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Water Resources Management in Agriculture under Drought and Water Shortage Conditions: A Case Study in Southern Italy

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Abstract: An example of water resources management in agriculture applied to a southern Italian study area is presented. In the context of a proactive approach, the steps followed for the developing of three Plans are described: an Agricultural Strategic Water Shortage Preparedness Plan (ASP), aimed at reducing the vulnerability of the water supply system through the use of long term mitigation measures in normal conditions, an Agricultural Water Supply System Management Plan (AMP), to be executed when the water shortage event is happening, and finally an Agricultural Drought Contingency Plan (ACP), that have to be adopted when the oncoming event involves a heavy impact. The developing of the three Plans requires the use of suitable tools for the simulation of the scenarios representing the adoption of different alternatives, and for the choice, through multicriteria decision analysis techniques, of the preferable alternatives minimizing the level of subjectivity in the selection process. The choice of appropriate drought indices is also relevant, both for the identification of the critical areas interested by drought risk, and to activate the planned measures for preventing or mitigating the impacts. Finally, the involvement of the stakeholders during the planning process is very important, in order to develop transparent and shared plans, leading to efficient and not extemporaneous actions.

Key words: drought, water shortage, agriculture, Mediterranean region, water resources management, Agricultural Drought Plans

1. INTRODUCTION

The term “drought” means a temporary reduction of water availability due, e.g., to reduced precipitation, instead the term “water shortage” represents a water deficit respect to the demand, which can occur due to a drought or other anthropic causes (Iglesias et al., 2007). Of course it is not possible to avoid a drought, but its impact on agricultural activities can be opportunely mitigated through planning and a correct management. The risk of shortage for a water supply system is linked not only to the severity of a drought event, but also to other factors varying in time, such as the growing up of water demand, and to structural and management measures that can be adopted both before and during emergence conditions. Hence a reactive approach, based on the implementation of actions after a drought event has occurred and is perceived, is not adequate and a *proactive* approach is needed (Yevjevich et al., 1983; Rossi, 2003). A proactive approach is based on mitigation measures planned in advance through appropriate tools and with the participation of the stakeholders. In detail this kind of approach includes two different phases: 1) the developing of plans allowing the identification of long and short term actions to face drought; 2) the implementation of such plans, on the basis of timely information provided by a drought monitoring system.

Along the years the legislative framework related to drought and water scarcity evolved in several countries worldwide, modifying the approach from reactive to proactive. The European Union (EU), mainly in the last 10 years, focused on the definition of a shared water policy. The Communication “Addressing the challenge of water scarcity and droughts in the European Union”, adopted by the European Commission on July 18, 2007 and elaborated with the active collaboration of organizations of stakeholders, concluded that the problems derived from drought and water scarcity have to be faced both as an essential environmental issue and also as a precondition for sustainable economic growth in Europe. Specifically, the communication states that progressing towards the full implementation of the Water Framework Directive 2000/60/EC (WFD), the EU's flagship Directive on water policy, is a priority in order to address mismanagement of water resources.

In Italy the EU WFD has been taken into account with the Legislative Decree 152/2006 on environmental protection. Though this act is quite recent, it shows numerous weaknesses: there is a not clear distinction between long term and short term measures and among the competences of the various authorities involved, while the needing for a proactive approach is not sufficiently highlighted.

Within a comprehensive drought management planning process, some organizational structures have been proposed. The National Drought Mitigation Center (NDMC, Wilhite et al., 2005) proposed a scheme for U.S.A. states providing a monitoring, alerting and weather forecasting Committee, a drought risk assessment Committee and a Task Force whose aim is to give operational responses in case of drought events. Rossi et al. (2007) instead proposed the identification of three main tools: Strategic Water Shortage Preparedness Plan, Water Supply System Management Plan and Drought Contingency Plan. In this paper the latter guidelines are applied to plan the best mix of measures for coping with drought phenomena on one of the most important agricultural areas in southern Italy, the Low Esaro and Sybaris Plain.

2. STRUCTURE AND OBJECTIVES OF THE PLANNING PROCESS

2.1 Organizational structure

The concept of the proactive approach is practically achieved through the development of three plans (Fig. 1): a "Strategic Water Shortage Preparedness Plan", aimed at reducing the vulnerability of the water supply system adopting long term mitigation measures in normal conditions; a "Water Supply System Management Plan", to be adopted to avoid the begin of a real water emergency; a "Drought Contingency Plan", to be adopted when exceptional droughts cause heavy impacts.

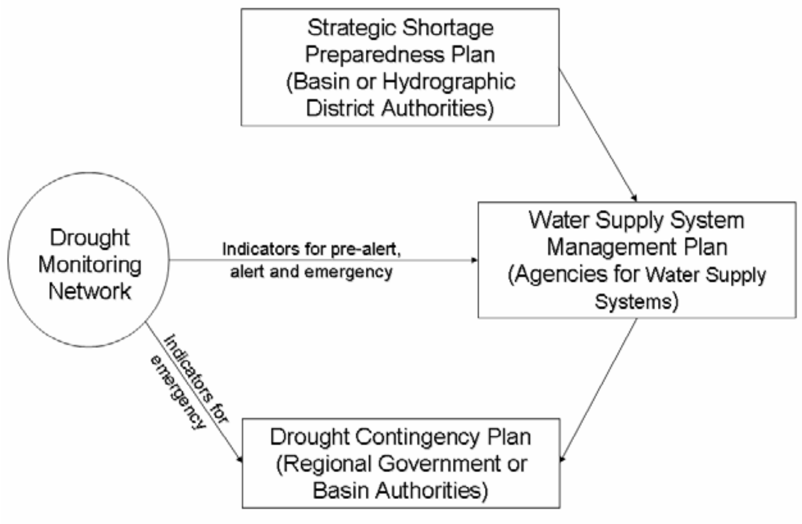

Figure 1. Organizational structure of the planning process proposed by Rossi et al. (2007).

In the present study the scheme shown in Figure 1 is followed, and the three plans are defined in a context including only agricultural users.

The Agricultural Strategic Water Shortage Preparedness Plan (ASP), developed and adopted by the River Basin or District Authority, may be considered as corresponding to the drought management plan suggested as an annex to the River Basin Management Plan provided by the WFD and adopted by the Italian Legislative Decree 152/2006. The Agricultural Water Supply System Management Plan (AMP), instead, should be realized and adopted by the Agency managing the water resources for the agricultural system (e.g. Land Reclamation Consortia), finally the Agricultural Drought Contingency Plan (ACP) should be developed by the Regional Government in collaboration with the Civil Protection.

