A contribution to the study of climate change and urban water cycle adaptation

EPAL Technical Editions

EPAL
Grupo Águas de Portugal

A contribution to the study of climate change and urban water cycle adaptation

EPAL Technical Editions

EPAL
Grupo Águas de Portugal

Edition: EPAL, Empresa Portuguesa das Águas Livres S.A.

Editors: Ana Margarida Luís and Maria João Cruz

TEAMS:

Scientific coordination: Filipe Duarte Santos and Maria João Cruz (CCIAM, FCUL)

EPAL coordination: Ana Luís, Basílio Martins, Vanessa Martins, Paula Aprisco, Alexandre Rodrigues, Lília Azevedo (Group for Climate Change - GAC, EPAL) and Francisco Serranito, Maria João Benoliel, José Figueira, Mário Maria (Project Monitoring Committee)

Socioeconomic scenarios: Rita Jacinto and Maria João Cruz (CCIAM, FCUL)

Climate scenarios: Mário Pulquério (CCIAM, FCUL)

Surface water resources: João Pedro Nunes, Jingxian Tao, José António Rodríguez-Suárez e María Ermitas Rial-Rivas (CESAM, UA), Paulo Diogo, Carmona Rodrigues and Pedro Duarte Colaço (FCT)

Underground water resources: Luís Ribeiro, João Nascimento, João Barradas and Joana Oliveira (IST, UTL)

Climate vulnerability: Nuno Grosso and Maria João Cruz (CCIAM, FCUL)

Adaptation: Tiago Capela Lourenço, David Avelar, Rita Jacinto and Nuno Grosso (CCIAM, FCUL)

BODIES PARTICIPATING:

EPAL – Empresa Portuguesa das Águas Livres, SA

CCIAM, FCUL – Climate Change Impacts, Adaptation and Modelling research group, Faculdade de Ciências da Universidade de Lisboa (Lisbon University Faculty of Sciences)

CESAM - Centro de Estudos do Ambiente e do Mar, Universidade de Aveiro (University of Aveiro Centre for Environment and Sea Studies)

IST, UTL – Instituto Superior Técnico, Universidade Técnica de Lisboa (Lisbon Technical University, Higher Technical School)

DCEA, FCT - Departamento de Ciências e Engenharia do Ambiente, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa (Nova University, Faculty of Science and Technology, Science and Environmental Engineering Department)

Art Direction / Graphic design: António Carvalho (GIC/EPAL)

Photos: Nuno Farinha, Luís Carvalho (p.38), Fabrice Ziegler, Abílio Leitão, Vera Marmelo, João Morgado (pp.50-51)

Printing: GRAFICOISAS - Indústria Gráfica Lda.
1000 copies

Legal deposit: 380165/14

ISBN 978-989-8620-05-7

1st edition September 2014

How to reference: Luís, A.M. and Cruz, M.J. (eds.) 2014. A contribution to the study of climate change and urban water cycle adaptation. EPAL, Empresa Portuguesa das Águas Livres S.A., Lisbon. 49pp. ISBN 978-989-8620-05-7

contents

Foreword

EPAL is the oldest and largest water utility in Portugal, assuming a relevant and reference position, due to its recognized innovative and of excellent quality public service provided to a large proportion of the Portuguese population.

Currently, the challenges posed to the water sector in Portugal encourage an increasing focus on efficiency gains, not only as the basis for the economic rationale of our management, but in this case exacerbated by the social responsibility arising from an activity with an intrinsic connection and dependency from natural resources, thus promoting the defense of environmental values and inter-regional and inter-generational solidarity, as well.

In recent years EPAL has outstood in the international benchmark of efficient management of water resources, namely in terms of water losses reduction. The pursuit of a policy of this nature is strengthened when supported in strategic risk assessments, which presupposes knowledge of the main threats posed to the system in the medium and long term, as it is the case of the impacts posed by climate change. In fact, the way EPAL has been planning structural matters such as investments in assets, has set up a system with considerable resilience and quality of service guarantee, which ought to be preserved in the future.

Therefore, EPAL decided to look for the best achievements in science about this subject in the Portuguese academia, promoting Adaptaclima-EPAL project and creating the conditions for knowledge internalization within the company. Thus, the results of the study will be reflected in the planning processes in the company, placing the dimension "climate change" among other relevant ones, aiming at improving the system and ensuring business continuity.

Despite the positive findings revealed by the study in terms of the projected impacts of climate change on EPAL water sources, the most important fact to point out is the opportunity that has been created to critically think about the system, assessing vulnerabilities and improvements to be made. Moreover, the need for a new methodology for monitoring climate change has aroused, as a support to decision-making on the phased implementation of the adaptation plan.

Therefore, EPAL will keep on pursuing its mission, creating value in a sustainable way and at the forefront of the water sector positioning as a player of maximum relevance on the national strategy for adaptation to climate change.

José Sardinha

Chairman of the Board of Directors

1. Background

Authors: Basílio Martins, Paula Aprisco, Alexandre Rodrigues, Vanessa Martins, Lília Azevedo, Ana Luís and Filipe Duarte Santos

1.1 EPAL history and system

EPAL - Empresa Portuguesa das Águas Livres, S.A is the oldest and largest water supply company in Portugal. It is the successor of the centuries-old "Companhia das Águas de Lisboa, SARL", which supplied water to Lisbon from 1868 up to 1974.

On 30 October 1974 the concession agreement between the Portuguese State and Companhia das Águas de Lisboa ended its term and EPAL - Empresa Pública das Águas de Lisboa, EP. was set up through Decree-Law no. 553-A/74. The transitory regime for managing the public water supply service was defined at that time and the company by-laws were only approved in 1981 by Decree-law no. 190/81 of 04 July.

A decade later the Public Enterprise was converted into a Limited Liability company with exclusively state capital through Decree-Law no. 230/91 of 21 June taking on the name EPAL - Empresa Portuguesa das Águas Livres, S.A., and its by-laws were updated. In 1993 EPAL was included in AdP - Águas de Portugal, SGPS, S.A., and became fully incorporated by this Group.

