Assessing the effectiveness of preventive measures for droughts - Issues and Solutions

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Abstract: Drought is an increasingly frequent phenomenon throughout Europe, but responses and their effectiveness vary significantly. The European Commission-funded PREEMPT project has assisted the relevant authorities in better appreciating the risks posed by droughts. The focus has been on the elements that are essential for policy implementation: improving knowledge about drought risk reduction and management; identifying, assessing and monitoring risks; and reducing the drivers of risk. The task involved collecting data about past disasters, filling knowledge gaps, and identifying and improving risk assessment methods in three river basins. Through this effort, the goal was to contribute to the harmonization of methodological approaches for risk assessment, and thereby improve the evidence base for reducing risks associated with droughts. In the three basins examined, the sector most affected by drought is agriculture. In the northern European basin (Scheldt), water shortages are mostly offset by irrigation systems. This is not the case for southern basins (Po, Ebro), where water supply systems are already stressed, and where socioeconomic losses due to droughts are more significant, although other factors such as crop type and irrigation system contribute to determining vulnerability. This paper presents an assessment of the socioeconomic impacts of drought in different European countries and of the factors that determine the vulnerability of different sectors to the risks posed by droughts. It also looks at the management approaches to deal with drought risks in different parts of Europe, highlighting potential approaches to evaluate the effectiveness of these measures and identifying gaps and management alternatives.

Keywords: Droughts, preventive measures, socio-economic impacts, management, policy.

1. INTRODUCTION

Recently, the European Commission[1] noted that "As evidenced by the Commission's Review of the Policy on Water Scarcity and Droughts, limited progress has been achieved in implementing the policy instruments identified in the 2007 Communication." (p.10) This paper focuses on policy approaches to manage and mitigate drought impacts, with the specific intention of:
(a) improving knowledge about drought risk reduction and management;
(b) identifying, assessing and monitoring risks; and
(c) reducing the drivers of risk.

The goal of the Project PREEMPT[2] has been to contribute to the harmonization of methodological approaches for risk assessment, and thereby improve the evidence base for reducing risks associated with droughts. In the three basins examined, the sector most affected by drought is agriculture. In the northern European basin (Scheldt), water shortages are mostly offset by irrigation systems. This is not the case for southern basins (Po, Ebro), where water supply systems are already stressed, and where socioeconomic losses due to droughts are more significant, although other factors such as crop type and irrigation system contribute to determining vulnerability.

This paper reviews various management alternatives to address drought risks in different regions of Europe, highlighting potential approaches to evaluate the effectiveness of these measures and identifying gaps and management alternatives.

2. OVERVIEW OF DROUGHT EVENTS

In Spain the 2005-2008 drought affected the Ebro river basin, particularly the provinces of Huesca and Lleida in the northeastern part of the basin. The drought resulted in water use restrictions in the city of Huesca and several small municipalities and in agriculture and hydroelectricity production. Significant agricultural insurance payments were made. Beyond the traditional water user sectors, the drought also impacted water-related recreational activities, aquaculture, increased the frequency and intensity of forest fires, and resulted in a deterioration of water quality in the basin. The fact that the Ebro River Basin Special Drought Management Plan (SDMP) was being developed at the time of the drought contributed to the significant amount of information available on this event (MARM, 2007).

The worst drought events registered in the Po river basin occurred in 2003 and 2005-2007. In 2003 the extremely low precipitation levels and high temperatures led to some of the lowest among recorded river discharges in the delta (-6.99 m or 270 m^3/s at the Pontelagoscuro measuring station) (ARPA ER, 2003). In July 2003 an emergency situation was declared in Veneto, Lombardy, Piedmont, Emilia-Romagna and other locations across the country. Between 2005 and 2007, the basin experienced another severe drought. From October 2006 Northern Italy was affected by anomalies in precipitation and seasonal

[1] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Blueprint to Safeguard Europe's Water Resources, Brussels COM(2012) 673 final

[2] PREEMPT "Policy-relevant assessment of socio-economic effects of droughts and floods", funded by European Commission, DG Humanitarian Aid & Civil Protection (ECHO). http://www.feem-project.net/preempt/

temperature (ARPA ER, 2006). At the end of 2006 the rainfall deficit reached 200mm and continued to rise until April/May. In May 2007, river discharges were lower than those of the 2003 and 2006 drought events. The drought spells of 2003 and 2006-2007 illustrated Northern Italy's vulnerability to climate variability and change. Although the Po basin is one of the more water-endowed regions of Italy, the over-commitment of water resources led to critical shortages for agriculture, energy production, and to a lesser extent the public water supply (AdBPo, 2006).

