adequacy of revenues from water services, equity and flexibility, environmental protection, administrative simplicity and transparency (Garcia and Reynaud, 2004; Reynaud, 2016). Cooper et al (2014) point out that these objectives might be in conflict with each other[5], and is likely hard to reconcile all in a single policy. Dono et al (2010) stress that FCR of water services achieved by increasing payments could hinder water protection, encouraging farmers to use alternative sources as groundwater or rivers. According to Reynaud (2016) the implementation of FCR would result in major changes in water use of households (in Italy among other countries), as well as in accessibility issues, since (not Italian) families in the lowest income decile will have to devote major shares of their income to pay the new water bills and wastewater. Moreover, inconsistent aspects are present: Garrido and Llamas (2009) point out that specify the resource cost would require functioning water markets; yet, if this trade becomes a usual practice, there will be no need to integrate the resource element in the water costs. In any case, according to Howarth (2009) a critical aspect is that WFD, and the documents on its application, are vague in defining the criteria to assess these issues. Gómez-Limón and Martin-Ortega (2013) stress that the vagueness of Article 9, can also lead to conclude that it is not required to apply increases in water tariffs. Also because of this vagueness, many river basin plans are mainly descriptive and devoid of

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[5] Achieve economic efficiency may conflict with ensure adequacy of revenues, both may conflict with reaching of equity.

prospective analysis. Hence, it would be useful strengthening their economic section to avoid that their choices appear arbitrary in tempering the social impact of FCR, and in protecting environmental quality.

2.2 Water Framework Directive and Mathematical Programming Models

We evaluate the impact of reforming water pricing with a Mathematical Programming Model (MPM) of our study area. Bazzani et al (2005) use a multi-criteria MPM to conclude that WFD would reduce only slightly agricultural water use, and would mainly reduce farm income and labour employment, even if differently among farm types. Mejias et al (2004) use a stochastic MPM to show that pricing would be even less effective in reducing farming use in the years of increased water scarcity. Instead, integrating objectives of WDF and CAP would increase the efficiency of water allocation. Riesgo and Gomez-limon (2006), and Bartolini et al (2007) use a MPM, respectively, with linear and multi-attribute utility, to conclude that agricultural policies are pre-eminent on the recovery, partial and complete, of the irrigation water costs. They also conclude that it is useful to maintain low water prices to achieve the environmental objectives of WFD. Semaan et al (2007) integrate the results of the EPIC crop model in a MPM, to conclude that water pricing is ineffective in reducing nitrate leaching; it is also socially resisted because, as the taxes on nitrogen fertilizer, charges farmers the cost of nitrate leaching reduction.

Garrido and Calatrava (2010) stress that MPMs overvalue the economic impacts of pricing policies and undervalues water demand elasticity because of its short/medium-term perspective, besides neglecting the uncertainties involved in farming. Stochastic Programming models may help in representing the effect of various types of risk or uncertainty on the agricultural water demand (Hardaker et al, 2004; Garrido and Calatrava, 2010). Quiggin et al (2010) use Discrete Stochastic Programming (DSP) to evidence the long-run role of water reallocation in limiting the adverse impacts of CC, and claim for global adaptation policies and pledge of local governs in protecting the environmental flows. Dono et al (2013) use a DSP model to investigate the concurrent impacts of CC on irrigation water availability and crop water needs, and stress the potential of EU Rural Development Policy in assisting RIBs to improve management and functionality of collective water infrastructure. Kahil et al (2015) use DSP to derive the ability of policy-assisted water markets in driving farmers' adaptation to CC.

Many of these studies use the Positive Mathematical Programming (PMP) to perfectly calibrate the water allocation models. Iglesias and Blanco (2008) recommend PMP to assist in implementing the WFD pricing and cost recovery, given its accuracy and replicability in diverse contexts. Cortignani and Severini (2009) extended the of Rohm and Dabbert approach (2003) to calibrate the PMP in order to simulate the application of new strategies and irrigation technologies. This enabled to overcome the dependence of the PMP from observed reality, which in other ways prevents to obtaining adaptive responses based on new activities[6]. Dono and Giraldo (2012) show the potential of PMP to assist water policy analysis , highlighting that *volumetric* pricing of water from a dam could increase over-extraction of groundwater, and speed up the on-going salinization of aquifers. PMP allows to establish interactions amongst economic, hydrological and other biophysical sub-models in complex multi-module models, given the ease to apply in several contexts thanks to its self-calibrated approach (Howitt et al, 2012). Dagnino and Ward (2012) use PMP to assess the effects of an incentive-assisted policy that encourages farmers of a sub-basin in North America's Rio Grande to convert from surface to drip irrigation. They show that, in face of a consistent reduction of farm-level water usage, a relevant shortcoming is represented by the increase of water depletion at sub-basin level, because increased irrigation efficiency generates higher yields and higher ET, moreover without the possibility of restoring aquifers through percolation. Finally, Gohar and Cashman (2016) stress that, producing smooth changes, PMP adequately assesses CC impacts on water and food security, as well as many scenarios of adaptation and cost of water, in dynamic optimization frameworks.