In order to develop the agricultural drought and water shortage planning and management processes, several information are needed about the analyzed water supply system, such as:

- Hydro-meteorological data
- Information about water availability and water demand
- Technical and management information about the water supply system
- Information about historical drought and water shortage events

The hydro-meteorological data can be provided by the National or Regional Hydro-meteorological Services. Data about surface water and groundwater availability can be achieved integrating information provided by the Hydro-meteorological Services, the water supply system management Agency (the Land Reclamation Consortium) and the River Basin or District Authority. Finally, information about the water supply system, water demand and historical drought should be provided by the Land Reclamation Consortium.

2.2 Tools required in the planning process

Not only information, but also several tools are needed in the planning process. Among them, drought indices are necessary at all levels: in the Strategic Plan they are used to identify the most exposed zones to drought risk, while in the Management Plan and in the Contingency Plan they are used to define trigger values for the activation of the measures for impacts prevention or mitigation. Most of the proposed methodologies for the characterization and the monitoring of drought phenomena are based on drought indices having the capability of synthetically summarizing drought conditions in a specific moment for a particular area. Nevertheless, drought is difficult to represent through a single index, hence frequently more indices or aggregate indices are used.

Tools are also needed for the selection of the optimal measures, through a reliable assessment of the potential economic, social and environmental impacts of the various mitigation measures on the analyzed system. To this aim, the modeling of the conditions of the water supply systems is essential. Simulation models are the ideal tools for assessing the performances of the systems to different management alternatives, nevertheless most of the mathematical river basin management models (e.g.: HEC 5, Hydrologic Engineering Center, 1989; MODSIM, Labadie, 1995; MikeBasin, DHI, 2006; WEAP, SEI, 1999; SIMDRO, Tsakiris et al., 2007a) are not able to identify optimal design and operation of the components of a river basin system, requiring in the process of selection of the best alternatives the use of trial-and-error procedures, rather computational expensive if the number of scenarios is high and the system is complex.

The typical flexibility of the simulation models can be assisted in the identification of the best alternatives by decision making techniques, largely developed in the context of the Operational Research. Several strategies have been adopted to combine simulation models and optimization techniques, even if mainly in research-oriented applications. Usually, an optimization model very much simplifies the physical process, with the aim of reducing the difficulties in mathematic analysis and the computational expense, and this can be a limit in practical applications, that researchers are trying to overcome (e.g. Sechi and Sulis, 2007).

The increase in the assessment criteria to be adopted in the decision-making process, derived from a greater awareness about the importance of not only economic, but also environmental and social factors, solicited in water resources management the use of the multicriteria decision analysis for the support of the simulation models. Already in the early 1980s Duckstein (1983) proposed a methodology based on a criteria-alternatives matrix for ranking the possible actions. Specifically, if multicriteria decision analysis models do not assume weighted methods of the criteria, conflict minimization methods (equity analyses) can be adopted in order to individuate the alternatives reaching the highest agreement among the stakeholders, having the highest probabilities to be executed.

In the analyzed water supply system two software have been used for the simulation and one for the multicriteria analysis.

A monthly distributed hydrological model (Mendicino and Versace, 2007; Mendicino et al., 2008) has been used for the hydrological analysis, while drought risk assessment has been made through the use of the commercial software MIKE BASIN (DHI, 2006), specialized in the management of hydrographic data and their interconnections with anthropic factors.

The choice of the optimal combination of the mitigation measures instead has been done through the use of a Decision Support System called NAIADE (Novel Approach to Imprecise Assessment and Decision Environments). NAIADE (Munda, 1995) uses a multicriteria analysis technique managing in an integrated way a procedure for the ranking of the alternatives and a procedure for the analysis of the conflicts.

The multicriteria analysis is based on a comparison algorithm of the alternatives made up by the following steps (JRC, 1996): 1) Completion of the criteria/alternatives (impact) matrix; 2) Pairwise comparison of alternatives using preference relations; 3) Aggregation of all criteria; 4) Ranking of alternatives. After this analysis an equity analysis can be performed by the completion of an equity matrix (stakeholders/alternatives). Through a mathematical reduction algorithm, it is possible to achieve information about the possible coalition formation, and level of conflict among the interest groups.

The values assigned to the criteria for each alternative in the impacts matrix may be expressed in the form of either quantitative (crisp), quantitative with a degree of uncertainty (stochastic or fuzzy) or qualitative, based on the reliability level of the estimates associated to the various alternatives. Furthermore, the same criterion can be at the same time crisp and fuzzy, if for some alternatives precise estimates can be provided for this criterion, while for other alternatives a certain degree of uncertainty exists. The qualitative evaluation is expressed by pre-defined “linguistic variables” such as “Good”, “Moderate”, “Very Bad” and so on, treated as fuzzy sets.

The equity analysis is instead based on an equity matrix containing the judgments on the alternatives provided by the interest groups. The judgments are formulated in a qualitative way through nine predefined linguistic expressions, again treated as fuzzy sets.

3. CASE STUDY: THE ESARO SUPPLY SYSTEM

The water resources planning and management issues have been practically dealt with in the Esaro River Basin, a tributary of the Crati River Basin placed in northern Calabria.

The core of the analyzed water supply system is the Farneto Dam (Fig. 2), closing the Esaro Catchment (about 245.4 km^2). The construction of the dam began in 1972 and was finished in 1989. The reservoir has a total capacity of 40.2 hm^3, an irrigation capacity of 27.35 hm^3 and a flood mitigation capacity of 11.5 hm^3. It is aimed at: (i) storaging the ordinary floods and mitigating the extraordinary ones, on condition that the reservoir level is maintained almost empty from October to March (reservoir level equal to 127.15 m a.s.l); (ii) supplying water to the downstream agricultural area sited in the Low Esaro and Sybaris Plain; (iii) assuring a minimum instream flow of about 2 l s^{-1} km^{-2}.

The areas downstream the Farneto del Principe Dam, characterized by a climate varying from sub-humid to semi-arid, are provided with an irrigation water main, managed by the Land Reclamation Consortium “Sibari Crati”. The irrigation network, whose main pipe is long more than 30 km, is designed to serve through its branches an area of about 85 km^2 falling into the Low-Esaro Plain, the Sibari Plain and into the so called “Q40” area. The total area, cleaned by the tares, is equivalent to 60.3 km^2 and forms the available agricultural area, where the main crops are sowable (80%) and orchards (20%). At present about the 63% of the irrigable area uses open channels. For the irrigation service, the farmers pay an annual fixed due, regardless of the real quantity of water used to irrigate their fields. This is the reason for which the daily outflow from the reservoir is not measured.

