Transbounday Douro River Basin Needs Adaptive Management to Face Future Uncertainties of Water Scarcity and Drought

Manuel A.F. Araújo (a52780@alunos.uminho.pt), Rui M. S. Pereira (rmp@math.uminho.pt),
Gaspar J. Machado (gjm@math.uminho.pt), Naim Haie (naim@civil.uminho.pt)
University of Minho, Campus of Azurem, 4800-058 Guimarães Portugal

ABSTRACT

The Iberian Peninsula is very susceptible to climate change and various studies have predicted a simultaneous rise in temperature and fall in precipitation for this century. More than one billion USD was the damages of the 2004/2005 drought in Portugal, mostly because of short term emergency measures rather than long term adaptive management. This study, using genetic algorithms, was carried out at a region of the Sabor sub-basin of the trans-boundary river basin of Douro to better understand the impacts of such changes on its water resources system and agricultural production. Any intervention in Sabor is controversial because it is one of the few relatively pristine areas of Douro. The idea is to devise adaptive schemes for situations of drought and water scarcity that are less intrusive and are cost optimized. The study of the scenarios shows that by better management, the water productivity can increase with less water use.

Keywords: Adaptive management, Water scarcity and drought, Transboundary Douro river basin

1. INTRODUCTION

Adaptation is about change, hopefully a proper one, in response to varying conditions. The climate of Iberian Peninsula is changing. The Intergovernmental Panel on Climate Change (IPCCa 2007) wrote the famous statement that "Warming of the climate system is unequivocal". The IPCC report projected with high confidence that the conditions (drought and high temperatures) in the Southern Europe will worsen. It stated that this region that includes Portugal is already vulnerable and will experience a reduction in water availability, hydropower potential and crop yield and productivity.

The European Union (EU) Commission wrote a Green Paper to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions and mentioned that (EU Commission 2007): "… climate change [*is*] already happening, societies worldwide face the parallel challenge of having to adapt to its impacts as a certain degree of climate change is inevitable throughout this century and beyond, even if global mitigation efforts over the next decades prove successful." It wrote that "The most vulnerable areas in Europe are [*see Figure 1 and 2*]: Southern Europe and the entire Mediterranean Basin due to the combined effect of high temperature increases and reduced precipitation in areas already coping with water scarcity."

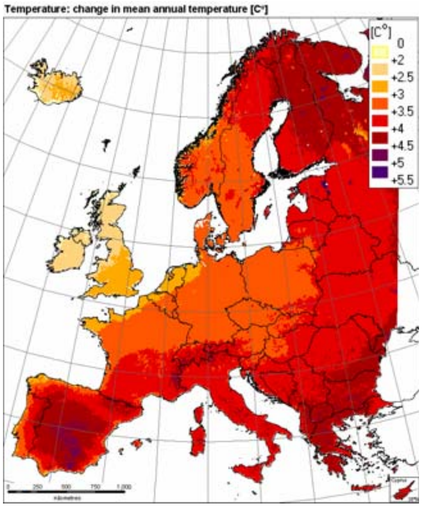

Figure 1: Change in mean annual temperature by the end of this century

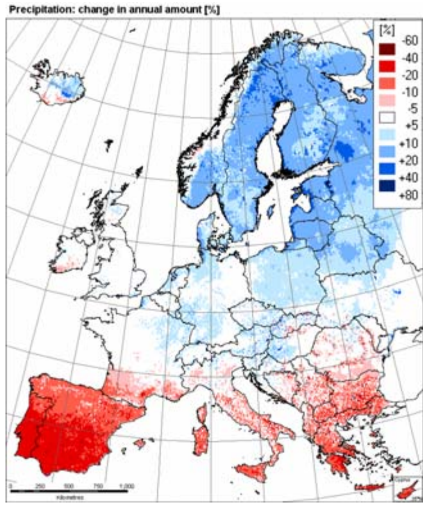

Figure 2: Change in mean annual precipitation by the end of this century

The evidence of such conditions have already struck Portugal when during the 2004-2005 hydrological year experienced one of its worst droughts in decades, with about a billion USD of damages (Oliveira 2006). In this hydrological year, records of low rainfall were experienced over the last 100 years in the majority of the places where records exist. By June to September of 2005, the whole territory was experiencing severe or extreme drought according to the Palmer Drought Severity Index-PDSI (RAR, 2005). In the first two weeks of the month of October 2005, the average water storage in the reservoirs of the Douro River Basin (DRB) was less than 50%, with a minimum of 6% at Sabugal (RAR, 2005). It should be noted that DRB, one of the Large River Systems of the world, is classified as Strongly Affected by dams and urbanised with large water and wastewater supply systems and equipments (UN, 2006). Irrigation is much dependent on these reservoirs. In broad terms, the basin can be divided in two zones in terms of water availability: West of the municipality of Vila Real and East of it. The first one has a 750 mm annual flow and the latter has a 260 mm (in Europe, only Spain has a drier zone) (MAOT, 2001). Precipitation and runoff patterns for the latter areas are shown in Figure 3.