The raison d'être of this company, which is over 145 years old, lies in the social commitment to supply its customers with drinking water in a sustained and sustainable manner, fully abiding by the standards of quality, complying with the legislation in force and maintaining the highest levels of service with regard to its reliability.

EPAL's business has a cycle of operations from the catchment of water at the source, its treatment and transport up to the point of delivery to the multi-municipal systems, municipalities and, in Lisbon municipality, to its end consumers.

In wholesale, EPAL supplies three multi-municipal clients (Águas do Oeste, Águas do Centro and Águas do Ribatejo) and 17 municipal customers. In retail, it ensures the distribution of water in the Lisbon municipality, covering about 350,000 customers. As such, EPAL's supply system (Figure 1) covers overall 35 municipalities and a population of around 2.9 million people, supplying an average daily amount of approximately 600,000 m^3 of water.

EPAL is responsible for a supply system that has more than 2,100 km of pipes, from catchment up to the city of Lisbon and neighbouring councils. The maximum production is 1,110,000 m^3/day.

This system collects water from two surface sources – the Castelo do Bode reservoir and the right bank of the Tagus River in Valada – and from around 20 underground sources located in Alenquer, Lezírias and Ota. In emergency situations EPAL can use the spring in Olhos de Água and underground sources in Valada.

EPAL has two Water Treatment Plants (WTP) for treating the water collected: the WTP of Asseiceira, located in the council of Tomar and which treats the water collected at the Castelo do Bode reservoir; and the Vale da Pedra WTP, which is located in the council of Azambuja and treats the water collected from the Tagus.

Currently the water collected underground is treated by disinfection using chlorine. In the Alenquer boreholes there is also a decarbonation station.

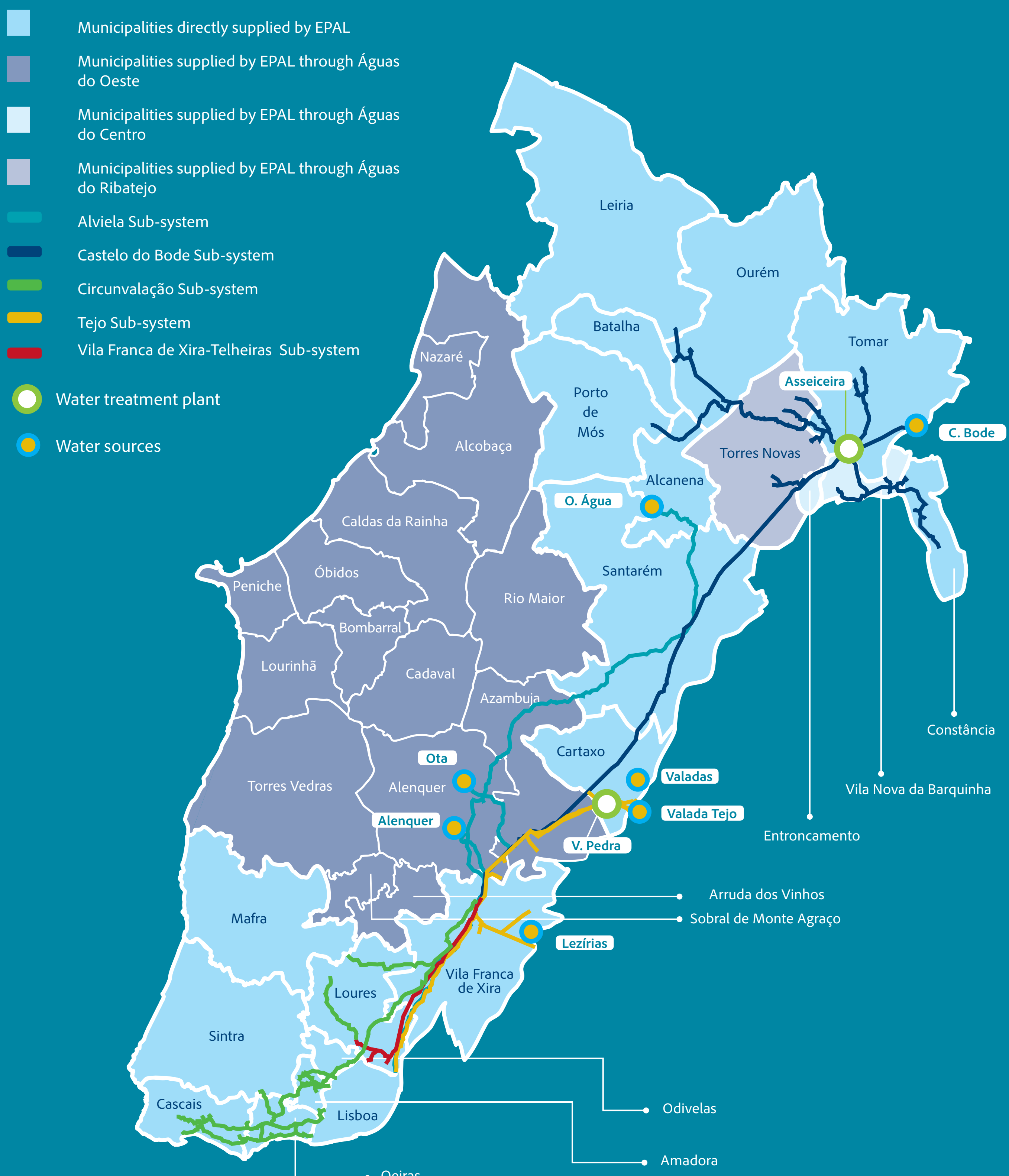


Figure 1 EPAL Water Supply System

EPAL's system has 26 chlorination stations (located next to the underground sources and throughout the distribution networks), as well as 41 pumping stations and 42 water tanks.

The above mentioned infrastructures account for the most significant part of the company's capital at an amount of approximately 740 million euros.