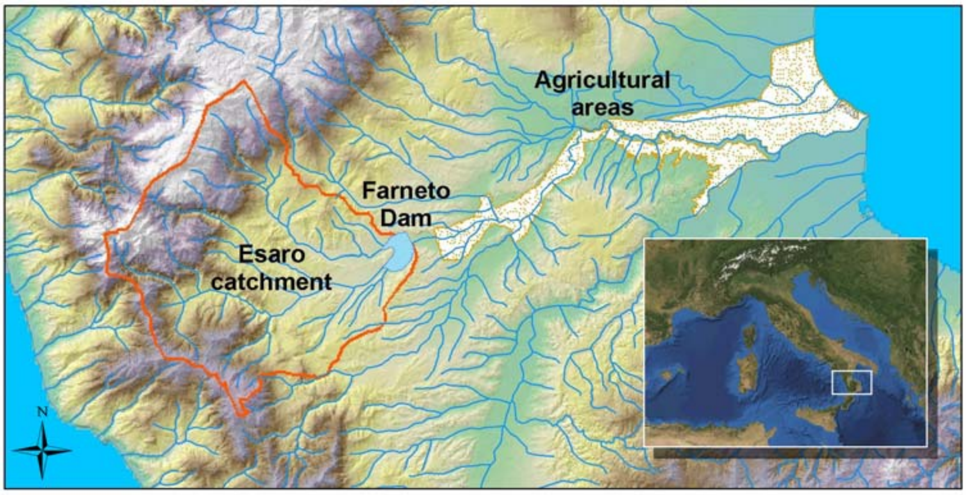

Figure. 2. Study area.

Presently the reservoir serves only about the 30% of the agricultural territory. The water required to irrigate the remaining areas is taken exploiting private wells, whose number strongly increased in the last decades (about 5000 wells today versus about 500 in '70s). The constant reduction in the aquifer of the plain is the result of both the decrease in precipitation and the increase in the groundwater extraction.

In the Sibari Plain also saline lands are present, which need a greater quantity of water for their irrigation. On the basis of the crop typology and climate the irrigation season goes from April to September. Several agronomic studies fixed the total water requirements in the irrigation season to about 30 hm^3, subdivided during the single months in the following percentages: April 3%; May 13%; June 26%; July 33%; August 16% and; September 9%.

4. APPLYING THE PLANS

4.1 Applying the ASP

The ASP is aimed at reducing the drought vulnerability in the analyzed area, through the adoption in normal conditions of long term mitigation measures.

The system is analyzed hypothesizing that the whole agricultural area receives water from the reservoir, with an increased demand of at least 20%, due to the wastes connected to an improper water management by the farmers. This percentage, estimated by the Land Reclamation Consortium Sibari-Crati, is also due to a taxation policy based on an annual tax paid by farmers depending on the extension of the irrigated area and on the crop typology, and not related to the actual quantity of water used. In this configuration also the project rules are hypothesized to be applied in the management of the Farneto del Principe Reservoir, considering a constant level of the reservoir during winter time equal to 127.15 m a.s.l.

The risk assessment of the current scenario (from now on called L0) is based on the analysis of 1000 years temperature and precipitation series, generated with a stochastic periodic ARMA (PARMA) model through the SAMS software (Sveinsson et al., 2007). The generated series have been used as input data of the water balance model proposed by Mendicino and Versace (2007) and Mendicino et al. (2008). The results of the hydrological analysis have been used for simulating, through the software MIKE BASIN, the behavior of the reservoir. The overall analysis provided a temporal reliability of the current scenario, intended as the percentage of the years in which the irrigation demand is fulfilled, equal to 49.6%, hence enough low to justify the adoption of long term mitigation measures.

With the aim of defining the strategic plan initially a series of alternatives have been individuated, i.e. single mitigation measures or combinations of these measures, then through a preliminary simulation the most significant ones have been selected. The five measures (from L1 to L5) whose combinations provide the series of alternatives are described as follows.

Measure L1 is related to the modernization of the irrigation network if it is still made up of open channels. Estimates of the Land Reclamation Consortium Sibari-Crati state that the efficiency of an irrigation system with open channels, together with the losses generated during the distribution of the water, is about 60%, while with pipes it grows up to 80%, with relevant water resources saving.

The actual scenario is shown in Table 1. The overall efficiency of the actual scenario is equal to 67%, obviously the efficiency of the "modernized" scenario will be 80%.

Table 1. Actual configuration of the irrigation system

	Total area	Open channels	Pipes
Low-Esaro plain	1390 Ha	-	1390 Ha
Q40 Area	1340 Ha	490 Ha	850 Ha
Sibari plain	3300 Ha	3300 Ha	-

Measure L2 consists in the construction of small reservoirs by the farmers. A mean storage volume of about 200 m^3 Ha^{-1} has been considered. It is noteworthy that a high number of these little artificial reservoirs could create a relevant impact on the environment, not affecting the vulnerability of the whole system.

Measure L3 is related to the construction of another Dam (the so called Alto-Esaro Dam) in an area called Cameli, designed some decades ago and still under construction since 1983. Its placement (Fig. 3) is upstream the Farneto del Principe Dam along the Esaro River, and it should provide also a volume for irrigation equal to 50 hm^3, without considering the hypothesized construction of some channels for flow diversion from other catchments.