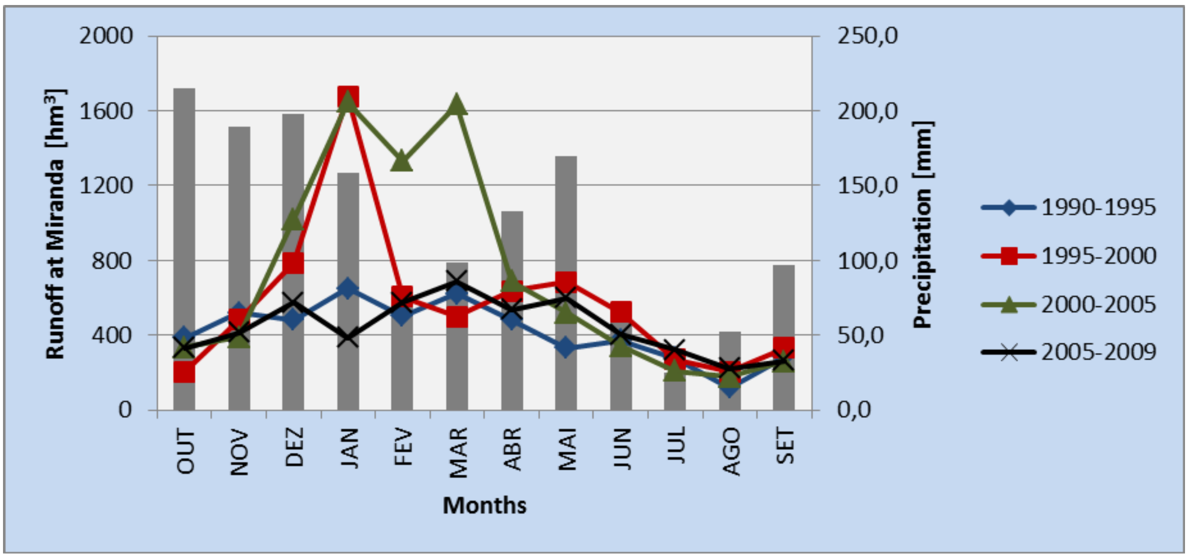

Figure 3: Evolution of the precipitation in the interior – Alfândega da Fé, Carviçais and Soutelo – as monthly averages (bar graph), and the average monthly runoff in Miranda (line graphs)

In this century, the temperatures in the DRB is expected to rise by 3-4.5ºC with an average of more than 3.5ºC (Figure 1), and the annual precipitation will reduce by 10-40% with an average of about 25% (Figure 2). This combination is one of the worst conditions for the hydrologic cycle, ecosystem in general, and human activities, such as irrigation (the biggest water user), and urban areas (the priority water user). Indeed the basin in its totality is vulnerable because of multiple stresses and drivers. Adaptation is one of the two key paths to reduce risks and increase resiliency.

In the Southern Europe (and also the Eastern Europe), increasing risk from Climate Change will be amplified by the increase in water withdrawals hence creating an extra driver. The regions with greater risk of drought are the Mediterranean countries (Portugal, Spain and others) where the highest increase in irrigation water demand is projected. Eurostat-AGR (2007) shows that the share of irrigable land over the total arable land varies a lot. For Greece we have a figure over 50%, 43% for Italy, 33% for Portugal and 23% for Spain.