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[6] Fragoso and Marques (2015) suggest that approaches as Econometric Mathematical Programming can overcome some limits of PMP in reproducing farmers behaviour under sweeping policy changes

3. Material and methods

We evaluate the impact of different water charging systems in an irrigated Sardinian area, partially or fully recovering water distribution costs (WDC) of the RIB and accounting for different recovery levels of the costs incurred by the ENAS[7], the Agency that manages the Sardinian water schemes and provides sectorial end-users (agriculture, industry, civil use). We simulate these impacts with a territorial economic model, divided into blocks that represent the sub-areas with different technologies to distribute irrigation water, and, inside the sub-areas, main farm types. Furthermore, the model uses the Discrete Stochastic Programming to represent the choices prone to uncertain conditions: different states of the nature of some parameters (yields and irrigation requirements) are considered with the possibility to correct the choices in later stages.

Another original contribution concerns the integration of the territorial model with a *Translog* function (Giraldo et al, 2014). This function estimates the WDC incurred by the RIB under the agricultural water use conditions generated by the pricing and cost recovery simulations. Concurrently, the territorial MPM accounts for the effects of the latter on the on-farm water usage and demand. We also consider that part of WDC is subsidized by a Regional aid to cover extra energy costs incurred by the RIB for water lifting, as a consequence of local orographic disadvantages. Finally, we consider the cost to providing water to the RIB, from the reports of the ENAS, which differentiates the tariffs among end-users in order to balance the environmental, economic and social impacts of cost recovery.

We now examine the study area, the mathematical formulation of the territorial DSP model and the simulated scenarios as regards the water costs and pricing systems

3.1. Study area and irrigation districts

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[7] ENAS – Ente Acque della Sardegna - Water Authority of Sardinia.

The study area has an acreage of 54,000 ha, in Centre-west of Sardinia (Italy): Dono et al (2016) describe its main features, as well as the process of their identification. Here we recall that two sub-areas compose it, with different water availability conditions. On 36,000 hectares, the *Oristanese* RIB annually provides 120 Mm3 of water from the Eleonora d'Arborea dam to 26 irrigation districts. Based on technological features, these districts can be grouped into three clusters. The first distributes water at high pressure (*HP*) with pipelines and pumping schemes. A similar network provides water at low-pressure (*LP*) in another group. Finally, a network of open channels conveys water by gravity (*GR*) in a third group. The unitary amount of the current acreage-crop fees are specified depending on the benefit that farms gain from irrigation, precisely in function of the adopted distribution technology. In this regard, the *HP* group is divided in a cluster for the districts of the Arborea municipality (HP_{Ar}), where higher fees are imposed, and in another *HP*-district clusters (HP_{Ot}). Hence, four *macro-districts* compose the RIB area: HP_{Ar}, HP_{Ot}, *LP* and *GR*, with a decreasing level of benefit. The water distribution facilities of the RIB are absent in the remaining 18,000 ha of the area, where rain-fed farming is practiced, with the exception of a limited number of hectares where private farm wells serve the irrigation. Thirteen main types represent the farms of the area; nine of them operate in the RIB zone. The main crops are silage maize and rice, Italian ryegrass and alfalfa, open-field and greenhouse horticultural crops, tree crops. The largest part of dairy cattle breeding of Sardinia operates in the Arborea area with a well-organized cooperative structure for producing, processing and marketing cow milk. Dairy sheep breeding of is also practiced in the RIB zone, although it is mostly concentrated in the rainfed zone.

3.2. Mathematical formulation of the territorial DSP model

We use a DSP supply model to consider various risk conditions in the decision-making that are typical of Mediterranean areas. Attention is paid to the role of climate variability in making uncertain several agricultural parameters, water needs of crops among the others. According to DSP modelling, farmers conceive the production process as a sequence of *stages*, whose structure depends on uncertainty on some parameters. For these parameters they formulate a PDF (Probability Distribution Function) that then discretize into main *states of nature*, with related representative values and probabilities[8]. Hence, farmers plan based on the probability of these climatic, therefore productive *states*, and the possibility to correct potentially unfavourable results, even if at a cost. In particular, the planning focuses on the *state* with the highest expected income. The resulting management is different from that of perfect knowledge of all parameters: in fact, since unfavourable *states* may occur, farmers take precautions whose cost reduces the potentially achievable income[9].

Dono et al. (2016) describe in detail the DSP model used in our simulations. Here we specify its structure in blocks related to the *macro-districts* and, within them, to the farm types. Moreover, respect to the formulation made in Dono et al. (2016), here is made explicit the component related to water pricing (*WP*), that represents the mechanism by means of which water costs are charged to end-users. As will be illustrated in the following paragraphs 3.3 and 3.4, this mechanism differs among the various simulations for what concerns both the entity of the costs charged to farmers and the pricing system used. Equation (1) is the objective function (Z_{GM}) (OF) as sum of gross margins related to each crop (j) and livestock activity in the 13 farm types (ty) operating in the five *macro-districts* (d) of the area[10]. It can be defined as follows:

$$\max_{x_{1\,j,d,ty},\, xr_{n_{s,d,ty}}} Z_{GM} = \sum_{j,d,ty} \left(gi_{j,d,ty}\, x_{1\;j,d,ty} - \sum_{n=2}^{N} \sum_{s=1}^{S} P_s\, Cr_{d,ty}\, xr_{n_{s,d,ty}} + Pm_{d,ty}\, Qm_{d,ty} - WP_{d,ty} \right) \quad (1)$$

subject to the constraints:

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[8] Farmers are assumed to build the PDF of many variables influenced by the normal climate variability by learning from individual experience and the local knowledge (Nguyen et al, 2014).