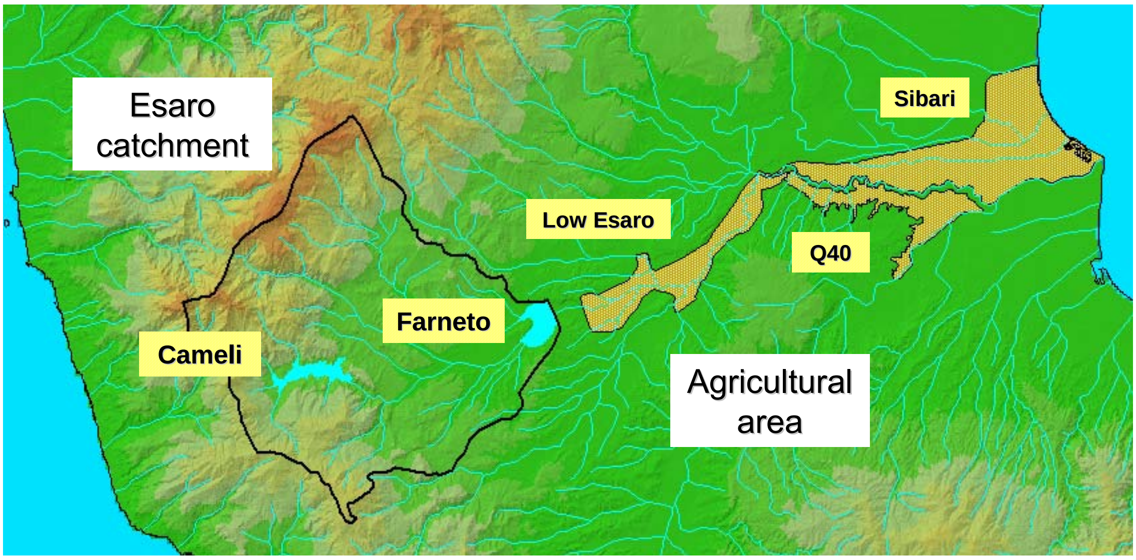

Figure 3. Farneto del Principe and Cameli Dams.

Measure L4 is the adoption of economic incentives and educational activities for water saving. Specifically it consists in:

- the adoption by the Land Reclamation Consortium Sibari-Crati of a new water tariff based on the real quantity of water used to irrigate, and not on the crop typology
- the organization of educational activities to promote water saving in irrigation

On the basis of the above mentioned actions a relevant reduction in water wastes should be reached.

Measure L5 is related to the variation of the reservoir level at the beginning of the irrigation season. The designed level on March is equal to 127.15 m a.s.l. (minimum storage elevation), corresponding to an available volume to be stored in case of floods equal to 40.2 hm^3. With the measure L5, instead, the storage level on April 1st is hypothesized to be equal to 130 m a.s.l., with an available volume up to the maximum hydraulic capacity elevation of 35.2 hm^3. Hence, if a starting level of 130 m a.s.l. is designed, the irrigation season could begin with an additional volume of about 5 hm^3, useful for irrigating the agricultural area.

The recorded runoffs in the period 1928-1952 (before the construction of the Farneto del Principe Dam) show that a volume of 40.2 hm^3 is enough to assure the flood routing of even extreme floods (Table 2). With a volume of 35.2 hm^3, instead, only in situations comparable to the maximum recorded flood (1951, 38.45 hm^3d^{-1}) problems would be encountered, but in this case a careful management of the spillways and an efficient early warning system should assure to avoid any kind of damages even with a reduced available volume in the reservoir.

Table 2. Maximum daily flow recorded for the Esaro River near the Farneto del Principe Dam

Year	Maximum daily flow [hm^3d^{-1}]
1951	38,45
1950	19,79
1935	15,03
1929	13,56
1937	12,53
1941	10,11

Of course measure L5 must account for an economic expense systematically and continuously ensuring an accurate maintenance of the available volumes inside the reservoir and of the downstream embankments. Furthermore, a collaboration between the Land Reclamation Consortium and the Civil Protection should be aimed to promote an efficient early warning system.

In Table 3 the alternatives selected for the successive comparison are shown (from A to M), made up of single mitigation measures or combinations of these measures.

Table 3. Long term mitigation measures and alternatives

Measures	Alternatives												
	A	B	C	D	E	F	G	H	I	J	K	L	M
L0	X												
L1		X				X	X			X			X
L2			X								X		
L3								X				X	X
L4				X		X			X	X	X	X	X
L5					X		X	X	X	X	X	X	X

The selected criteria for the comparison and the selection of the most appropriate long term alternatives account for economic, social and environmental aspects as follows:

- Criterion 1 (ECON1): it is the first economic criterion, related to the construction cost of the infrastructures, expressed in M€. This criterion is crisp
- Criterion 2 (ECON2): the second economic criterion is related to the average yearly operation and maintenance costs, expressed in M€. Also this criterion is crisp
- Criterion 3 (ECON3): the third economic criterion is related to crop yield losses, expressed in M€. Also this criterion is crisp
- Criterion 4 (ECON4): the fourth and last economic criterion is related to public aids, provided by the National Government when water shortage occurres. According to the Legislative Decree 102/2004 a natural disaster starts in a disadvantaged area when the damages exceed the 20% of the annual production, and a reimbursement equal to 80% of the suffered damages is provided. This criterion expresses the number of years in the total 1000 simulated years in which the water deficit overcomes 20% of the demand. Also this criterion is crisp
- Criterion 5 (ENVI1): it is the first environmental criterion and is related to minimum instream flow. Specifically, it expresses the percentage of months (in the whole 1000 simulated years) where the ecological requirement is not met downstream the Farneto del Principe Dam. Also this criterion is crisp
- Criterion 6 (ENVI2): the second environmental criterion is related to the reversibility of the alternatives. It is a qualitative criterion considering, for each alternative, the possibility of restoring the initial conditions of the system within economic and/or environmental feasibility
- Criterion 7 (SOC1): the first social criterion is a proxy of the system vulnerability, computed as the mean of the squared irrigation deficits in hm^3. The calculated value of this crisp criterion is a mean annual value
- Criterion 8 (SOC2): the second social criterion is related to the temporal reliability of the system, intended as the percentage of years when a given irrigation demand is met. Also this criterion is crisp
- Criterion 9 (SOC3): it is the third social criterion and is related to the realization time of the infrastructures proposed by the different alternatives. It is a qualitative criterion
- Criterion 10 (SOC4): the fourth and last social criterion is a qualitative criterion taking into account the increase in employed persons during the phases of construction, operation and maintenance of the infrastructures

The estimates related to crop yield losses (ECON3) in the different alternatives have been made using a production function proposed by Cai et al. (2006), accounting for:

- Crop typology (in terms of potential evapotranspiration)
- Quantity of water used for irrigation
- Technology used in the irrigation system
- Saline concentration of the water used

The production function is expressed as follows:

$$y = \frac{y_a}{y_m} = a_1 + a_2 \cdot w + a_3 \cdot \ln(w) \qquad (1)$$

where:

$w = WF/ET$

WF is the water applied to the crop field (mm)

ET is the crop potential evapotranspiration (mm)

y_a is the crop yield (tons per hectare)

y_m is the maximum attainable yield (tons per hectare)

a_1, a_2, a_3 are regression coefficients, depending on parameters that in their turn are functions of the crop type, the salt concentration in water application and the water supply system technology. Since observed values of y_a/y_m were not available for the analyzed area, the values of the parameters proposed by Cai et al. (2006) have been adopted, taking into account also the presence of saline lands.