The Weser river basin in Northern Germany experienced droughts of considerably less intensity and a shorter duration than those experienced in the Mediterranean regions of Europe. Moreover, the basin as a whole, together with other basins in Germany, have ample supplies of water stored mainly as groundwater, and until now there has been sufficient replenishment of these stores in the winter months. Nonetheless the frequency of drought events is increasing in Germany as in other regions of Europe and this takes its toll on a number of sectors, most notably agriculture. The drought event examined in the Weser river basin of Germany took place in 2003. In the summer of that year, Germany experienced temperatures that were on average 2°C higher than the average temperature for the 30 year-period of 1961 to 1990. It was the warmest summer on record according to the German Weather Service (Bundesanstalt für Gewässerkunde, 2006). Much of rest of Europe also experienced record temperatures during these months. Of greater concern, especially for agriculture, were the low levels of precipitation: in Germany this was 71% of the long-term average (1961-1990). The forage crop deficit in Germany was 30%, and maize and potato production was approximately 23% below the annual average (COPA-COGECA, 2003).

3. MEASURES TAKEN TO MITIGATE DROUGHT EFFECTS

The wider scope of the impact assessment undertaken in the PREEMPT project includes the losses avoided through the timely implementation of preventive measures, and potential of additional measures. A series of assessments of the preventive measures in place at the time of the selected drought events was undertaken for each of the three case study river basins. These were assessed in terms of economic and social losses that were prevented by the measure or that could have been prevented by its more timely implementation.

The issues of water scarcity and droughts have been further addressed in the Communication of the European Commission (COM (2007) 414 final) and, more recently, in the Blueprint for Safeguard Europe's Water Resources (COM (2012) 673). The latter attested limited progress in terms of the actions identified in the 2007 Communication. For similar reasons, the European Parliament (2012) called several times upon the Commission to submit legislation, 'similar to the directive on floods, which encourages the adoption of an EU policy on water shortages, droughts and adapting to climate change'.

Given the higher exposure of agriculture to drought events, drought management measures tend to focus on the agricultural sector. In more water-stressed regions of the south, measures also focus on urban water supply systems that may be vulnerable to drought risks. To a much lesser extent measures are in place to address other vulnerable water-related sectors such as the industrial sector that also requires large volumes of water for cooling and manufacturing. In addition, the forestry sector in the German Weser basin is an important source of income, and highly susceptible to losses due to drought.

Potential measures that hold promise for reducing losses from, and hence improving resilience to, drought and water scarcity are listed in Table 1 by river basins, although many of the measures can be considered appropriate for all river basins in the study.

Table 1: Recommended Measures for Drought Management in PREEMPT Case Study Basins

	River Basin(s)
Institutional measures recommended	
Water Audit: implement intelligent application of water in the operational farm management	Scheldt
Implementation of demand management for more efficient water use	All
Fine-tuning of water markets and regulatory changes	Ebro
Implementation of national legislative framework for water exchange	Ebro
Integration of water trading in the process of hydrological planning	Ebro
Improved control of water uses and adaptation of water rights to real consumption levels	Ebro
Increased flexibility prioritising allocation for water use among sectors	Ebro
Redefinition of water allocation priorities	Ebro
Improvement of allocation decisions based on socioeconomic importance of various uses by region	Ebro
More transparent price-setting mechanisms	Ebro
More active role of Public Exchange Centres (Water Banks) in pursuing other forms of market exchanges	Ebro
Improvement of irrigation insurance (stochastic factors)	Ebro
Development of drought emergency plans for all urban water supply systems	Ebro
Integration of sectoral policies (esp. Between land use planning and water management)	Ebro
Economic incentives based on benchmarking in irrigation districts	Ebro
Risk-sharing instruments for hydroelectric companies	Ebro
Development of water scarcity/drought management plans	Weser
Improvement of documentation and monitoring of periods of water scarcity	Weser
Implementation of the statement of the Federal Spatial Planning Act (ROG, 2008) - climate protection must be taken into account by implementing measures (for mitigation /adaptation)	Weser
Provide financial incentives for adaptation to climate change	Weser
Improvement and implementation of water retention measures to recharge surface/ groundwater body	Weser
Improvement of transboundary cooperation/agreements and regional planning to promote water retention among adjacent municipalities	Weser
Inter-sectoral and interregional water transfers	Po
Water tariffs in urban areas	Po
Informational measures recommended	
Extension of agrarian training and education to include adaptation in the context of agribusiness	Weser
Research in hydro-geological systems to understand groundwater recharge, extraction and water substitution	Weser
Public education and awareness-raising to encourage efficient use of water and reducing virtual water use	Weser
Operational measures recommended	
Recycling water (e.g. implementation of use of treated sewage water or grey water for irrigation)	Scheldt
Implementation of pumping drainage water back to reservoirs /water silos	Scheldt
Water quality improvements	Ebro
Water use efficiency improvements in residential and commercial, agriculture and industry	Ebro
Environmental impact assessment and ecosystems monitoring	Ebro
Improvements in energy/water efficiency of new thermoelectric plants (dry cooling systems, closed cycles)	Po /Weser
Development of metering and smart metering in agriculture	Po