[9] Details can be found, among others, in Hardaker et al (2004), Connor et al (2009), Dono et al (2016).

[10] The fifth block includes the area outside the RIB.

$$\sum_j a_{j,d,ty}\, x_{1\ j,d,ty} \leq b_{d,ty} \qquad \forall\ d,ty \qquad (2)$$

$$\sum_j wreq_{s,j,d,ty}\, x_{1\ j,d,ty} \leq RIBw_{d,ty} + \sum_{n=2}^{N} xr_{n_{s,d,ty}} \qquad \forall\ d,ty,s \qquad (3)$$

$$\sum_j nutr_j\, y_{s,j}\, x_{1\ j,d,ty} + \sum_{n=2}^{N} xr_{n_{s,d,ty}} \geq r_{d,ty} \qquad \forall\ d,ty,s \qquad (4)$$

$$x_{1\ j,d,ty} \geq 0\ and\ xr_{n_{s,d,ty}} \geq 0 \qquad \forall\ d,ty,s \qquad (5)$$

$gi_{j,d,ty}$ are the gross margins of the annual cropping activities, whose acreage is chosen in the first stage ($x_{1\ j,d,ty}$); *n* is the number of *stages* of the decision making; *s* are the *states of nature* that uncertain variables can assume; P_s are the probabilities of occurrence of each *state of nature* in the subsequent stages (*n* = 2,..,*N*), which, if not expected, make it necessary to undertake corrective actions ($xr_{n_{s,d,ty}}$) with a unitary cost ($Cr_{d,ty}$); $Pm_{d,ty}$ and $Qm_{d,ty}$ are, respectively, the unitary price and total quantity of cow and sheep milk; $WP_{d,ty}$, as already mentioned, relates to irrigation water pricing, estimated in different ways depending on the pricing system and level of cost recovery considered in the various scenarios and charged to the farm typologies operating in a given *macro-district*. We present these simulated scenarios in the next two paragraphs. Equations 2-5 are the constraints. In (2) $a_{j,d,ty}$ is the unitary land and labour needs for each activity; $b_{d,ty}$ is the respective availability[11]. Constraint (3) by $wreq_{s,j,d,ty}$ expresses irrigation needs: this represents uncertainty by considering the diverse needs in the various *states of nature*. Depending on the *state* that occurs in the second *stage*, their sum could exceed the availability of water from RIB ($RIBw_{d,ty}$): in that case, additional water has to be integrated from wells ($xr_{n_{s,d,ty}}$). Constraint (4) refers to animal feeding: $nutr_j$ are the unitary contributions in

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[11] For reasons of compactness in the formal specification of constraint equations, we jointly consider land and labour needs, as these variables are not subject to uncertainty in our model differently from irrigation water requirements and animal feeding needs.

nutritional elements of fodder crops, $y_{s,j}$ is their unitary yield, whose amount depends on the actually occurring *state of nature*: some of them depress fodder crop productivity, and, given the overall nutrient requirements, additional purchased feed ($xr_{n_{s,d,ty}}$) is needed in the following *stages*. The positivity constraint (5) concerns the levels of cropping activities ($x_{1\ j,d,ty}$) and the intensity of the corrective actions performed ($xr_{n_{s,d,ty}}$).

3.3. Water costs and pricing systems: simulated scenarios

3.3.1 Irrigation water costs charged to farmers

We simulated the recovery of the costs incurred by both the *Oristanese* RIB and the ENAS.

The *costs of the RIB* include salaries, and purchases of materials and energy to distribute water, and maintain and administer the irrigation network from the dam to the farms[12]. The RIB uses a two-part tariff to charge fixed costs with a fee per hectare served by the water distribution network, and variable costs based on the actual irrigation activities. The RIB does not charge depreciation of the distribution facilities because their construction was publicly funded. Environmental and resource costs are computed as described in the following sub-paragraph 3.3.2., accounting respectively for water volumes that is necessary to preserve from withdrawal to ensure the minimum vital outflow of the rivers, and for the predominant role of industry in determining quality depletion of water resources (ENAS, 2010). However, these costs are already included in ENAS fees and are not accounted among the RIB costs. Our simulations change pricing system and cost recovery level, therefore, modify the amount of water used by farms, and the variable component of the WDC of the RIB[13]. We determined these costs in the various scenarios by using a transcendental logarithmic function (*Translog*) that considers prices and amount of

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[12] Italian Law (R.D. n. 215/1933) entitles the RIBs to impose taxes on members (including Public Institutions) to contribute to maintenance of land-reclamation facilities and irrigation, as well as to their operating costs. These fees, in whatever way are calculated, are not intended as the price paid for an economic good (irrigation water) or service (water supply), but as a contribution to the collective expenses (or payment).