With the aim of evaluating the economic damages, the prices at origin have been considered for every single product (provided by the web site of the "Istituto di Servizi per il Mercato Agricolo Alimentare – ISMEA", www.ismea.it). Multiplying the crop yield losses, evaluated through the production function, by the prices of the different crop typologies, it has been possible to achieve an estimate of the economic damages.

On the basis of the described criteria the evaluation of the alternatives has been made through the criteria/alternatives matrix (Table 4).

Table 4. Criteria/alternatives matrix for the supply water system of the River Esaro Basin

Criteria	Alternatives												
	A	B	C	D	E	F	G	H	I	J	K	L	M
ECON1	0	50	115	0	0	50	50	200	0	50	115	200	250
ECON2	1.57	0.77	2.17	1.58	1.67	0.78	0.87	1.81	1.67	0.88	2.27	1.82	1.02
ECON3	2.46	1.7	2.12	1.57	1.31	1.09	0.81	0.5	0.74	0.46	0.6	0.24	0.12
ECON4	339	222	302	216	217	133	124	64	120	76	100	29	10
ENVI1	0.75	0.75	0.75	0.75	0.71	0.75	0.69	0.71	0.69	0.68	0.69	0.59	0.39
ENVI2	P	VG	VB	P	P	VG	VG	EB	P	VG	VB	EB	EB
SOC1	93.15	44.41	80.96	41.66	51.24	19.78	21.64	18.81	20.1	8.5	16.26	6.17	2.14
SOC2	49.6	61.9	52.3	62.8	59.7	74.4	73.3	82.1	74.3	85.5	77.7	93.3	97.1
SOC3	P	MLB	MLG	VG	P	MLB	MLB	VB	VG	MLB	MLG	VB	VB
SOC4	VB	MLG	MLB	VB	M	MLG	G	VG	M	G	MLG	VG	P

Note: EB=extremely bad; VB=very bad; B=bad; MLB=more or less bad; M=moderate; MLG=more or less good; G=good; VG=very good; P=perfect.

The results for the criteria ECON1 and ECON2 are provided through exclusively economic considerations. The criterion ECON3 instead is based on the described production function. The values of criteria ECON4, ENVI1, SOC1 and SOC2 have been provided for the different alternatives on the basis of the simulations made using MIKE BASIN. Criteria ENVI2 and SOC3 are based on qualitative considerations about the nature of each alternative, and finally the criterion SOC4 provides estimates based on socio-economic considerations taking in account the alternatives and the territorial context where they are proposed.

Once the implementation of the criteria/alternatives matrix has been completed, the multicriteria analysis through the Decision Support System NAIADE has been carried out.

The comparison of criteria scores (values) of each pair of alternatives in NAIADE is carried out by means of "preference relations", expressed by the user, for each single criterion (JRC, 1996). Preference relations are defined by means of 6 functions that allow to express, for each criterion, a "credibility index" I_c of the statements that an alternative is "much better", "better", "approximately equal", "equal", "worse" and "much worse" than another. The credibility index goes from 0 (definitely non-credible) to 1 (definitely credible) increasing monotonically within this range. Particularly significant in these relations are the "crossover values", to be set by the users, meaning that an alternative becomes to be "credibly" much better/worse than another if the difference in the selected criterion is equal or greater than these values.

NAIADE allows a ranking of alternatives. The final ranking comes from the intersection of two separate rankings. The first one $\Phi^{+}(a_i)$ is based on the better and much better preference relations and with a value going from 0 to 1 indicating how the alternative a_i is "better" than all other alternatives. The second one $\Phi^{-}(a_i)$ is based on the worse and much worse preference relations, its value varying from 0 to 1, which indicates how the alternative a_i is "worse" than all the other alternatives.

Figure 4 shows partial rankings and the final ranking resulting from their intersection. The best alternative is J. Alternative M, considering also the Cameli Dam, is the best only in the Φ^{+} ranking. A sensitivity analysis, carried out to assess the robustness of the achieved solution varying the parameters of the "preference relations", has shown a substantial stability of the ranking, constantly confirming alternative J as the optimal one. Specifically, the sensitivity analysis pointed out that:

- Alternative J is always the best
- The ranking J-I-G-F remains constant
- The ranking M-L is also constant
- The incomparability of alternatives J and M, respectively the best solutions in the Φ^{-} and in the Φ^{+} rankings, is constant. This means that the two alternatives have completely different profiles

The ranking of the alternatives has been followed by an equity analysis. The equity analysis shows the conflicts and the possible coalitions among the various interested groups, and is based on an equity matrix containing the judgments on the alternatives expressed by these groups, expressed in a qualitative way through nine predefined linguistic expressions, with values comprised within "perfect" and "extremely bad".

Once the list of the stakeholders is defined (farmers, Land Reclamation Consortium, Basin Authority, environmentalists, Municipalities having at least part of their territories upstream the Cameli Dam), they have to be involved in the planning process through meetings and questionnaires calibrated for each one of them, taking in account their fields of action and their interests. Unfortunately this kind of survey has not been systematically realized and, the results have to be considered as provisional. Nevertheless, with the aim of showing completely the procedure leading to the definition of a strategic plan, the equity matrix achieved is shown in Table 5.

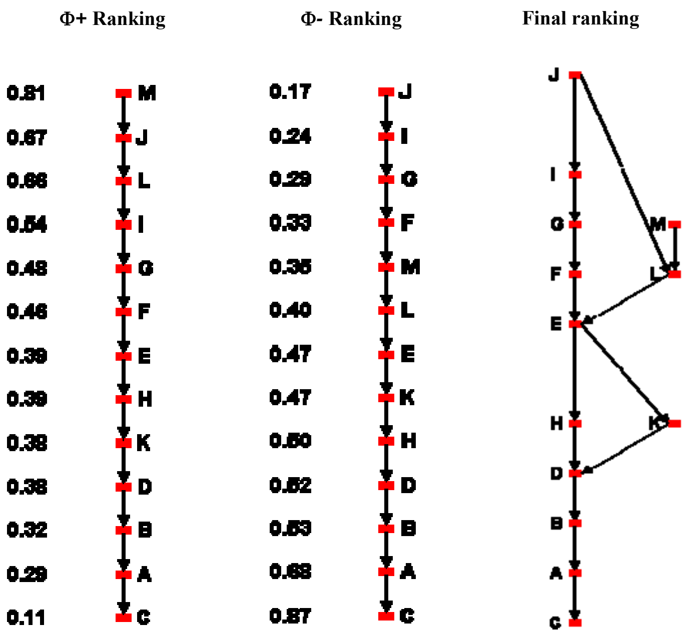

Figure 4. Partial and final ranking of the drought mitigation alternatives in the Esaro River Basin.