1.2 The challenges faced by EPAL due to climate change

There is currently ample scientific consensus that the climate change brought on by the increase in the anthropogenic greenhouse gases will worsen during the 21st century (IPCC, 2007). One of the sectors that is most vulnerable to climate change in southern European countries is that of water resources (EEA, 2012).

Over the last 40 years, this region has already witnessed a slight trend of decreasing average annual precipitation and a clearer trend of an increase in the variability of precipitation accumulated in the winter time, with greater frequency of both much dryer winters and much wetter winters (SIAM, 2006). The projections up to the end of the century, obtained using various available global climate models agree that there is an intensifying of the abovementioned trends (SIAM, 2006; Pulquério *et al.*, 2014).

EPAL's position and its importance in providing an essential service to practically a third of the Portuguese population lead the company to take into account all the factors that in time may jeopardise the fulfilment of its mission; climate change is one such factor. This matter cannot be ignored by any company or organisation that needs to project its operations into the future, bearing in mind all the variables that could affect its capability to perform a fundamental service, such as the supply of drinking water.

Society's approach to the problem of climate change is done in two ways: mitigation, aiming at reducing the greenhouse gas emissions, in order to slow down global warming; and adaptation, preparing society's structures in order to resist the impacts of the changes that are expected to occur by the end of this century. This is done from a point of view of risk reduction, yet also by making the structures more resilient, that is, with a greater capacity to recover following the occurrence of an anomaly that may affect its normal functioning (IPCC, 2007; 2014).

1.3 The Adaptaclima-EPAL Project

The Adaptaclima-EPAL project is included in a strategy that aims to reduce the company's vulnerabilities in the medium- and long-term. It falls under the adaptation side, and its goals have been to assess the potential impact of climate change on EPAL's system, as well as identifying the necessary adaptation measures.

The study began on 30 September 2010 and lasted 30 months. It was developed by a multi-disciplinary team from several universities, coordinated by Prof. Filipe Duarte Santos from the Faculdade de Ciências de Lisboa (Lisbon Faculty of Science). The project's development was monitored by EPAL's Grupo das Alterações Climáticas (Group for Climate Change - GAC).

The study area covered not only EPAL's catchment area, but practically the whole of the Tagus River's basin in Portugal, taking into account the location of the EPAL system's water sources. The river basins of the Zêzere upstream of

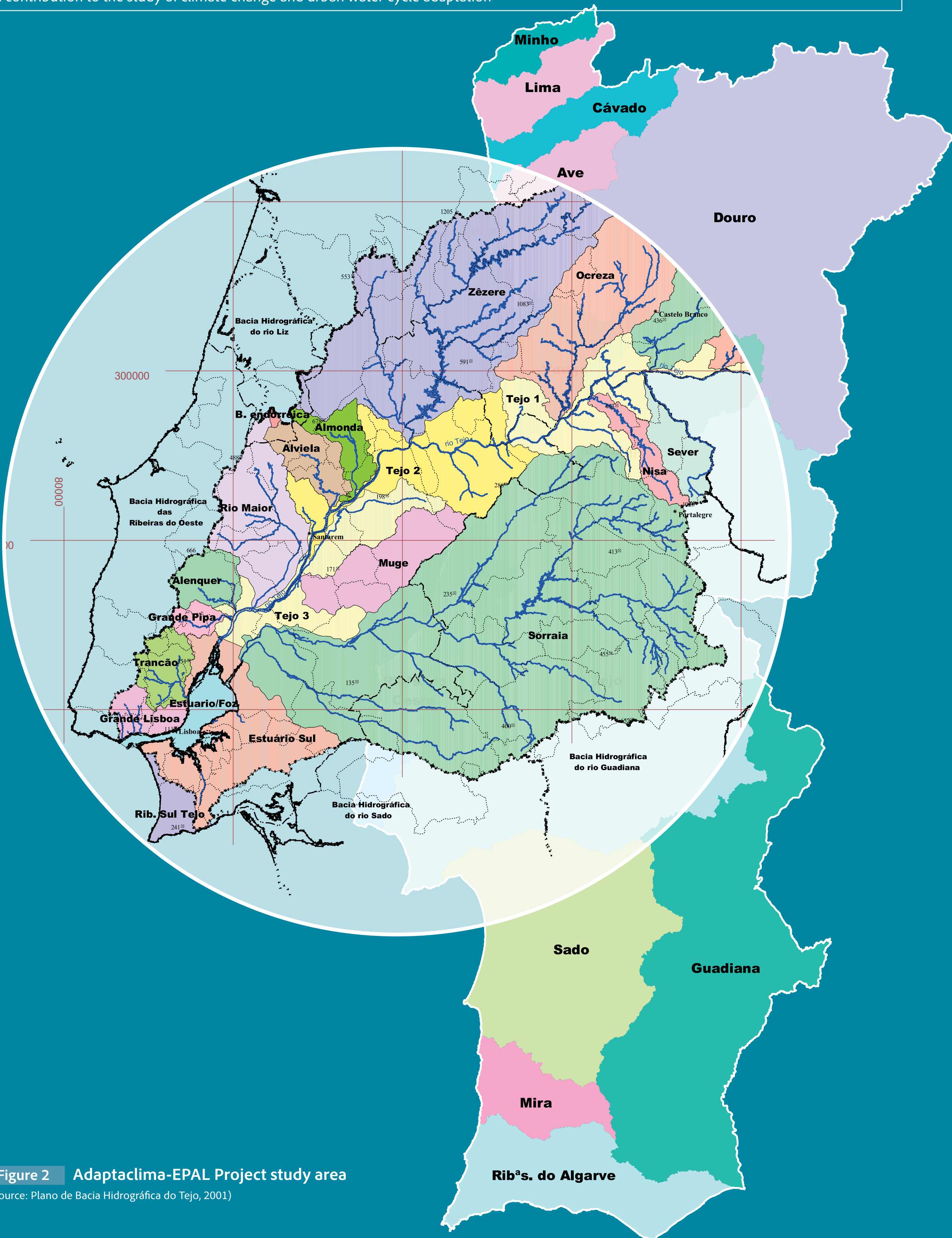


Figure 2 Adaptaclima-EPAL Project study area

(source: Plano de Bacia Hidrográfica do Tejo, 2001) the Castelo do Bode reservoir, and the Tagus upstream of the Valada source were given particular emphasis, as well as the Tagus - Sado and Ota – Alenquer aquifers (Figure 2).