[13] The extent of this latter modification depends on the water distribution technology.

energy and labour inputs, amount of distributed water, and technological characteristics of the various districts of the network (Giraldo et al, 2014). Being estimated on observed data, this cost function represents the actual cost operating condition of the Oristanese RIB. It can be expressed in general terms as:

$$lnC(z) = \alpha_0 + \sum \alpha_i \ln(z_i) + \frac{1}{2}\sum_i \sum_k \alpha_{ik} \ln(z_i) \ln(z_k) \ , \alpha_{ik} = \alpha_{ki} \qquad (6)$$

This form expresses the logarithm of the WDC (C) in each *macro-district* as a function of the independent variables z_i and z_k, in our case the components in which the volume of distributed water can be divided: irrigated acreage, watering intensity and, in the *gravity macro-district*, network losses[14]. The coefficients α_i and α_k, and the α_0 constant term, have distinct values in the districts at high pressure, low pressure and gravity. The α_i represent the cost elasticity of the independent variable, hence, their relative importance in generating the WDC. Giraldo et al (2014) show that the *irrigated acreage* variable largely prevails over *irrigation intensity* and the *network losses* in determining the WDC. Our baseline provides a partial recovery of these costs. This is made possible by a regional subsidy that compensates the higher hydraulic lifting energy costs of RIBs due to unfavourable orography and climate of Sardinia.

The *costs of Water Authority*, charged by ENAS to end-users, relate to management, maintenance and development of dams and primary water infrastructures, and, as mentioned, include environmental and resource components. The ENAS evaluates the resource stored in the dams, assigns volumes to industry, households and agriculture, and defines the plan to recover the costs of supplying them water. To this end, ENAS subtracts these costs from regional subsidies received to pay a portion of the high energy costs[15], as well as other revenue from sources other than the sale of raw water, such as the sale of hydroelectricity. The residual cost has to be recovered by means of tariffs per cubic meter, obtained dividing the former by the difference between the available water and the water released downstream of

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[14] These components are normalized with respect to their average values in each *macro-district*.

[15] We have seen that regional contributions with an analogous role are provided to the RIBs.

the dams to protect the instream flow[16]. Finally, ENAS modulates this tariff among end-users to balance possible social and economic impacts of cost recovery. Particularly, the burden is reduced on households and, appreciably, on farms: indeed, in 2009-2014, compared with an average of 0.046 €/mc, industry paid 0.23 €/mc, families were at 0.04 €/mc and farms at 0.007 €/mc[17]. Industry pays higher fees because is considered predominant in determining resource and environmental costs (RAS, 2009). Therefore, unlike the subsidy to extra energy costs, this measure transfers part of the agricultural water cost to other users of the resource and the public service, and not to the taxpayers.

3.3.2 Water pricing systems

We simulated four pricing systems at four different cost recovery levels. The latter were: (1)-(2) current partial coverage of RIB's WDC, and no coverage of ENAS 2010 *modulated* agricultural rate; (3) current partial coverage of RIB's WDC, and FCR of ENAS 2010 *modulated* agricultural rate; (4) FCR of RIB's WDC and of ENAS 2010 *modulated* agricultural rate; (5) FCR of RIB's WDC and of ENAS 2010 *non modulated* agricultural rate (0.0461 €/mc). Here we describe the simulated water pricing systems.

Acreage Crop. This is the currently applied system whose fees are applied to each irrigated hectare based on two indicators reflecting water needs of crops, and benefit generated by the distribution scheme (these latter are: 1,24 for HP_{Ar}; 1,00 in HP_{Ot}; 0,72 for LP; 0,44 for GR)[18]. Its implementation requires the RIB to verify the crops that farmers actually grow. Our baseline considers the current partial coverage of WDC, allowed by the Regional subsidy, and no coverage of *Water Authority* costs. FCR of both RIB and ENAS costs is obtained by proportionally increasing the fees to the crops and *macro-districts*.

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[16] This subtraction increases the rate in proportion to the action to protect the environmental quality of the waterways.

[17] To encourage an efficient use of water, the tariffs to agricultural end-users (as well as to household) are divided into two volume blocks, a unitary price of 0.005 €/mc for 80% of the volume assigned to the RIB (140 Mmc for the *Oristanese* in 2010), and 0.015 €/mc for the higher 20%.

[18] The indices are also modulated to consider the soil characteristics and climatic of the various RIB areas, which affect the potential for exploiting the available water. They also take into account that the mode of water delivery and the oldness of the facilities determine the on-field usage costs level, hence the general profitability of irrigation.

<u>*Irrigated Acreage + Watering.*</u> This pricing is obtained by introducing the WDC function in the objective function of the DSP model, and directly bind water payments to irrigated acreage extension, irrigation needs of crops, and water losses, estimated to generate the WDC of the RIB. Another tariff element per used cubic meter considers the payment to ENAS. The basis of this pricing system (irrigated acreage and irrigation needs) is similar to the currently adopted system though, unlike this latter, it does not consider pedo-climatic conditions of the RIB areas. Also, it assumes perfect information of farmers about WDC formation, and consciousness on the impact of their choices (Giraldo *et al*, 2014). Being absent these conditions, we consider its results as a hint on the best use water obtainable with this type of rates, rather than the outcome of a technically applicable pricing[19].

<u>*Volumetric.*</u> This method ignores the importance of the *irrigated acreage* in generating the WDC, and debits to farmers only according to the used volume of water. Its implementation requires an accurate metering that can generate significant costs of investment and measurement to the RIB. Yet, this system is considered the most consistent with the guidelines of the WFD about using the pricing to direct towards the efficient use of water. We implemented the water price at *macro-districts* level by dividing the estimated WDC, plus ENAS cost, by the respective volume of distributed water (including network *losses*), to allow the cost recovery at the various levels.