4. THE EFFECTIVENESS OF DROUGHT MEASURES

This section reviews some of the measures to address drought that were implemented in the three case studies. It summarizes the results of several quantitative evaluations of costs and benefits of these measures in each river basin.

4.1. Evaluation of cost-effectiveness in the Po

According to the Po Basin authority the winter 2002 to 2003 was abnormally dry. The early spring was characterized by normal precipitation but in May and June the basin experienced another dry period. Lower rainfall combined with high temperatures (i.e., higher evaporation rate) triggered an earlier start of the irrigation period . As a result, the water level in the Po river substantially decreased from June until precipitation returned in August of that year (AdBPo, 2010). The measures implemented to manage water scarcity are presented in the Po Basin's memorandum of understanding called “Protocol of Intent” (PI). The PI prioritises household water use in accordance with what is foreseen by the law. In addition, it guarantees the water requirements for power plants in order to reduce the risk of black out. To serve this purpose, several actions were proposed: (a) an increase in the outflow from the mountain reservoir; (b) a direct transfer of water to the valley; and (c) a reduction of 10% in irrigation withdrawals from the main tributaries with respect to the amount allowed by the concession.

According to the information given by the Land Reclamation and Irrigation Boards (LRIB), between 50% and 60% of the irrigation water needs were guaranteed. As a result of the decrease in water availability, agricultural production also decreased. This caused an increase in food and fodder prices of approximately 20 to 25% (AdBPo 2010).

Ex-post evaluation of the effects of the Protocol of Intent

The ex-post evaluation of the economic effects of the PI has been conducted designing as benchmark a hypothetical Scenario 0 where no-action was taken. The evaluations considered the demand curves for the two principal uses of water, agriculture and hydropower for the short period between the introduction of the PI (active from the 18th of July to the 3rd of August 2003) and the end of the state of emergency (considered officially closed with the rainfalls of the 15th of August). For this purpose, the production value has been calculated without taking into consideration the production costs. This assumption makes sense if it is considered that the production costs incurred by the farmers are not impacted by the implementation of the PI (AdBPo 2010).

Scenario 1: Comparison between the situation with and without the Protocol of Intent

Scenario 1 is represented by the conditions resulting from the implementation of the measures contained in the PI. In this scenario the additional water released from the mountain reservoirs is known, but the distribution of the release per day is unknown.

The hydroelectric production that is theoretically possible with the volume of water released according to the Protocol of Intent has been estimated at around 192 GWh, with a value of €16.5 million (Euro). The actual revenues registered were €9.5 million. The PI did not significantly affect hydroelectric production in the longer term, mostly thanks to the abundant precipitations registered in the months after the drought period. In order to estimate the effects of the PI on the agricultural sector, it was assumed that the additional water available was used to maximize agricultural production. The estimation of agricultural productivity has been based on the coefficient of production in the Po basin under three different climatic and technological conditions. The productivity in optimal climatic conditions with the use of irrigation, in average climatic conditions without the use of irrigation, and in dry climatic conditions without irrigation, have been considered for estimating the production of six types of crops (AdBPo 2010).

The estimated results (Table 2) demonstrated that, under Scenario 0, where no action is taken, the losses for the farmers are estimated in around 1,948 million €, with no losses registered for the hydropower sector. The introduction of the PI, Scenario 1, reduces the losses for the agricultural sector to 1,328 million €. In this case, the damage for the hydropower sector is estimated at 7 million € (AdBPo 2010). Under Scenario 1 the economic losses decrease by approximately €613 million compared with Scenario 0 (AdBPo 2010).