In terms of methodology, the project consisted of seven tasks, split into four main areas: climate scenarios, socioeconomic scenarios, assessment of impacts and vulnerabilities and, lastly, adaptation measures (Figure 3).

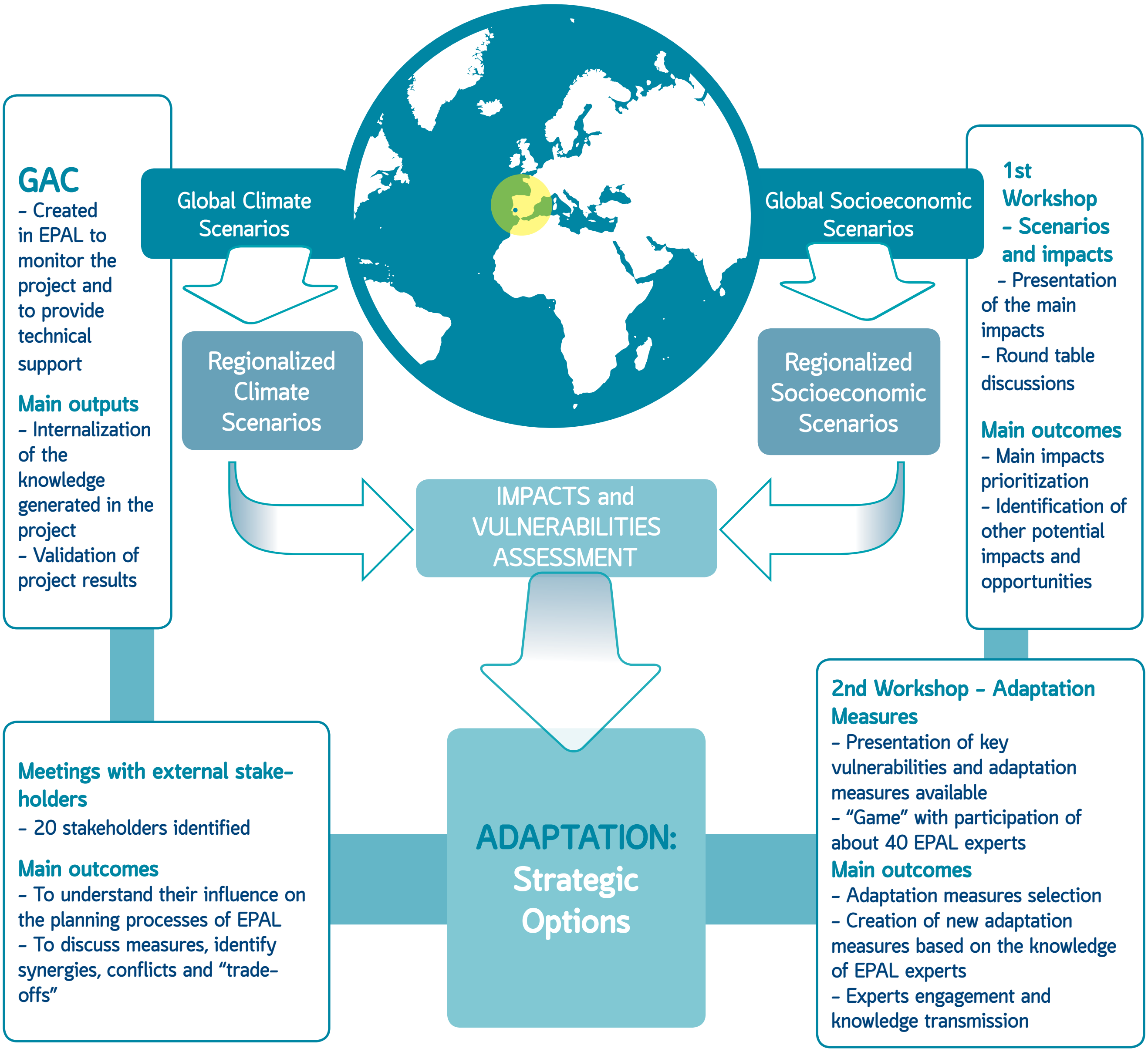


Figure 3 **Global methodology of the Adaptaclima-EPAL project**

This project is an example of how companies in the sector can innovate, integrating into their management the know-how acquired by academia to solve specific and concrete problems. With the team that had already developed the only inter-sector project on the subject in Portugal – the SIAM project (SIAM, 2002; 2006), which made Portugal one of the first countries in the world to apply the analysis methods that had already been developed on a global scale by the International Panel on Climate Change (IPCC) – EPAL was likewise pioneer in studying the subject, applied to the water sector and covering an area that accounts for practically 1/3 of national territory.

The challenge of mitigating anthropogenic climate change and overcoming its impacts successfully is intimately tied with the issues of sustainable development that society and future generations are faced with, focusing on the values of inter-regional and inter-generational solidarity (Santos, 2012). These challenges, especially when dealt with at the level of public policy, yet also at the level of the scope of action of a company with the scale and features of EPAL, require a systemic and multi-disciplinary approach. This is due to the many fields of scientific knowledge that are mobi-