Table 5. Equity matrix (stakeholders / alternatives) of the water supply system of the Esaro River Basin.

Stakeholders	Alternatives												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Farmers	VB	MLG	B	B	MLG	M	G	VG	M	G	MLB	G	VG
Land Reclamation Consortium Sibari-Crati	VB	G	B	G	MLG	VG	G	MLG	G	P	M	M	MLG
Basin Authority	B	G	M	G	M	VG	M	MLB	M	MLG	M	MLB	MLB
Environmentalists	MLB	MLG	VB	VG	MLG	VG	G	EB	G	VG	B	EB	EB
Municipalities upstream the Cameli Dam	M	M	M	M	M	M	M	VG	M	M	M	VG	VG

Note: EB=extremely bad; VB=very bad; B=bad; MLB=more or less bad; M=moderate; MLG=more or less good; G=good; VG=very good; P=perfect

Also the equity analysis shows that alternative J, already resulted the best one in the impact analysis, is the only alternative accepted by all the stakeholders. Thus, it becomes the basic scenario for implementing the management and emergency plans. Figure 5 shows the dendrogram of coalitions achieved, highlighting the possible formation of coalitions among the different groups for the different alternatives.

At the end of the definition of the ASP, in the analyzed case the measure associated to the construction of the Cameli Dam deserves a brief consideration. Indeed the dam should not be considered as a possible alternative among the others, but as a part of any future scenario, considering that its construction is proceeding since 1983. Nevertheless, the path leading very slowly to the building of this structure is rather complex (today the works are very far from their conclusion, and the precise volume that will be stored in the reservoir is not yet clear, depending on the construction of some diversions from other catchments). With the aim of making the case study more interesting, proposing sensibly different alternatives, and in the meanwhile less complicated, getting free from any prediction about the conclusion of the works of the dam, the final stored volume and its use, the Cameli Dam has been considered like an alternative among the others. The results show that the alternatives considering the dam, built without lateral channels and used only for irrigation purposes in the Low Esaro and Sibari Plans, are not the best ones. Indeed, if the construction of the Cameli Dam will be abandoned, the other alternatives should take in account the dismantling costs of the already realized works.

4.2 Applying the AMP

The AMP is aimed at defining the indicators and the triggers for establishing the Normal, Pre-Alert and Alert conditions for the agricultural areas of the system. It has to take in account the guidelines provided by the ASP. In fact, it has to select the best combination among the optimal long term mitigation measure previously determined (J) and the several short term measures that can be adopted in the drought management in the analyzed area. Whereas the long term measure J is adopted, the short term measures vary following the status of the system. Specifically, for this case study:

- In the Normal condition no short term actions are taken
- In the Pre-Alert condition the exploitation of the groundwater resources in the irrigated area till 1/3 of maximum estimated volume (742570 m^3) is considered
- In the Alert condition the exploitation of the groundwater resources like in the Pre-Alert condition, the reduction of the release for minimum instream flow till 50% and the reduction of the release for irrigation (till 80% of the requirements) are taken into account.

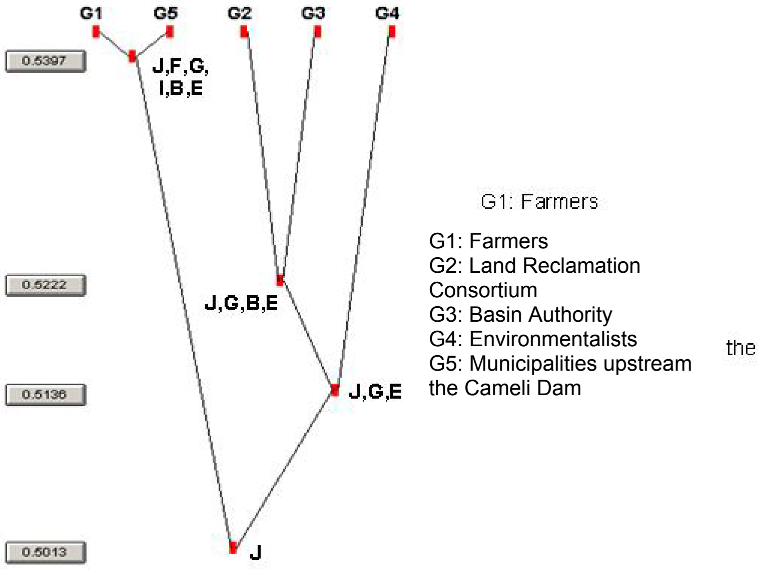

Figure 5. Dendrogram of coalitions and related agreement among the stakeholders.

The multicriteria analysis of the effects through NAIADE has been made again for the evaluation of the threshold values of the indices indicating the passage from one status to another. The conflicting objectives are:

- Minimizing the vulnerability of the system
- Minimizing groundwater withdrawals (with the aim of avoiding salt water intrusion, a serious problem in the irrigated area)
- Minimizing the failures to meet the minimum instream flow

For each month, starting from April, an impact matrix has been implemented where, following the criteria shown in Table 6, the optimal combination of the thresholds triggering the Pre-Alert and Alert status has been selected.

Table 6. Scheme of the impact matrix for the selection of the thresholds

Criteria	Alternatives			
	1st combination pre-alert alert thresholds	2nd combination pre-alert alert thresholds	…	nth combination pre-alert alert thresholds
Percentage of months with failures in meeting ecological requirements [%]	…	…	…	…
Groundwater withdrawals [hm^3]	…	…	…	…
System vulnerability [sum of the squared irrigation deficits $(hm^3)^2$]	…	…	…	…

It is noteworthy that the criterion related to the minimum instream flow (1st criterion) mainly influences the selection of the Alert threshold, while the criterion considering the groundwater withdrawals (2nd criterion) mainly affects the Pre-Alert threshold.