Scenario 2: Double the volumes of water released from the mountain reservoirs with respect to the Protocol of Intent

Scenario 2 analyses a hypothetical case in which the Protocol establishes more stringent actions for the hydropower sector, and transferring more water for irrigation. Scenario 2 considers doubling the volumes of water released from the mountain reservoirs with respect to the volumes established by the PI (AdBPo 2010). Under this scenario, electricity production would increase to 384 GWh with a revenue estimated at €33 million. Scenario 2 limits the reduction in water available for irrigation to 20% in Piedmont and Lombardy and 30% in the Emilia Romagna region. The increase in water available for agriculture is estimated to reduce agricultural losses to €710 million. Table 2 compares the production losses for hydropower and agriculture under the conditions of Scenario 0, 1 and 2 (AdBPo 2010). In conclusion, the measure simulated for in Scenario 2 has the potential to reduce losses for the overall economy by approximately €1.23 billion with respect to the Scenario 0 and of 609.8 million Euro with respect to the Scenario 1 (AdBPo 2010).

Table 2. Effects of the different scenarios – short term. Source: IEFE, Bocconi University (AdBPo 2010).

		Scenario 0	Scenario 1	Scenario 2
Hypothesis	Reduction of the irrigation in comparison with the valued allowed by the concession	Piedmont: 60% Lombardy: 60% Emilia- Romagna: 70%	Piedmont: 40% Lombardy: 40% Emilia- Romagna: 50%	Piedmont: 20% Lombardy: 20% Emilia- Romagna: 30%
Results	Loss in revenue for farmers (bill. of Euro)	1.948	1.328	0.710
	Loss in revenue for hydroelectric sector (mil. of Euro)	0	7	15.2

Scenario 3: Allocation of water use to highest value-added crops

Scenario 3 is similar to Scenario 1, though it gives priority to the irrigation of crops with the highest added value (AdBPo 2010). For the production of rice and fruit approximately €797 million gains would be made and the losses for the other crops would be approximately €334 million (Table 3) (AdBPo 2010). This could allow result in the reduction of losses in the agricultural sector estimated in Scenario 1 of approximately €463 million (Table 3). Impacts on the energy sector are similar to those of Scenario 1 (€7 millionin losses) (AdBPo 2010). In Scenario 3 expected losses for the agricultural sector are estimated at around €866 million, lower than Scenario 1 (Table 2) (AdBPo 2010).

Table 3. Evidence from the Scenario 3. Source: IEFE, Bocconi University elaboration for AdBPo, 2010.

	Losses caused by the reduction in the supply of water (million Euro)	Benefits ensured by "optimal" irrigation (million Euro)
Wheat	0.279	
Fruit		547.722
Rice		248.901
Soybeans	10.434	
Forage	89.419	
Maize	233.599	
Tot.	333.732	796.623
Overall benefit	462.891	

Scenario 4: Removing water supplies for lower added value crops

Scenario 4 is considers optimal and full irrigation of the three highest added value crops (fruit, rice and forage), and removing water supply for crops with the lowest value added:wheat, maize and soybeans (AdBPo 2010). Compensations to farmers may be needed to implement this measure. Impacts on hydropower are equivalent to Scenario 1 (€7 mil). Scenario 3 could allow a reduction of losses in the agricultural sector equivalent with that estimated in Scenario 1 of €612 million (Table 4).

Table 4. Results from the scenario: interruptible supply (compare with the scenario 1). Source: IEFE, Bocconi University elaboration for AdBPo, 2010.

	Losses caused by the interruption of the supply (million Euro)	Benefit from the "optimal" irrigation (million Euro)
Wheat	0.599	
Fruit		547.723
Forage		143.585
Rice		248.900
Maize	304.502	
Soybeans	22.982	
Tot.	328.043	940.208
Overall benefit	612.165	

Scenario 5 – substitution of high water-demanding crops

Scenario 5 considers substituting all irrigated crops in the Po basin (with the exception of the more profitable rice and fruit) with less water demanding crops. In the event of a drought event similar to the one registered in 2003, Scenario 5 could reduce agricultural losses to just €26 million, almost €1.3 billion less than Scenario 1 (AdBPo 2010), keeping the losses to the hydropower sector at around €7 million. (AdBPo 2010).

The problem with this scenario is that it is not the most profitable production mix under normal climatic conditions. In a normal year where water scarcity does not occur, total revenues for the agricultural sector cultivating a crop mix similar to that produced in the Scenario 1 have been estimated at €3.553 billion. Introducing the crop mix designed for Scenario 5, total revenues are estimated to decrease to €2.986 billion, with total losses of €585 million (Table 5) (AdBPo 2010). Scenario 5 could be the most advantageous only in a situation of structural water scarcity in the Po basin.