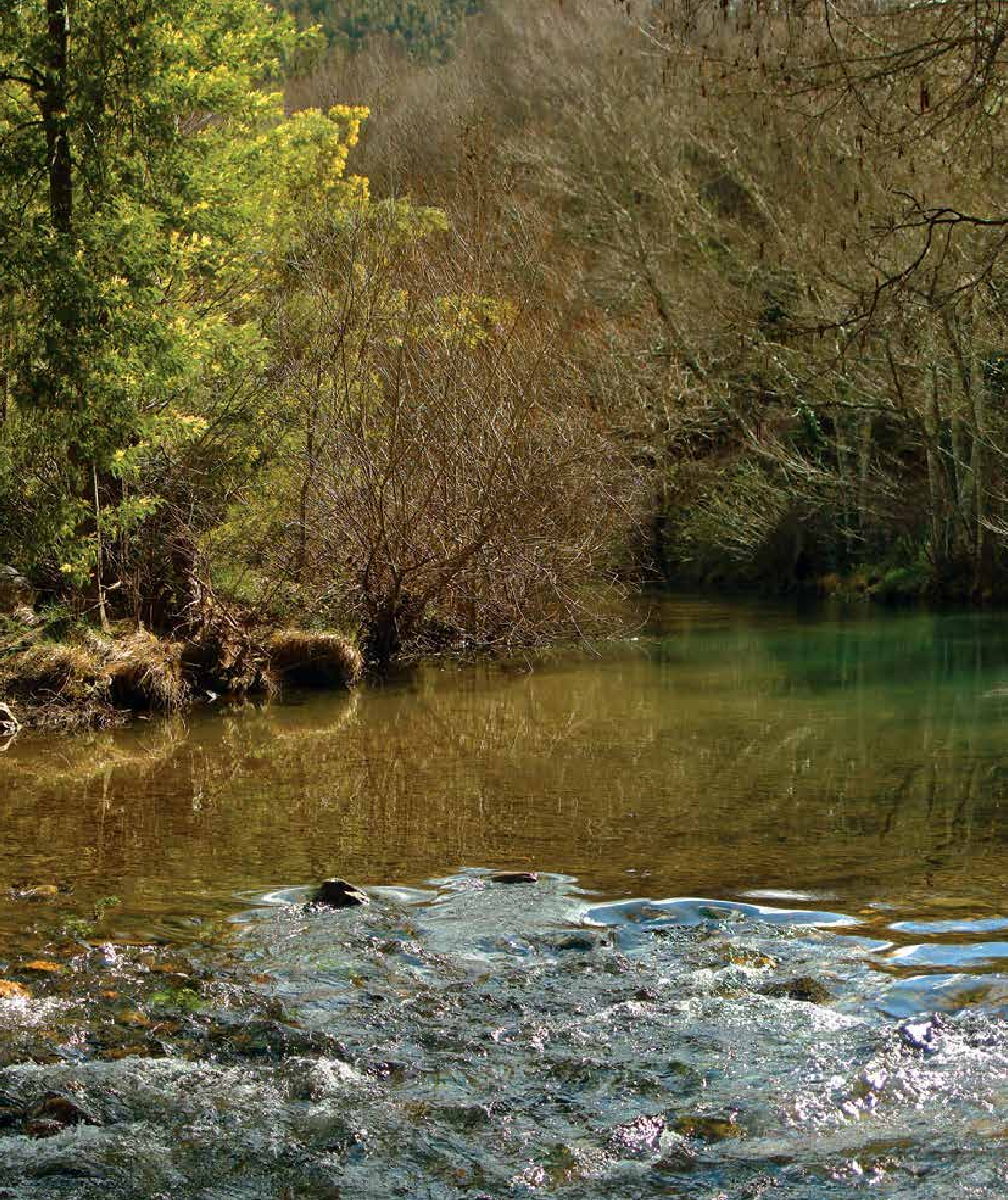
lised, ranging from the physical sciences of earth, oceans and atmosphere to the social sciences, and the fact that the answers must be found within the dynamic of the social and institutional relations at a local, national and global scale.

The creation of a team composed of experts from several of EPAL's departments – the GAC, for monitoring the Adaptaclima-EPAL project enabled the company to retain in-house the know-how acquired with this study.

Furthermore, the critical sense and knowledge of EPAL held by the GAC members led to a greater application of the conclusions found to the company's reality: besides supplying all the internal data and the information for the models, on several occasions the opinions of EPAL team helped to improve the perspective of the problems, to define the context, and to improve the reasoning behind choosing the different options.

The problem of climate change cuts across the broad as it affects in a more or less negative way the various structures of society and the economy. This also applies when seeking adaptation solutions, leading to stakeholders from various sectors and in different types of relations with EPAL being involved. In many cases this involvement stems from legal reporting duties, as with the health authority and the water sector regulator.

There were meetings held with a set of stakeholders during the project to let them know about the study's development and also, more importantly, to prepare the context for future collaboration in the coordinated implementation of adaptation measures that could ensure the availability of drinking water with acceptable quality in scenarios of climate change.



2. Main expected climate and socioeconomic changes

Authors: Mário Pulquério, Rita Jacinto and Maria João Cruz

2.1 Introduction

The earth's climate results from the interaction of many processes occurring in the atmosphere, oceans, land surface and the cryosphere. These processes are simulated in global atmospheric circulation models. There is currently a considerable amount of such models (for instance, HadCM3, CGCM2, CSIRO-MK2, ECHAM4) which are used to understand climate evolution.

Climate scenarios obtained from these models are used in order to explore potential climate change impacts. These require quantitative projections of the evolution of global greenhouse gas emissions.

The Intergovernmental Panel on Climate Change (IPCC) constructed four future scenarios (A1, A2, B1 and B2 - Figure 4) that are organised into two fundamental axes: type of governance – regional versus global – and the prevailing values – economic versus environmental. These scenarios are not forecasts or projections, rather trends of a demographic, social, economic and technological nature, that create internally coherent descriptions of possible futures. These scenarios of socioeconomic evolution (stories of the future) enable obtaining quantitative projections of the development of greenhouse gas emissions. They also enable exploring possible changes in several factors such as population, land use or water consumption, which have direct or indirect consequences on water resources.