<u>*Irrigable acreage.*</u> Farms pay based on the acreage served by the RIB facilities, independently from the actual water use: we divide the total cost among farms based on the parameters that in the current pricing reflect the benefit generated by the water distribution technology. This system is totally opposite to the principles of WFD, but represents for the RIB the less expensive and easiest way to implement and manage, because it does not even require verifying whether or not farmers irrigate. Conversely, it does not generate any economic incentive to evaluate even the opportunity to use or not the water resource. In our simulations, the farms pay a fixed value per each hectare to partially or fully cover water cost.

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[19] Yet, this pricing mechanism does not require high investments for the implementation and management costs: in fact, satellite imagery allows the detection of irrigated surfaces and intensity of water use, and to build a coherent pricing

4. Results

4.1. *Impact on the entire RIB area*

Table 1 reports the impacts of modifying the pricing system and/or the level of cost recovery on the agricultural income of RIB area, water payments of the farms to RIB, WDC paid by taxpayers, average WDC of the RIB, water use, nitrogen and labour. The section (1) reports the results of the current pricing system, expressed in absolute value (baseline - 2010). The results reported in the following sections are expressed as percentage changes over the baseline. Section (2) reports the results of the other tariff systems at the current level of water cost recovery. Sections (3), (4) and (5) report the results of the current tariff system and of the alternative ones, at progressively increasing levels of recovery of water costs.

[Tab. 1]

The data of the current situation in section (1) remain as shown in Dono et al. 2016. Compared to what is shown in that publication, the table also shows the 1.983 Million € (M€) of water costs that are charged to taxpayers, due to the regional energy subsidies to the RIB, and to non-payment of the ENAS rates. Based on these values, we can say that the current Acreage Crop pricing recovers 61% of the 3,527 M€ of the estimated RIB's WDC. Cost recovery reduces to 52% if we add 0.6 M € of not payed ENAS costs at the modulated rate. Instead, if we consider non-modulated ENAS rate (0.0461 €/mc), Acreage Crop only covers 24.3% of the 8,813 M € of the total water cost, 60% of which represented by ENAS costs . This situation is expressed in detail by Table 1a. This shows in detail the various components of the WDC at the baseline: total value, unit value of 114.7 Mm^3 of water from the RIB, percentage weight over the total, and the subjects who are paying .

[Tab. 1a]

Section (2) of table 1 shows that changing the pricing, and maintaining the baseline level of cost recovery, causes very limited impacts on the area's income and water payments to RIB. Instead, differences emerge on the cost to the *taxpayers*, and resources use. The *Irrigated Acreage + Watering* influences the allocation of resources based on surface area to be irrigated, and use of water. This leads to make more extensive farming, reducing the use of nitrogen, water from aquifers and the RIB, and labour. Also decrease the financial burden on the *taxpayers* and the average WDC of RIB, suggestsing an increase in efficiency in providing that water. *Volumetric* pricing charges the entire payment on the use of RIB water and ignores the surface component of WDC: this decreases more the use of RIB water, has almost no impact on the groundwater use, and increases the use of nitrogen. Despite the decline in water use RIB, the cost to the *taxpayers* does not decrease, while the average WDC is even increasing. Finally, *Irrigable Acreage* decouples the payments from water use and intensifies cropping patterns towards more water-, nitrogen- and labour-demanding crops. Increasing the use of RIB water also visibly increases the burden on the *taxpayers*, as well as the average WDC.

The simulations of section (3) maintain unchanged the regional energy subsidies to the RIB, but require the full recovery of the ENAS costs, even if at modulated farm tariffs. The increase of water payments charges to agriculture a notable part of the burden to manage the dam. Despite the appreciable increase, the limited importance of water payments on total farm income generates a very limited impact on the latter; and the impact is similar across the different pricing systems. The effects on resource use and efficiency of the RIB water distribution accentuate the trends observed in previous simulations. *Crop Acreage* and *Watering + Irrigated Acreage* have analogous impacts, though the latter increases more the burden on farmers and, conversely, reduces more the use of resources and the average WDC of the RIB. The *Volumetric* has the least impact on irrigation payments, though notable, and yet reduces more the use of RIB water. *Irrigable Acreage*, acting as a fixed income levy, maintains the same impact of the previous simulation, which remains unchanged in the following.

Section (4) reports the results at FCR by irrigation payments, with elimination of energy subsidies to the RIB, and entire payment of the ENAS modulated rate. The various pricing increase their impacts on net incomes and resources use, but remain in the same mutual relationship of the previous cost recovery scenarios. The only exception is that *Crop Acreage* is more incisive than *Watering + Irrigated Acreage* in increasing the irrigation payments, and reducing the use of water from the RIB. Conversely, the latter pricing reduces more the average WDC , increasing at a lesser extent the irrigation payments.

Section (5) shows the results at FCR with ENAS non-modulated agricultural rate: farmers pay all the energy costs of RIB, as well as the costs of the Sardinian water scheme currently charged to industrial users. All pricing systems greatly reduce the agricultural income of the area because of the increase, up to fourfold, of the irrigation payments. A heavy de-intensification of cropping patterns is generated in all cases, except *Irrigable Acreage* as already noted. A drastic drop of the RIB water use reaches up to 14%; also appreciably decline groundwater extraction, use of nitrogen and of labour. *Irrigated Acreage + Watering* maintains a lead in the reduction of average WDC and, as in previous case, combines it with the smaller increase of the irrigation payments.