Table 5. Scenario 5 vs. Scenario 1. Source: IEFE, Bocconi University elaboration for AdBPo, 2010.

	Scenario 5	Scenario 1
Loss in revenue based on the drought of 2003 (bill of Euro)	0.026	1.328
Revenue in optimal conditions (mil. of Euro)	2.986	3.553

Scenario comparison and conclusions

Table 6 compares all the scenarios described and presents a summary of impacts on agriculture and hydroelectric production. It suggests that damages caused by a drought could be reduced with adequate planning. Having a plan in place that provides a clear set of measures to be implemented in case of drought could contribute to the mitigation of drought impacts in the Po River basin (AdBPo 2010). The agricultural sector seems to be more vulnerable to drought than hydropower. This might not be the case in the extreme situation in which the reduction in hydropower production would provoke a blackout (AdBPo 2010). The solution implemented during the 2003 drought (Scenario 1) allowed mitigation of the impacts on the economic productivity in the Po river basin.

Table 6. Comparison among different scenarios. Source: IEFE, Bocconi University elaboration for AdBPo, 2010.

Scenarios	Results	
	Loss in revenue for the farmers (mil. of Euro)	Loss in revenue for the hydro- electric production (mil. of Euro)
Scenario 0 – Without protocol	1,948	0
Scenario 1 – With protocol	1,328	7
Scenario 2 – Double release	710	15.2
Scenario 3 – Improvement of the cultivation with more value added	866	7
Scenario 4 – Interruptible supplies	716	7
Scenario 5 – Less hydro-demanding crops	26*	7

** see caveat in the text about Scenario 5*

4.2. Evaluation of cost-effectiveness of measures in the Weser

As in other regions of Europe, agriculture is one of the most important sectors to suffer losses from a drought period. The Weser basin study focused on that part of the basin falling within the state of Lower Saxony. The estimated economic cost of the 2003 drought to the agricultural sector in this region was determined to be approximately €370 million when compared to values of production in 2009.

The assessment of the effectiveness of the measures to address drought in the agricultural sector was based on an analysis of grains, potatoes, sugar beet, winter rapeseed and meadow/pasture. The calculations were supported by statistical data of the Chamber of Agriculture Lower Saxony (CALS) and a semi-structured interview with Jürgen von Haaren of CALS (2012)

Irrigation of otherwise non-irrigated crops is considered an adaptation measure in Northern Germany, largely because until now the region has adequate water stored in groundwater aquifers that are sufficiently replenished during the winter months. Irrigation is seen as the most effective measure for addressing water scarcity in Northern Germany, particularly when combined with farm practices that enhance the efficiency of water use such as (rain) water retention techniques, soil protection measures and adapting sowing and harvesting dates.

In 2003, irrigation was the main measure implemented to counter the effects of drought. Without irrigation, agricultural losses resulting from the 2003 drought would have been considerably higher. Table 8 presents a significant difference in yields of potatoes, grain and maize with and without irrigation. It has been estimated that for potatoes, grain and maize, an economic loss of approximately 83.5 million € may have been prevented by the existence of irrigation systems. The method for calculating the losses prevented by irrigation involves an estimation of the economic losses in terms of the percentage of the increase in yield of a given crop as a result of irrigation. Losses were calculated on the basis of yield, area under cultivation, market price and the percentage of the yield that can be attributed to irrigation. Several studies carried out by CALS estimated that irrigation as an adaptation measure results in a yields that are 48% higher for potatoes, 32% higher for grains and 30% more for maize (Fricke and Riedel 2010).

Table 7: Agricultural yields with and without irrigation 2003 (data adapted from Fricke and Riedel 2010, NLS 2004)

	With irrigation		Without irrigation		
	Harvest in dt	Harvest in Mil. Euro	Harvest in dt	Harvest in Mil. Euro	Losses in Mil. Eur
Table potatoes	6.4	80.6	3.3	41.9	-38.7
Grain	7.1	79.2	4.8	53.9	-25.3
Maize	5.1	64.9	3.5	45.4	-19.5
Total		224.7		141.2	-83.5