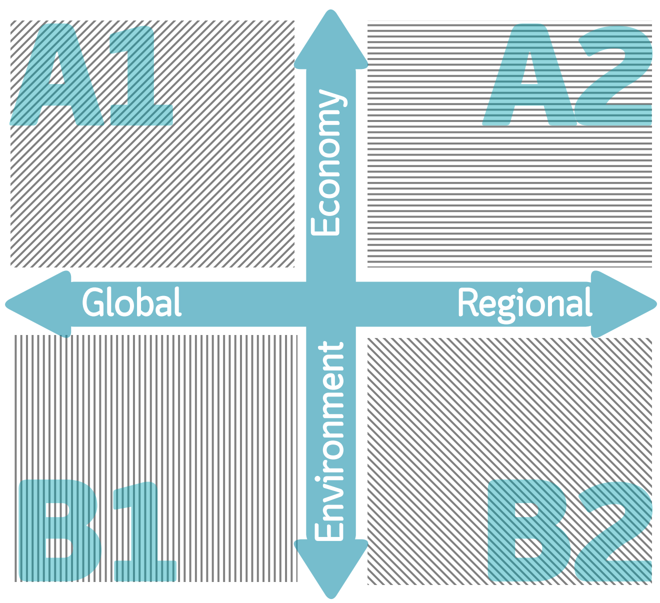


Figure 4 **IPCC Scenario building: SRES scenarios, dominated by the type of governance (horizontal axis) and predominant values (vertical axis) (source: IPCC, 2007)**

2.2 Climate scenarios

The Global Circulation Model (GCM) used in this project was the HadCM3, developed by the University of East Anglia Hadley Centre (Collins *et al.*, 2006). This model uses a grid of approximately 416 km x 277 km for the planet, which corresponds to 96 x 73 quads. This scale makes a direct use of the GCMs in Adaptaclima-EPAL insufficient, since practically the whole study area would fit into a single quad. Accordingly, it was necessary to downscale the global model to obtain a scale with a higher resolution.

For this project statistic downscaling (Wilby *et al.*, 2004) was used. The precipitation, maximum temperature and minimum temperature variables were regionalised for the IPCC A2 and B2 scenarios. The validation of the models obtained indicated a good adjustment of the models to the data observed. Below are the main results obtained. More detailed information on the methods and results can be accessed at http://siam.fc.ul.pt/adaptaclima-epal/.

Precipitation

The GLIMCLIM programme (Chandler, 2010) was used for precipitation downscaling, which has a generalised linear model implemented (Pulquério *et al.*, 2014). After calibration and validation of the model, the results of the projections for precipitation up to the end of the 21st century point towards a decrease of 28% for scenario A2 and 16% for scenario B2 (Table 1) in relation to the reference period of 1960-1999.

	Mean annual average		Anomaly (mm)		Anomaly (%)	
Period	A2	B2	A2	B2	A2	B2
2010-2039	686,9	693,2	-111,9	-104,6	-13,9	-13,9
2040-2069	653,8	666,6	-144,7	-131,2	-18,4	-16,5
2070-2099	572,8	668,1	-225,4	-129,7	-28,5	-16,3

Table 1 **Anomaly in precipitation for 30-year periods compared to the reference period of 1961 to 1990.**

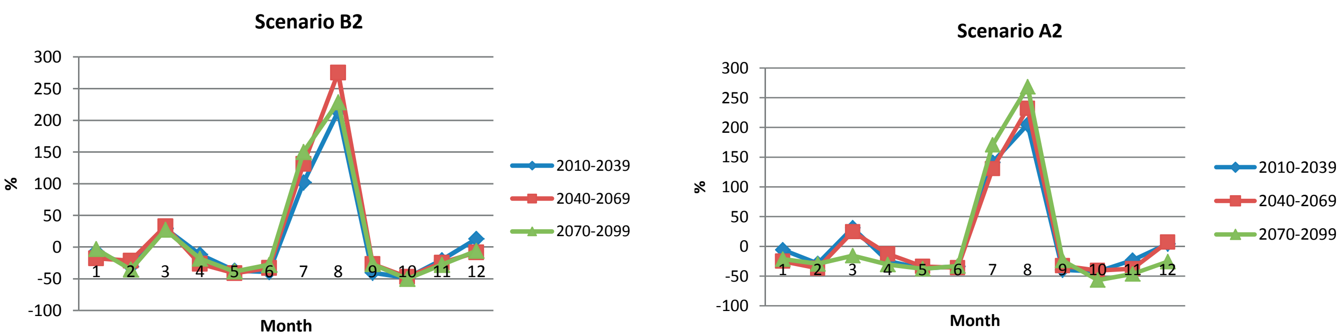


Figure 5 **Anomaly (%) in precipitation for the different months in 30-year periods**

With regard to the precipitation in the different months of the year, both scenarios point towards an increase in precipitation from 200% to 275% in the months of July and August (Figure 5). However, one must consider that the model overestimates precipitation for the summer months. Yet, even taking into account this overestimation, it is possible to observe that in both scenarios forecast precipitation is higher in these two months than that found for the validation period. In scenario B2 there will also be an increase in March, while in scenario A2 this increase in March will only be felt from 2010 to 2069, and there will be a decrease in the last 30 years of this century.

The autumn months will be the ones with the greatest decrease in precipitation, both in scenario A2 and B2, and the decrease can be greater than 50% when compared to the reference period. In sum, there will be an anticipation and extension of the dry season for spring and autumn, respectively.

Maximum and Minimum Temperature

Linear regressions were used for downscaling minimum and maximum temperature, using the ASD (Automated Statistical Downscaling) programme. The projections for minimum and maximum temperature point towards an increase for the end of the century of about 3°C for scenario A2 and 2°C for scenario B2 (Figure 6). Minimum and maximum temperature will increase continuously throughout the century and the average values will no longer be below the values for the reference period (1961-1990) from the mid-century onwards, in both scenarios.