4.2. Impact on the farm typologies

Table 2 is similar to the previous ones: the absolute values of the baseline refer to the average farm income of the types, in decreasing order, while the results of all the other pricing and cost recovery levels are percentage changes over the baseline. Section (2) shows that substituting the pricing at the current level of recovery may generate a certain, for some pricing wide, heterogeneity of income impacts on the single types. Yet, in all the simulations the types with *higher* net income (*NI*) [cattle breeding (*CATA* and

CATB) and rice growing (*RISP*)[20]] improve their condition, while the other types always lose *NI*, even notably [-5.0% mixed crops type (MIX 3); -2.3% sheep type (SHA)]: hence, the current *Crop Acreage* pricing supports the lower income farms. The parameter on crop irrigation needs generates this support: indeed, *Irrigable Acreage* that applies the current parameter on the water distribution technology, does not support the lower income farms. This is due to the elimination of any link between water use and cost under this pricing, that prevents farmers from making any adjustment in order to limit income impacts. Increasing the cost recovery level generally reduces farm incomes, and gains of the *higher NI* types gradually narrow and finally become negative. Yet the considerations made in advance remain: the *Crop Acreage* allows the types with *lower NI* to face milder impacts, while the opposite happens with the other pricing. Again, the greater redistributive effect is generated by applying the fixed fee of the *Irrigable Acreage*. Finally, FCR generates appreciable income impacts in many cases even at modulated ENAS rates: -13.1% SHA, -6.0% MIX2, -4.9% MIX3 and GRH. Implementing the non-modulated farm rates generates significant impacts (-15.5% CATB; -14.4% CITR; -14.0% GRH and MIX3), which in some cases become dramatic (-31.9% SHA).

[Tab. 2]

We conclude with the impacts on the irrigation payments of the farm types that are immediately visible and comparable among farms and, thus, even more of income changes, may alter the consent of farmers on the choices of the RIB and of Region about water resources management. Table 2a reports these impacts. We note that changing the pricing [section (2)] would have very large negative effects, always on farms with lower incomes; these would increase greatly with *Irrigable Acreage*. Pursuing the FCR of ENAS cost would act in a more balanced way with the current pricing, though in a wide range of 20-27% impacts. Disparities would become consistent with the other pricing systems and, of course, would grow

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[20] These types represent 18.1% of farms, and 54.9% of the RIB area net income (not reported in the table).

by charging to farmers, first, also the entire WDC, then, also the ENAS cost at the non-modulated rates. In this latest simulation the current pricing would reach up to quadruple payment of the type with the lowest *NI*. Other pricing might result in increases of up to eight times the current level.

[Tab. 2a]

5. **Discussion**

We used the *Translog* function of Giraldo et al (2014) to identify the WDC in the *macro-districts* of the RIB under the water demand conditions arising in the various simulations of pricing and cost recovery. We interviewed local farmers and agricultural technicians to derive the crops water needs that, integrated as coefficients of the DSP model, generated the use conditions of water and the other resources. Based on these elements, our results indicated that the coverage level of the Oristanese RIB's WDC is about 61%, which is in the upper range of cost recovery cited by Massarutto (2003) for Southern Italy irrigated RIBs, and very close to the range of the northern Consortia. In this context, the current pricing system generates an indirect support to the lower *NI* farms by embodying social assessments that would not be met by the other pricing systems of this study. Adopt the latter would have a relatively limited impact on incomes; instead, the impact on irrigation payments would be considerable and, above all, would be very different between types, primarily damaging the low income farms. Such payments are visible and comparable by farmers associated with the RIB, which may increase the disputes on redistributive effects of these other tariff systems. Maintaining the current pricing would cost, since adopting *Irrigated Acreage + Watering* would reduce by 3.4% the average WDC, as measured by our function. This savings would reduce the inefficiencies that FCR charges to farmers, approaching the condition of water tariffs that only include costs of efficient management (Massarutto, 2007): this could, at least partly, balance the social impact of a different distribution of water cost among farmers. Other results address the various cost-recovery levels. The first concerns full debiting to farmers ENAS costs at modulated rates: this option is causing right now appreciable tensions between farmers, the RIB, ENAS, and Sardinia Region (La Nuova, 2016). This allocation would have limited income impacts, although significant on some farm types. Instead, the impacts on irrigation payments would be high and, even with the current pricing, would affect many farms with low incomes: the social visibility of this cost component is contributing to determine the mentioned disputes. Adopting our alternative pricing would further increase payments, and much on low income farms. Continuing with cost recovery and transferring to farmers all the electricity costs for water pumping, obviously would increase the impacts on farm incomes and irrigation payments, along with the distribution divergences. In this case, changing also the pricing would lead to cases of extreme income impacts. Finally, also abolishing the modulation of ENAS tariffs would reduce more than 10% income in many types, to reach 30% in extreme cases. Even in this case, coupling FCR to a pricing more directly linked to WDC might generate social tensions because neutralizes the current support to *low NI* farms. Other Authors find that an exhaustive WFD policy might jeopardize sustainability of irrigated agriculture (Gómez-Limón and Riesgo, 2004; Berbel et al., 2011). Tariff modulation appears essential for its impact: it reflects the regional evaluation that the user cost in Sardinia is mainly generated by the water pollution impact of industrial use, while farming has a negative user cost because of its relatively lower impact.