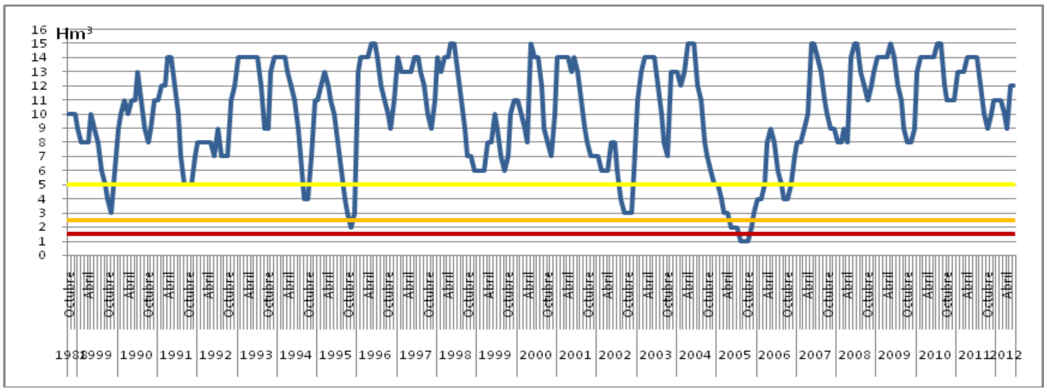
There are a number of other measures, such as storm- and flood water storage, rainwater harvesting techniques, soil conservation, drought-tolerant crop types and others that support or improve the effectiveness of irrigation as a measure for adaptation. Because of the influence of a range of conditions such as input costs, market price and so forth, it requires considerable effort to quantify the effectiveness of these adaptation measures, but it is clear that these measures positively influence the effectiveness of irrigation or reduce the need for water abstraction from groundwater sources. It is estimated by CALS (Von Haaren, 2012) that crop management measures, when implemented with irrigation during dry months, can contribute to an additional 5 to 10% decrease in crop losses.

4.3. Evaluation of cost-effectiveness in the Ebro

In order to offer an estimation of the cost-efficacy of the measures implemented in the Ebro it is necessary to compare the cost of the measure with the avoided losses, to the extent that these are known. In the case of the city of Huesca, the use of groundwater resources and the construction of the pipeline to the Cinca irrigation canal and of a larger storage facility for the city's water supply required an investment of €4.162 million in 2005 (€0.27 million annualized in 25 years) (Table 8).

Figure 1 shows the evolution of the Vadiello dam reserves between 1988 and 2012. The city of Huesca has an allocated volume of 7.5 Mm^3 from the Vadiello Reservoir. According to the Ebro SDMP, the system needs minimum reserves of 5 Mm^3 to maintain normal conditions (guaranteed supply for 12 months). Below that storage level the system goes into a drought pre-alert stage. Below 2.5 Mm^3, which is equivalent to a 6-month supply, the system goes into alert, and restrictions to outdoor water uses can be put in place (e.g. garden watering, swimming pools, etc.) . When reserves fall under 1.25 Mm^3, the system enters emergency status.

Figure 1. Evolution of the Vadiello Reservoir reserves between 1998 and 2012



The pipeline connection of Huesca's water supply system to the Cinca irrigation canal had some additional costs that need to be considered. The Cinca canal supplies an irrigated area of approximately 45,000 ha. A cost-effectiveness analysis must therefore take into consideration the opportunity cost of the irrigation water that was diverted to supply Huesca. The Cinca canal receives water from the Grado and Mediano reservoirs. The water transferred to supply Huesca was small compared to the volume of water consumed for irrigation. The gross productivity (value of the harvested crops) of the water used for irrigation in the Cinca Canal is, on average, 0.97 €/m^3 (calculations made by Gil et al. (2010) data). Assuming the net margin obtained from each cubic metre of water allocated to irrigation in that region is 30% of gross productivity[3], the surplus of every cubic metre allocated to other uses was estimated to be 0.29 €/m^3. This is the forgone net revenue (opportunity cost) of the water reallocated to Huesca.

Table 8 summarizes the avoided losses as a result of the implementation of connection of the Huesca water supply system to additional sources of water (groundwater and Cinca canal). The results indicate that the measures were cost effective.

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[3] On average, the cost of agricultural production is about 70% of gross productivity.