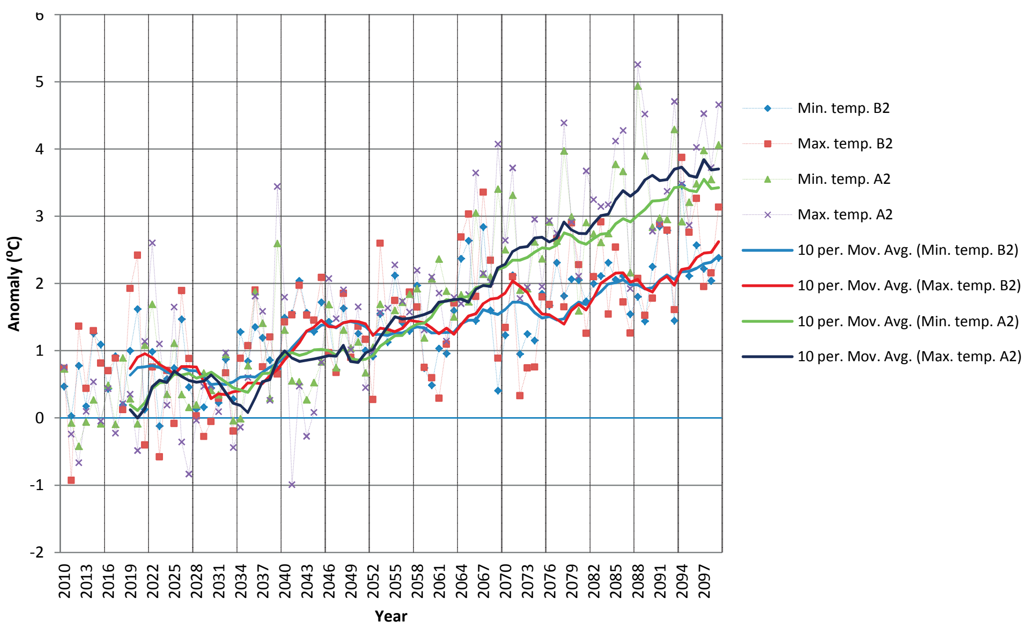


Figure 6 Anomaly (°C) and 10 years moving average of the maximum and minimum temperature up to the end of the century for the A2 and B2 scenarios.

As for the evolution of the temperature over the different months, an increase in minimum and maximum temperature is expected for all months; this increase will be greater for maximum temperature in May, June and October in both scenarios. This increase could be greater than 6°C for May in scenario A2, for the last 30 years period. The increase in minimum temperature is more homogeneous in all months but will follow the same general trend as that of maximum temperature.

These results indicate that at the end of the century the maximum and minimum temperatures may be closer during the spring to autumn months, thereby extending the hot period.

Extremes

Extremes take on particular significance in impact studies, especially hydrological studies, due to the way in which they can affect populations. A lot of attention has been given to studying extremes in climate change situations; this is one of the hardest aspects to quantify.

For this study the precipitation and maximum and minimum temperature climate series were used to estimate 23 extremes indices defined by the CCI/CLIVAR/JCOMM Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI - http://www.clivar.org/organization/etccdi/etccdi.php), which were used in the STARDEX project (Statistical and Regional Dynamical Downscaling of Extremes for European Region - http://www.cru.uea.ac.uk/projects/stardex/).

The results of the temperature series generally present an increase in the frequency and intensity of hot weather extremes and a decrease in cold weather extremes by the end of the century (Table 2). The maximum and minimum indices of maximum and minimum temperature are an example of this – here a clear upward trend over this century can be observed.

	Observed		A2						B2					
	1961–1990		2010–2039		2040–2069		2070–2099		2010–2039		2040–2069		2070–2099	
Index	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Maximum of the maximum temperature[1]	35.89	7.38	37.28	7.43	38.16	7.51	40.09	7.60	37.34	7.44	38.54	7.40	38.78	7.58
Duration of heat waves	11.13	10.02	19.32	35.81	36.87	49.06	81.91	70.50	18.89	33.13	35.26	46.75	44.09	48.89
Average number of summer days per year	110.11	21.14	117.50	23.78	133.97	25.22	163.63	24.98	119.62	24.89	135.15	22.00	144.34	22.54
Average % of hot days per year	0.10#	0.11	0.13	0.14	0.22	0.18	0.40	0.25	0.14	0.13	0.22	0.18	0.26	0.19
Average annual precipitation	792.21	264.15	680.63	275.01	646.99	251.69	567.09	212.27	687.62	296.09	660.71	265.01	662.22	230.09
SPI12: drought events	3	n.a.	9.0	1.1	6.2	1.4	5.9	1.3	7.5	1.1	8.3	1.5	9.3	2.0
SPI12: magnitude of droughts	24.2	16.0[2] 37.8[3]	28.3	8.8[2] 68.1[3]	43.6	8.1[2] 157.5[3]	71.2	11.5[2] 227.7[3]	36.0	9.8[2] 88.4[3]	31.3	4.8[2] 76.4[3]	27.4	5.5[2] 71.1[3]

Table 2 Mean values and standard deviations (SD) for some extremes indices for 30-year periods. [1] maximum value instead of mean. [2] minimum and [3] maximum of the scale of drought.

For the duration of the heat waves there will also be a significant increase of this index, indicating longer heat waves (Table 2). However, this index is significantly underestimated by the model, which may be indicative that in the future, heat waves will be even more severe than that forecast by the model. A pretty accentuated decrease is to be expected by the end of the century for the length of the cold waves index.

In relation to the extremes associated with precipitation, projections point to a decrease in the number of days of heavy precipitation, total precipitation and intensity. This decrease may also come with a decrease in the variability of the indices, as can be seen in the reduction of the standard deviations for many of the indices. The results also point towards a significant increase in the number and magnitude of droughts throughout the century (Table 2).