Hence, the current *Crop Acreage* system, supported by the regional contribution to electricity costs, and the modulation of the rates to end users, minimizes the economic and social impacts of water pricing, and addresses the resource and environmental costs generated by the industrial sector. The problem is to reconcile these aspects with the environmental issues, precisely, water protection and conservation that may be directly related to the farming activity. In this regard, the *Irrigated Acreage + Watering* and *Volumetric* result to better fulfil the concerns of WFD. Indeed, even at the current level of cost recovery, the first one saves the RIB water and causes a lower environmental pressure, reducing the groundwater use and nitrogen. The second one, by relating payments to the use of the RIB water, reduces it even more but, on the other hand, increases the use of the other two resources. These impacts on the resources use are emphasized at FCR, where the extensification effect of the *Irrigated Acreage + Watering* is greatly reinforced, while a notable capability of saving the sole RIB water emerges for the *Volumetric*.

6. **Conclusions**

Our assessment of various water pricing in an farming area of South Italy confirms that a multi-purpose policy as WFD requires the use of articulated tools. We found that *Volumetric* pricing generates savings of RIB water, but increases the use of chemicals and fails to reduce, even increases, groundwater use. The large availability of RIB water makes these relatively limited externalities; yet, the impact could be larger in a condition of scarcity. *Irrigated Acreage + Watering* more properly considers the structure of water supply costs, namely their relationship to the extension of the irrigated area. This induces a more equilibrate de-intensification of cropping activities, which better controls groundwater and nitrogen use, and reduces the aid requested to the *taxpayers* under partial cost recovery. Under FCR this has more limited impacts on farms, even if causes the strongest negative impacts on labour employment. The current *Crop Acreage* has an intermediate performance; yet, more than the other two, minimizes social and economic impacts of water pricing. As a general result, a dichotomy emerges between fulfilling the environmental objectives of WFD and preventing intense social and economic negative impacts. This type of analysis can help to specify the pricing policies of local water authorities, making their watershed plans less descriptive. This way their choices and actions will appear less arbitrary in mitigating social and economic impacts of water FCR.

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Tables

Table 1: RIB area – farming net income, water payments to the RIB, cost not covered by farmers, and average WDC of RIB; use of water [from RIB and groundwater (GW)], of nitrogen and of labour [family (FAM) and external (EXT)]

Simulations		Farming Net Income M €	Water Payments to RIB M €	Taxpayers M €	Average WDC of RIB €/m^3	Use of water Mm^3		Use of Nitrogen Tons	Use of Labour M h	
						RIB	GW		FAM	EXT
(1)	Crop Acreage	68.2	2.14	1.98	0.031	114.7	3.8	8,188	4.2	0.7
(2) Δ% on (1)	*Irrigated Acreage + Watering*	0.0	0.0	-3.4	-2.6	-0.9	-1.6	-1.4	-0.3	-1.8
	Volumetric	0.0	0.0	0.0	1.7	-1.1	0.1	0.9	-0.1	-0.3
	Irrigable Acreage	-0.1	0.0	3.4	2.4	1.0	-0.1	1.4	0.0	0.9
(3) Δ% on (1)	*Crop Acreage*	-0.9	25.5	-31.4	-0.4	-1.2	-0.4	-0.6	-0.1	-0.7
	Irrigated Acreage + Watering	-0.8	32.3	-34.3	-4.0	-1.8	-2.3	-2.3	-0.5	-2.9
	Volumetric	-0.9	20.9	-30.8	1.6	-2.4	-0.2	0.6	-0.2	-1.0
	Irrigable Acreage	-1.0	32.3	-27.9	2.4	1.0	-0.1	1.4	0.0	0.9
(4) Δ% on (1)	*Crop Acreage*	-2.8	82.2	-100	-0.9	-4.0	-1.4	-1.8	-0.4	-2.5
	Irrigated Acreage + Watering	-2.7	74.3	-100	-6.2	-3.8	-4.0	-3.8	-0.9	-5.0
	Volumetric	-2.9	83.8	-100	1.5	-5.2	-1.2	0.1	-0.6	-2.7
	Irrigable Acreage	-3.1	99.0	-100	2.4	1.0	-0.1	1.4	0.0	0.9
(5) Δ% on (1)	*Crop Acreage*	-9.1	258.3	-100	-0.3	-12.8	-4.2	-4.4	-1.4	-7.5
	Irrigated Acreage + Watering	-9.3	244.1	-100	-12.1	-12.1	-8.2	-9.5	-2.9	-11.0
	Volumetric	-9.6	254.0	-100	1.4	-14.4	-5.0	-1.8	-2.0	-8.7
	Irrigable Acreage	-10.0	319.3	-100	2.4	1.0	-0.1	1.4	0.0	0.9

Table 1a: WDC components at the baseline - total value, unit value, percentage weight over the total, paying subjects

Component	**Costs**			**Payer**
	.000 €	€/m^3	%	
Resource cost[21]	4,239.0	0.037	48.1	Industrial sector
Environmental cost[22]	447.2	0.004	5.1	
ENAS agricultural payment[23]	600.0	0.005	6.8	Taxpayers
RIB's WDC - *extra energy cost*	1,382.9	0.012	15.7	
RIB's WDC	2,143.8	0.019	24.3	Farmers
TOTAL	**8,813.0**	**0.077**	**100.0**	

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[21] Resource cost is computed by subtracting the environmental component (calculated as in footnote 2) and the ENAS agricultural payment (calculated as in footnote 3) to the ENAS payment at the un-modulated fee of 0.0461 €/m^3.