Table 8. Avoided socioeconomic losses and annualized cost of measures in the city of Huesca in the 2005-2008 drought (million Euro)

		2005	2006	2007	2008	TOTAL
Avoided losses as a result of measure implementation	Outdoor water use restrictions	-	0.55	0.55	-	1.05
	Indoor water use restrictions	1.17	1.17	1.17	-	3.51
Costs of the emergency urban water supply infrastructures	25 years	0.27	0.27	0.27	0.27	1.08
Opportunity costs of using Cinca canal water for Huesca's water supply		0.66	1.02			1.62

Source: Own calculations and deliverable D1 PREEMPT Project: "Comprehensive impact assessment report: Ebro case study - Droughts".

Demand management measures

As a result of the infrastructural improvements and public education campaigns that were put in place because of the drought, per capita water demand in Huesca decreased. In 2004, Huesca's treatment plant (with a built capacity to treat 26,000 m^3/day) processed a daily average of 22,000 m^3/day (City of Huesca, personal communication, June 2011). In 2010, the daily average volume treated was 17,313 m^3/day (Instituto Aragonés del Agua)[4], a 21% reduction.

If this reduction in water consumption had been achieved by implementing demand management measures as early as October 2004, 1.65 Mm^3 could potentially have been saved in the 2004-2005 hydrologic year (21% of annual Huesca's water allocation).

Using data from Vadiello reservoir (see Figure 1), and assuming water savings of 0.13 Mm^3/month, we can estimate that the total volume of water available in Vadiello in June 2005 would have been 3.17 Mm^3, significantly higher than the 2 Mm^3 that was available on this date, and above the 2.5 Mm^3 level that determines the onset of alert drought status and the implementation of outdoor water use restrictions and other drought measures (see Table 9). Had the monthly savings of 0.13 Mm^3 been sustained, restrictions in outdoor water uses and the resulting welfare losses would have been avoided.

4 http://www.aragon.es/DepartamentosOrganismosPublicos/Organismos/InstitutoAragonesAgua/AreasTematicas/DepuracionAguasResiduales/MapaDepuradoras/Huesca/ci.16_Huesca.detalleDepartamento?channelSelected=0 (last checked August 2012)

Table 9. Comparison of the hypothetical evolution of Vadiello reservoir storage with early implementation of demand management measures with the real evolution observed (in Mm^3)

	2004-2005 (real)	2004-2005 (hypothetical)	2005-2006 (real)	2005-2006 (hypothetical)
October	7	7.13	1	2.69
November	6	6.26	2	3.82
December	5	5.39	3	4.95
January	5	5.52	4	6.08
Februray	4	4.65	4	6.21
March	3	3.78	5	7.24
April	3	3.91	8	10.47
May	2	3.04	9	11.6
June	2	3.17	8	10.73
July	2	3.3	6	8.86
August	1	2.43	5	7.99
September	1	2.56	4	7.12

Note: Yellow indicates pre-alert, orange alert and red emergency drought status

Risk-based management of the Vadiello reservoir

In addition to meeting the demands of Huesca, the Vadiello reservoir supplies water to an irrigated area of 2215 ha, with an annual demand that ranges between 5 and 6 Mm^3. This irrigation demand is only met when reserves in Vadiello remain above 3 Mm^3 (EID Consultores, 2005).

A risk analysis of the dam management schedule allows us to evaluate observed management during the drought and consider possible alternatives. This approach requires taking into consideration the evolution of reservoir storage in response to management decisions and precipitation. Reservoir management could take into account the variables represented in equation 1:

$$\widetilde{S_{j+n}} = \overline{R_j} + \widetilde{V_{j-n}} - \overline{G_j} \qquad \textbf{[Eq. 1]}$$

where S is the Supply for the month $j+n$ calculated in month j, R represents stored volumes at the time management decisions are made (month j), V is the variability in storage from the time of the decision (month j) until month n (in this case the summer months, when the risk of scarcity as a result of drought is highest), and G is the minimum storage volume that is established in month j as a guarantee for Huesca's water supply.

Table 10 shows the evolution of monthly storage volumes $(\overline{R})$ between 2002 and 2007. Storage volumes dropped below 2.5 Mm^3 in May 2005 Entering in the 'alert status'.