The pairwise comparison of the alternatives is based on the preference relations already mentioned. The crossover values for the functions “much better” and “much worse” are:

- 1st criterion: 0.5% of the minimum instream flow
- 2nd criterion: 20% of the maximum estimated possible monthly withdrawal
- 3rd criterion: 0.1% of the yearly squared irrigation requirements

The selected index for the definition of the drought thresholds is the volume stored in the dam from May to September, while for the month of April a meteorological index has been chosen, among the several available in literature (e.g. the Reconnaissance Drought Index – RDI, Tsakiris et al., 2007b; the Standardized Precipitation Index – SPI, McKee et al., 1993). This option is due to the rules adopted for the management of the dam in the ASP, stating that at the end of March the dam level cannot be higher than 130 m a.s.l. In this way the dam level (and the related stored volume) is not a significant index. For the month of April an analysis has been made relating the yearly irrigation deficit to the 6 month SPI (McKee et al., 1993) calculated in March (considering in this way the first six months of the hydrologic year, from October to March).

In the selection of the threshold values a rule has been followed considering that, if the multicriteria analysis provides more optimal solutions, the one with the lowest irrigation deficit is selected. Figure 6 shows month by month the values achieved for the drought thresholds.

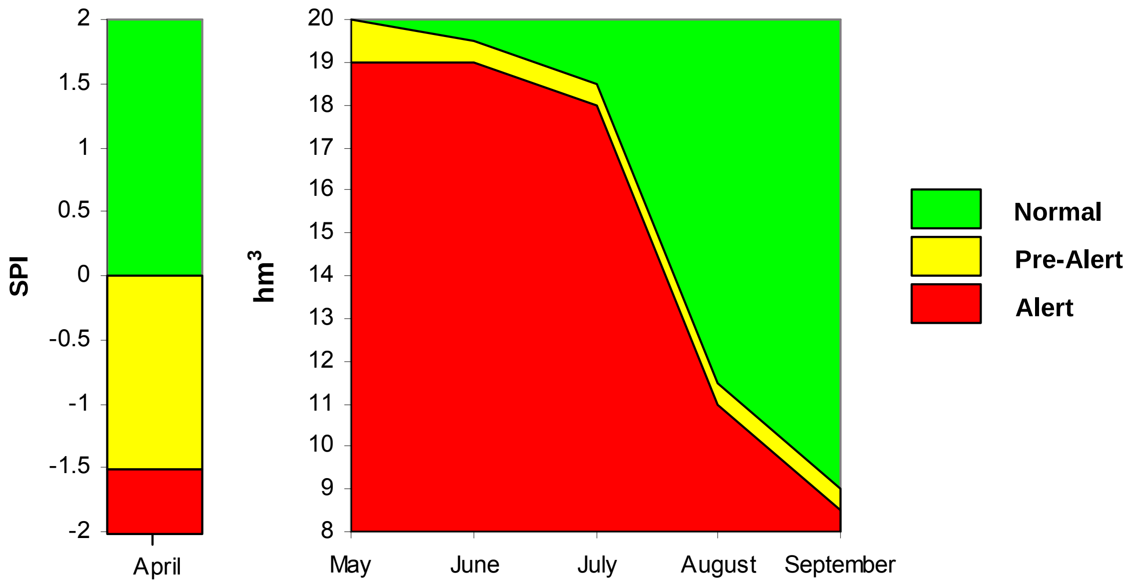

Figure 6. Pre-Alert and Alert thresholds

The adoption of the AMP modifies the vulnerability of the system, together with other significant parameters. Table 7 shows a comparison between the values of these parameters achieved applying only ASP, and applying ASP plus AMP. The results are related to simulations made on 1000 years. Specifically, the number of years with irrigation deficit shows that the temporal reliability passes from 85.5% to 98.7%, and also the irrigation deficit sensibly decreases. These results are achieved through the exploitation of the aquifers and the failures in fulfilling the minimum instream flow.

Table 7. Significant parameters of the status of the water supply system

	Adopting only ASP	Adopting also AMP
Number of months with irrigation deficit	352	32
Number of years with irrigation deficit	145	13
Sum of the irrigation deficits over 1000 years [hm^3]	868	51
Percentage of minimum instream flow failures [%]	0.68	3.4
Sum of the groundwater withdrawals over 1000 years [hm^3]	0	506

4.3 Applying the ACP

The first objective of the ACP is the definition of the indicators and their thresholds for univocally establishing the beginning of an emergency situation. Since the hydrologic analysis in April shows that the water demand is always less than the water availability in Farneto del Principe reservoir, and that every year the volume stored grows up during this month, the thresholds are selected starting from May, choosing as an indicator, such as in the AMP, the volume stored in the reservoir.

Since the temporal availability of the system is very high (98.7%), it is not useful to evaluate the emergency thresholds considering the few residual years. The adopted approach is probabilistic, and is composed of the following steps:

1. every single month, from May to September, a series of simulations (considering the generated 1000 years runoff series) is run where the stored volume at the beginning of the month is fixed at different values (e.g. in May a simulation fixes the stored volume in the first day of the month equal to 24 hm^3, independently from the water incoming in the previous period, another simulation fixes the stored volume equal to 23.5 hm^3, another one to 23 hm^3 etc.); in the months following the analyzed one, independently from the stored volume, the Alert measures are adopted
2. for every month and every fixed stored volume the failures in the remaining irrigation season are calculated, i.e. the number of years where, in spite of the application of the long term measures proposed by the ASP and the short term measures proposed by the AMP, the water supply system is not able to fulfill the water demand; for each volume stored at the beginning of the month also the intensity of the failures can be calculated, i.e. the percentage of deficit respect to the monthly demand

The adopted procedure leads to the graphs in Figure 7, showing the probability of having failures in the system and the related intensity, depending on the volume stored at the beginning of the analyzed month (in the same figure also the Pre-Alert and Alert thresholds are shown, achieved developing the AMP). It is noteworthy that the adoption of the measures described in the ASP and in the AMP allows a very low probability of having significant water deficits. In fact, the developing of the ACP is in a certain way "uncoupled" from the previous analyses, aiming just at providing to the decision maker suggestions about the value of the stored volume that, with a quite high probability, can lead to emergency. A correct developing of the ASP and AMP assures that, adopting the prescribed long term and short term measures, emergency will happen very seldom.