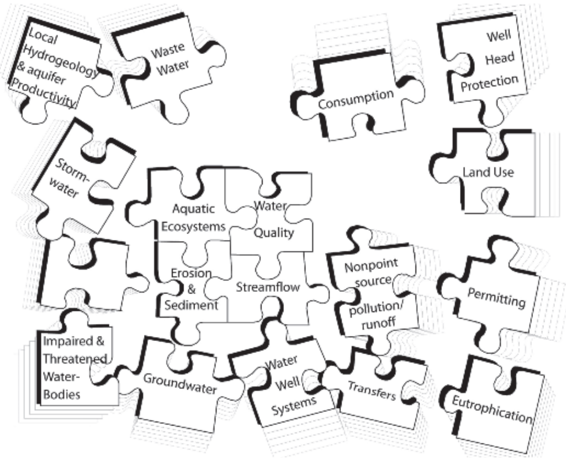

Figure 4: The water management puzzle

“Managing water resources is akin to solving a jigsaw puzzle that continually changes, so you never really get to finish it, frame it and put it on a wall.” (Najjar and Collier 2011) They illustrate this as Figure 4, which lacks other pieces but is a good start to show the complexities and the adaptations needed to “solve” a water resources management setting. In this paper we try to help the solving of this puzzle by constructing models that help us study possible scenarios that may improve water management for the Douro Transboundary basin.

2. STUDY AREA

Our study area is the DRB, an international river basin, shared between Portugal, the downstream country, and Spain (which calls it Duero). DRB is 897 km long (3rd longest in the Iberian Peninsula) and about 97.500 km2 drainage area (the largest there) and rises in Sierra de Urbión (2080 m) in central Spain and crosses the Numantian Plateau (INAGa, 2001; UNEP, 2008). It flows west across the North of Spain, then southwest to form part of the Spanish-Portuguese border before flowing west across the Northern part of Portugal to the Atlantic Ocean at Foz do Douro, Porto (Table 1 and Figure 5). One of the longest rivers of the Iberian Peninsula, it drains most of the northern portion of the central plateau. The basin has a pronounced mountainous character with an average elevation of about 700 m above sea level.

Table 1– Douro River Basin

	Portugal	**Spain**
Area, km2	18,500 (19%)	79,000 (81%)
Average natural runoff, km3/year	8.2 (35%)	15.0 (65%)
Liters/m2/year	443	190
Population	1,730,000	2,270,000
Volume/Person, m3/capita	4,740	6,608

To study the basin, a number of important sub-basins are identified, one of them explained in this paper. One of the pristine sub-basins of the DRB is called Sabor, which has a region called Azibo river, with an agricultural zone named “Aproveitamento Hidroagrícola de Macedo de Cavaleiros” (AHMC). The reason for our choice was twofold: first we wanted to study the Portuguese part of the DRB (particularly the part closer to the border, i.e., the 2nd zone of the Portuguese DRB as explained above), and, on the other hand we needed to have some available data that allowed us to build a mathematical model that we could test. Most of the data obtained for Azibo sub river basin was taken from the National Water Resources database and the monitoring


Figure 5: Douro River Basin shared between Portugal (left) and Spain (CHD 2008)

points (SNIRH, www.snirh.pt).

The study area is composed of 3 main blocks: Macedo de Cavaleiros, Salselas and Cortiços (Figure 6). This region has about 5300 hectares of cultivated area that benefits from the water of the Azibo dam. This region is characterized by very dry and hot summers, and, water shortage is a reality.

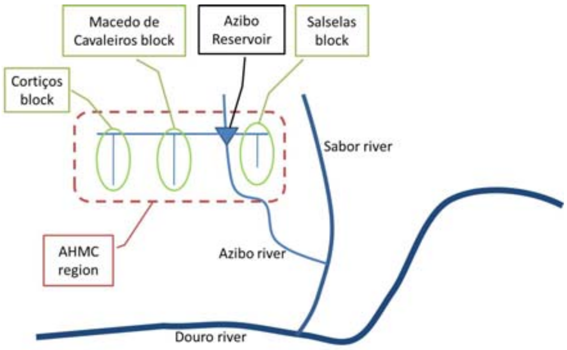

Figure 6: Schematization of the Azibo region

In the Macedo de Cavaleiros Block, there are 35.8% forage and horticulture represents 31.8% of the total irrigated area. In Salselas Block, 27.9% is grass,horticulture and corn with 25.2% of the area each. In the Cortiços Block, there are 35.0% olives and horticulture, 24.7%. From the various products produced in the region, two of them were selected for the purpose of our optimization: corn and olives. Furthermore, only six pipelines could be part of the study, because volumetric measuring devices are needed in order to have the amount of water used in each canal. These are: the conduit of the Salselas Block, the conduits C1 and C2 of the Macedo de Cavaleiros Block, and the conduits C8, C9 and C10 of the Cortiços Block. The study area has 5 parcels of corn and 6 parcels of olives. Partial historical productivity data for the two crops are given in Table 2 and Table 3, taken from the National Statistics Institute (www.ine.pt).