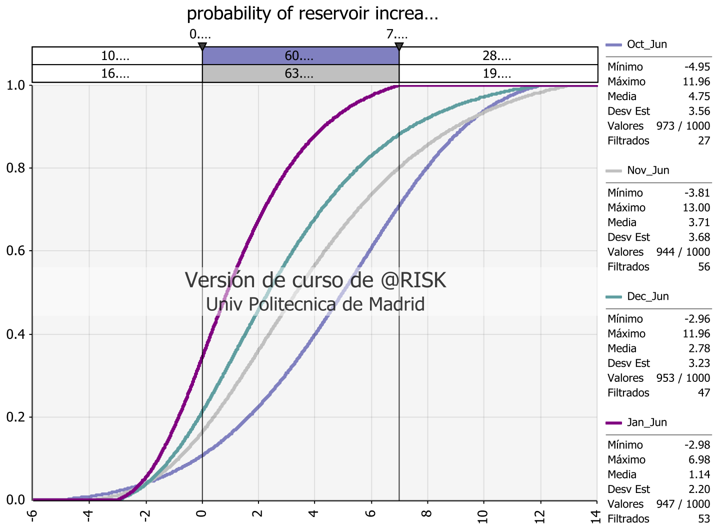
Table 10. Evolution of reservoir storage volumes in the Vadiello reservoir (2002-2007) in Mm3

	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007
October	3	7	7	1	4
November	3	13	6	2	5
December	6	13	5	3	7
January	11	13	5	4	8
Februray	13	12	4	4	8
March	14	13	3	5	9
April	14	15	3	8	10
May	14	15	2	9	15
June	14	15	2	8	15
July	12	12	2	6	14
August	10	11	1	5	13
September	8	8	1	4	11

Note: Yellow means pre-alert, orange alert and red emergency
Source: Own elaboration form MAGRAMA Hydrological Bulletins.

Using the data in Table 10 and equation 1, Figure 2 shows the likely increases in dam storage (V_{j-n}) between October and June 2005. The different curves illustrate how, as the months (and the meteorological drought) progressed, the probability of having lower or no increases in reservoir storage volumes gradually increased. For instance in October 2004 (light mauve line), when storage in Vadiello was 7 Mm^3, there was a 30% probability that reserves would only increase by 2.5 Mm^3 or less by June 2005. By January of 2005 (dark purple line), that probability exceeded 80%.

Figure 2. Evolution of probable increase in reservoir storage in Vadiello reservoir using historical storage data. (from Oct to June mauve line; Nov to June grey line; Dec to June green line, and Jan to June, purple ine).



Source: Own elaboration form MAGRAMA Hydrological Bulletins

It is worth noting that the risk analysis performed here is based on historical evolution of dam storage levels at Vadiello, and does not incorporate meteorological information directly. However, this relatively simple analysis already shows the high risk of

Huesca's water supply early in the year 2005. Delaying responses added a social cost that could have been avoided.

5. DISCUSSION AND CONCLUSIONS

Potential measures that hold promise for reducing losses from, and hence improving resilience to, drought and water scarcity are as diverse as the regions, sectors and levels to which they could be applied. Recommendations for such measures have been made in the various case studies and range from structural techniques such as the reuse of waste water for irrigation and the modification of the cooling systems of thermal power plants to non-structural approaches such as financial incentives for water saving and the development of drought emergency plans for urban areas.

In the Po case study the additional prevention measures that can be implemented to reduce vulnerability and resilience to droughts are fundamentally based on modification of existing measures to make them more efficient. For instance, the adoption of strategic management plans following the drought preparedness method, policies to increase water efficiency in building or smart metering devices could be considered.

In the Ebro river basin the newly proposed measures can be grouped into three categories: (a) economic instruments for drought management: including water markets, benchmarking, and insurance coverage for irrigated farms; (b) institutional measures, such as the important role played by CAP's single farm payment as a rent-stabilizing and risk-reducing instrument, inclusion of new agents in decision making processes, improved control of water uses, redefinition of water allocation priorities to reflect current social preferences, or risk-sharing instruments for hydroelectric companies; and, (c) operational measures, such as water quality and use efficiency improvements or binding contracts with recipients of public funds that require implementation of drought measures in order to improve their resilience to future droughts.

Currently, the transfer of scientific and traditional knowledge takes place primarily through international and national research projects. However, a significant improvement in the dialogue and knowledge exchange among experts of the various federal states in Germany could ultimately strengthen resilience to drought. This exchange is especially important for the various Chambers of Agriculture in Germany, and which is restricted by the federal system of governance.

The PREEMPT project has elaborated on a number of measures for which a quantitative assessment has been undertaken. Although the measures are basin specific, they can be useful in other river basins regardless of the frequency or intensity of drought events.

ACKNOWLEDGMENT

The research leading to these results has received funding from the European Commission DG Humanitarian Aid and Civil Protection, Grant Agreement no. 070401/2010/579119/SUB/C4, under the research project PREEMPT "Policy-relevant assessment of socio-economic effects of droughts and floods".

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