[22] Environmental cost is obtained by the difference between the unitary payment computed by ENAS accounting for the cost of maintaining the minimum vital flow after the withdrawal (0.0461 €/m^3) and without accounting for it (0.0422 €/m^3).

[23] ENAS agricultural payment is calculated according to the unitary payments set by the ENAS for the agricultural sector of 0.005 €/m^3 for RIB water volumes up to 112 Mm^3 and 0.015 €/m^3 for the volumes exceeding this threshold.

Table 2: Average net income per farm type at baseline and percentage changes on baseline in the other simulations

	Simulations	*CATA*	*RISP*	*CATB*	*MIX2*	*SHA*	*CITR*	*MIX1*	*GRH*	*MIX3*
(1)	*Crop Acreage* (,000 €)	202.3	179.9	170.1	85.7	49.1	39.3	33.4	26.8	12.0
(2) Δ% on (1)	*Irrigated Acreage + Watering*	0.4	3.3	0.4	-0.4	-0.1	-0.4	-1.1	-0.8	-0.2
	Volumetric	0.3	3.3	0.3	-0.2	-0.1	-0.4	-1.2	-0.8	-0.2
	Irrigable Acreage	1.0	2.8	1.5	-5.0	-2.3	-0.6	-1.1	-0.9	-1.3
(3) Δ% on (1)	*Crop Acreage*	-0.9	-0.8	-1.4	-1.1	-1.0	-0.4	-0.5	-0.8	-0.9
	Irrigated Acreage + Watering	-0.8	-0.3	2.8	-0.5	-1.5	-0.6	-1.0	-2.2	-1.9
	Volumetric	-0.9	-0.4	2.8	-0.7	-1.3	-0.6	-1.1	-2.3	-1.9
	Irrigable Acreage	-1.0	0.4	2.1	0.8	-7.4	-3.4	-1.2	-2.2	-2.1
(4) Δ% on (1)	*Crop Acreage*	-2.8	-2.6	-4.7	-3.7	-3.2	-1.4	-1.6	-2.6	-2.9
	Irrigated Acreage + Watering	-2.7	-1.8	1.7	-2.8	-4.1	-1.5	-2.3	-4.7	-4.2
	Volumetric	-2.9	-2.2	1.7	-3.2	-3.7	-1.6	-2.6	-4.9	-4.6
	Irrigable Acreage	-3.1	-0.9	0.5	-0.9	-13.1	-6.0	-2.7	-4.8	-4.9
(5) Δ% on (1)	*Crop Acreage*	-9.1	-8.7	-15.5	-12.0	-9.4	-3.6	-5.7	-8.7	-9.1
	Irrigated Acreage + Watering	-9.3	-7.5	-1.3	-11.2	-11.5	-3.6	-7.6	-13.7	-12.0
	Volumetric	-9.6	-8.0	-1.0	-11.4	-10.1	-3.6	-8.3	-14.0	-12.6
	Irrigable Acreage	-10.0	-5.3	-4.7	-6.4	-31.9	-14.4	-7.8	-13.3	-14.0

Table 2a: Baseline values and percentage change on baseline of water payments of farm typologies under the different scenarios of water pricing and cost recovery

	Simulations	*CATA*	*RISP*	*CATB*	*MIX2*	*SHA*	*CITR*	*MIX1*	*GRH*	*MIX3*
(1)	*Crop Acreage* (,000 €)	6.0	9.5	6.9	3.3	0.8	0.7	1.0	0.9	0.1
(2) Δ%	*Irrigated Acreage + Watering*	-16.4	-63.6	-12.1	3.4	3.8	20.3	38.5	19.8	15.1
	Volumetric	-9.7	-65.0	-7.6	4.4	5.0	23.6	39.6	24.3	15.6
	Irrigable Acreage	-31.2	-53.4	-36.3	131.8	135.9	30.7	38.8	30.9	119.3
(3) Δ%	*Crop Acreage*	25.3	26.0	26.8	22.7	20.5	27.4	26.1	24.2	27.2
	Irrigated Acreage + Watering	3.7	-55.4	9.8	28.2	27.4	52.5	75.4	48.1	46.9
	Volumetric	12.5	-57.7	15.4	27.9	25.0	58.1	77.9	54.5	49.0
	Irrigable Acreage	-12.0	-40.4	-18.4	196.6	201.9	67.2	77.6	67.5	180.6
(4) Δ%	*Crop Acreage*	80.8	82.9	88.1	67.5	57.0	90.9	87.0	76.1	89.9
	Irrigated Acreage + Watering	51.5	-40.2	57.8	72.0	62.3	125.4	157.9	107.7	119.1
	Volumetric	66.5	-45.2	72.5	72.8	56.0	141.7	165.9	121.9	122.3
	Irrigable Acreage	32.4	-10.3	22.7	346.2	354.1	151.5	167.1	152.0	322.2
(5) Δ%	*Crop Acreage*	270.5	254.6	258.2	148.9	57.3	312.7	288.9	222.5	304.9
	Irrigated Acreage + Watering	236.7	-9.3	236.6	175.0	48.0	417.2	382.6	270.9	352.5
	Volumetric	231.6	-32.2	235.7	108.5	-38.4	459.2	461.0	300.6	366.4
	Irrigable Acreage	179.0	89.0	158.5	840.3	856.9	430.0	462.8	431.1	789.6