Table 2: Parcelar productivity of crops

	PRODUCTION [kg]					
	CORN			OLIVE TREES		
Conduit	2005	2006	2007	2005	2006	2007
Sal1	43093	42682	48418	648	1406	400
MCB1	16654	5689	4019	678	1263	520
MCB2	10558	3426	0	894	3602	1312
CB8	6067	3489	9131	1072	1421	464
CB9	4550	2829	5626	2413	1392	576
CB10	4104	11252	900	18519	41472	16456

Table 3: Productivity of olives in the Northern Portugal

Data reference period	Geographical location (NUTS - 2002): North		
	Productivity of major crops (kg/ ha) by Geographical location (NUTS - 2002) and Agricultural species		
	Agricultural species		
	Olive trees	Table olives	Olives for oil
2008	1282	1016	1299
2007	800	770	802
2006	1435	1199	1450

2005	771	773	770
2004	1074	1231	1064
2003	1003	1284	985
2002	979	1424	950
2001	1113	1697	1075
2000	577	601	576
1999	1225	1141	1230
1998	789	735	792
1997	1233	1106	1241
1996	1085	1119	1083
1995	1154	1118	1156
1994	714	1001	696
1993	1114	779	1134
1992	473	1827	385
1991	1903	2643	1850
1990	652	2481	524
1989	1121	2515	1024
1988	538	2426	410
1987	1200	2456	1119
1986	1463	2777	1380

3. BRIEF METHODOLOGY

One of the most difficult tasks was to obtain the necessary data, even though we chose one of the better zones as far as data availability is concerned. Some of it was not available or was scarce, and had to be obtained in an indirect way. The objective function was defined as the sum of all the benefits obtained from the considered parcel/conduit pairs for corn and olives, and using their prices per *Kg*. In order to be able to model the benefits of the use of water by a certain crop associated with a certain conduit, we used a regression analysis. For the study to be complete the coefficients of each regression equation used still need to be tested. On the other hand, to define the restrictions to our model, we imposed a maximum and minimum amount of water for each conduit, and a maximum and minimum amount of water for the sum of water used by all the conduits. The maximum amount of water in all the conduits was employed in our simulations to create different scenarios: abundance of water (scenario I), scarcity of water (scenario II), and actual situation (scenario III). Genetic Algorithm toolbox of MatLab via *ga* function was used in these simulations. For more information about the methodology and the results, the interested reader should consult Araújo (2010). The process of optimization used was based on Genetic Algorithms which are free derivative methods that allow for both non linearity of the objective function and constraints, and also allow for the search of a global minimum or maximum. We used MatLab to implement the numerical procedure.

4. PRELIMINARY RESULTS AND MEASURES

As mentioned above, three scenarios are analysed in this study. They are based on the total water used by the region. Scenario I: maximum value of total water usage of 3200 m3/ha (Abundance); Scenario II: maximum value of total water usage 2000 m3/ha (Scarcity, taken using the provisions of Figure 1 and Figure 2); Scenario III: maximum value of total water usage 2450 m3/ha (Actual); and the results are given in Table 4.

Table 4: The results of the three scenarios

	Without Optimization: (current values)	**Optimization: Scenario (I)**	**Optimization: Scenario (II)**	**Optimization: Scenario (III)**
Water [m3] corn	92451	39902	49064	40337
Water [m3] olive	37283	129378	56736	89268

Total water [m3]	**129735**	**169279**	**105800**	**129605**
Production [kg] corn	74162	10756	22307	13583
Production [kg] olive	31503	144037	77658	103449
Total production [kg]	105665	154793	99965	117032
TOTAL BENEFIT [€]	**35309**	**95775**	**54939**	**70959**

This shows that the productivity of the current system can be drastically increased by 100%, by just making a better management and adaptation of land, water and crops. However, this gain will be reduced by about 30% in the Scarcity Scenario, but still higher than the current mis-managed conditions. If these adaptations are not done, the total benefits will be reduced by at least 40%.

The Portuguese Government adopted a series of adaptation measures, one of them being a ten year National Program for Efficient Use of Water-PNUEA (PCM, 2005). It states that agriculture accounts for 87% of the total demand of water, urban demand for 8% of the total and the rest goes to the industry, as shown in Figure 7. However, if we take into account the effective costs of the water use, we verify that the urban sector becomes the most relevant Figure 8.