The choice of the value of the emergency index to be adopted month by month depends on the failure risk that the decision maker agrees to accept. Higher the accepted risk of having failures, lower the value of the stored volume chosen as a threshold for declaring an emergency situation. The emergency thresholds will be in any case lower than the Pre-Alert and Alert thresholds.

The selection of the threshold value for declaring an emergency situation is linked to many economic and politic factors, and is not investigated in this study, that only aims at proposing an example of drought plans developing useful to the decision makers. However, the measures to be adopted when an emergency situation is declared could include the use of additional sources of low quality or high exploitation cost, the over exploitation of the aquifers without taking in account environmental consequences (e.g. sea water intrusion in the coastal areas), the temporary permission of using some protected sources or the temporary reallocation of water resources, the limitation of irrigation just to perennial crops, if necessary with reduced turns, public aids for crop losses, for damages to perennial crops and for other non reversible damages.

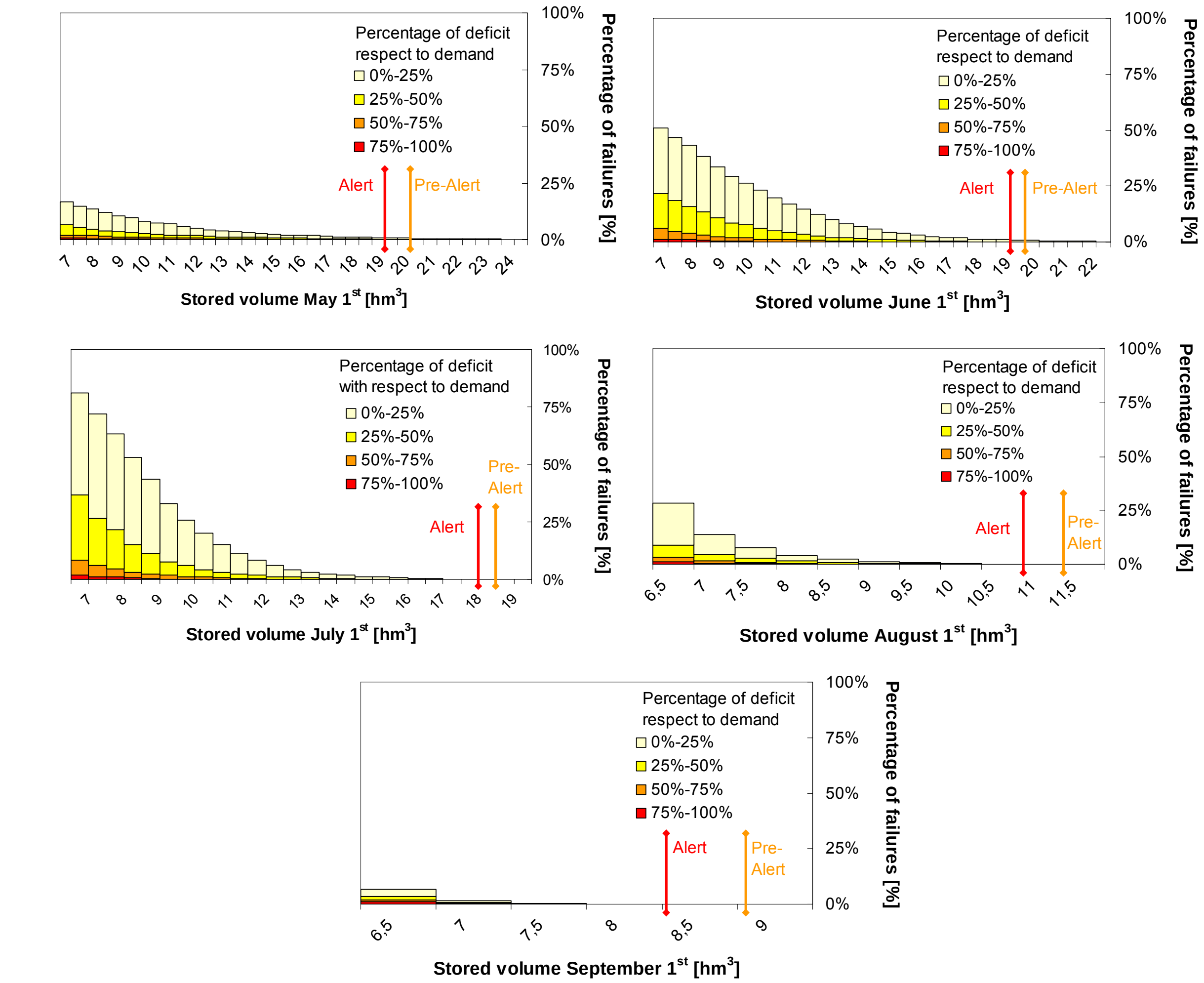

Figure 7. Probability of having failures and percentage of deficit respect to demand fixing the stored volume on May 1st, June 1st, July 1st, August 1st and September 1st. In the graphs also the Pre-Alert and Alert thresholds are shown, achieved developing the AMP

5. CONCLUSION

In the framework of a proactive approach in water resources management, currently well-established in the legislation of several countries (but not in Italy), an application of the organizational structure of drought planning process in an agricultural system is shown, composed of a drought strategic plan, a management plan and an emergency plan.

The adopted methodology, using simulation models and multicriteria decision analysis techniques, shows an example for the choice of the preferable alternatives minimizing the levels of subjectivity, considering economic, environmental and social aspects and taking into account the viewpoints of all the involved stakeholders, whose active participation in the planning process should be promoted. Transparency and participation of the stakeholders in the steps concretizing the planning process are as much important as the adoption of rigorous and sound analysis procedures (such as water balance models and optimization and multicriteria analysis models). In the same way, a correct selection of the drought indices is not sufficient if not supported by an efficient and reliable monitoring system, that should be able to communicate in due time to the users and the decision-makers the data needed to assess the actual level of drought risk, in its turn linked to specific measures defined previously, in a non-emergency situation.

The results obtained in the analyzed case study are influenced by several levels of approximation, mainly due to the actual management procedures of the irrigation system, that do not provide systematic measures of the water volumes really used and, regarding the equity analysis, to the impossibility of performing an overall analysis on all the stakeholders. Nevertheless, this study shows a concrete example of proactive planning at all levels, from strategic to emergency measures, reducing in this way the gap between theoretical research and practical applications, and pointing out a feasible way for overcoming an emergency approach, that not seldom in the past produced economic, environmental and social damages in the analyzed region.

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