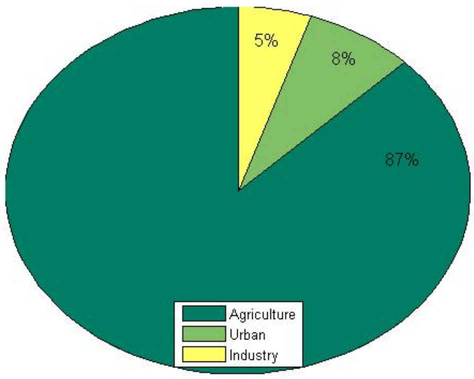

Figure 7- Percentage of total water demand by sector per year

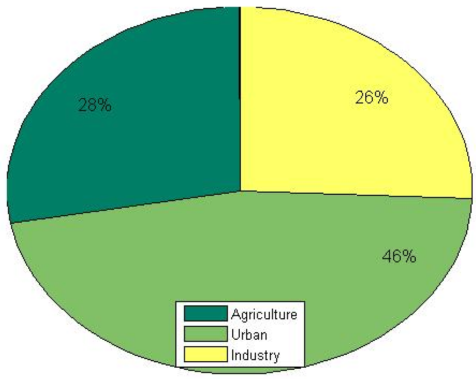

Figure 8- Percentage of cost of water per sector per year

In PNUEA four areas of intervention and adaptation were proposed to achieve the increases needed in efficiency, all of great importance for the area under study for this paper. They are:

- Measurement and conversion of equipments of water use,
- Information and education and public awareness,
- Legislation and normalisation, and
- Training and technical help.

In order to achieve these results in the Agricultural Sector, a series of adaptive measures are being considered (INAGb, 2001):

1) General measures, applicable in all types of irrigation used, either in new projects or conversion of old systems. This is included in a group of measures to take in situations of scarcity of water. Some of these measures are:
   a) Improvement of the quality of projects.
   b) Adaptation of the irrigation techniques used.
   c) Irrigation warning systems.
   d) Adequate pricing of water.
   e) Reduction of irrigation volumes of water in scarcity situations.
   f) Reduction of the irrigated area in severe scarcity situations.
2) Measures related with the transportation and distribution systems:
   a) Management optimization of the reservoirs.
   b) Reduction of losses in the transportation system.
   c) Management procedures to adjust demand / consumption.
   d) Improvement of the transport and distribution network.
3) Measures related to gravity irrigation:

    a) Conversion of the processes of furnishing furrows and borders with water
    b) Improvement of gravity irrigation subsystem.
    c) Management improvement of gravity irrigation.
4) Measures related to sprinkler irrigation
    a) Adaptation of the procedures in sprinkler irrigation: installation of natural / artificial cut-winds, surface water flow control and irrigation during the night.
    b) Substitution of sprinkler irrigation systems in windy regions.
    c) Suitability of using Cannon sprinkler systems.
    d) Substitution of mobile sprinkler irrigation equipments.
5) Measures related with drip irrigation
    a) Adaptation of procedures for drip irrigation
    b) Substitution of equipment taking into account the soil texture.

5. CONCLUSIONS

The 2007 report of IPCC projected with high confidence that the conditions (drought and high temperatures) in Portugal and Spain will worsen to the detriment of water availability, hydropower potential and crop yield and productivity. The 2004-2005 drought was the worst in decades with various months experiencing sever to extreme drought according to PDSI index. "[W]ater is driving the interest in climate adaptation in the West" (Iseman and Willardson 2011), and not higher temperatures. As water scarcity becomes a dominating issue in political decision making processes, water drives the interests not only in the Western United States, but all over the world including the Iberian Peninsula.

Portugal is now equipped with a new Water Law (AR 2005; transposition of the EU Water Framework Directive) and a new ten year National Program for Efficient Use of Water-PNUEA. Having in mind that adaptation is our response to the changing conditions; this paper shows the importance and the need to adapt now. But some level of integration is crucial if adaptation is to work properly, however, the record of ´adaptive management´ is somewhat spotty" (Iseman and Willardson 2011), and integration is a work in progress and puzzle (Figure 4). However, the studies made in the DRB, including the one briefly explained in this paper, showed that without adaptation, the costs are much higher as time passes by, which is a known conclusion, for example: "The earlier effective action is taken, the less costly it will be." (Stern 2006). Some adaptive measures are enumerated for the DRB. Note however that our model only treats benefits and does not take into account the costs of production. This will be the basis of our future work, together with the study of the regression equations.

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