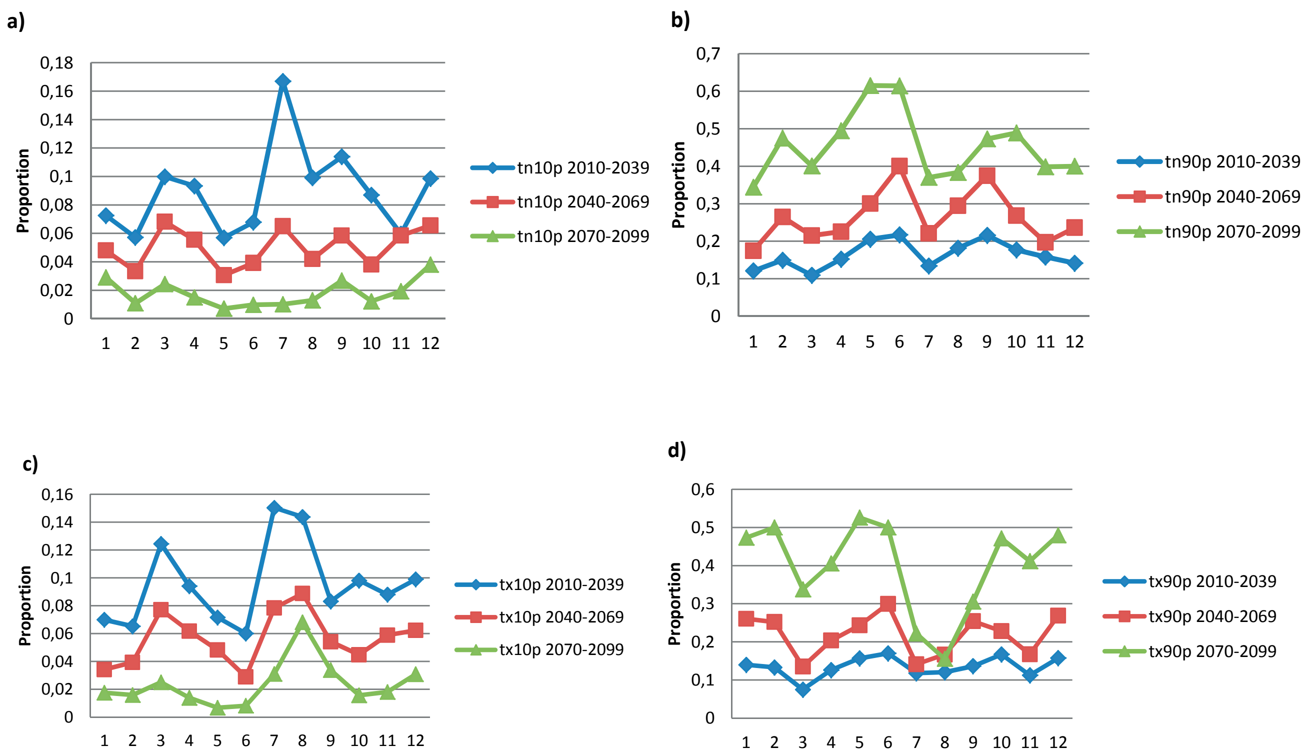


Figure 7 Projections of extreme indices for temperature by month up to the end of the century for scenario A2. a) cold nights; b) warm nights; c) cold days; d) hot days.

The analysis of the different months indicates that there will be a marked increase in the percentage of warm nights in the spring and autumn months, and may reach 60% of the days of the months of May and June for scenario A2 at the end of the century (Figure 7b). Likewise, the percentage of hot days will also increase in the spring and autumn months (Figure 7d). In fact, the months of July and August are the periods in which this index will increase the least. This will happen at the same time as the percentage of cold days and nights will decrease in a very significant manner at the end of the century (Figure 7a/c), especially in scenario A2, in which these indices will only be detected in 2% of the days.

2.3 Socioeconomic scenarios

The construction of socioeconomic scenarios for 50 to 100-year periods includes identifying a small number of key parameters, with which all the other socioeconomic aspects are related (IPCC, 2007). The trends of these parameters form the axes of reference of the space of possibilities of world evolution. The scenarios thus correspond to regions in this space and, if enough regions are considered, it is possible to include all the possibilities that are sufficiently plausible and internally consistent (Figure 4).

In this project the IPCC SRES scenarios (Special Report on Emissions Scenarios, IPCC, 2007) were downscaled, which enabled forecasting the evolution of various indicators in the medium- and long-term, such as population, changes in land use and water consumption. The study area included the councils covered or crossed by the boundary of the Tagus River's basin (where EPAL's water sources are located) and also the councils of the Oeste (Western) region.

Below are the main results obtained. More detailed information on the methods and results can be accessed at http://siam.fc.ul.pt/adaptaclima-epal/

Population growth scenarios

With regard to the population growth scenarios in the study area, a linear downscaling of the CIESIN (2002) scenarios was done for Portugal up to 2100. Scenario A2 points towards a 16% increase of the resident population in the study area by the end of the century. The remaining scenarios point towards a decrease in population of around 6 to 8% (Figure 8).

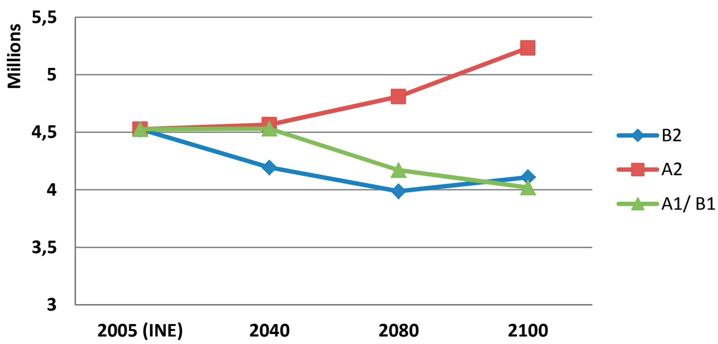


Figure 8 **Downscaled population growth scenarios for the study area**

Land use scenarios

Concerning land uses the methodology followed included: 1) characterising the land use by council in the study area using the Corine Land Cover map (CLC, 2006) and adapting the CLC classes to those used by the IPCC (2007); and 2) regionalising the trends indicated in the SRES scenarios for Europe, based on an extensive list of publications (namely, IPCC, 2007; Rounsevell *et al.*, 2006) for the study area, taking into account the characteristics of each council and the trends witnessed over the last few years. All the scenarios, but particularly A1, indicate an increase in the urban areas and a significant reduction of agriculture areas, offset by the increase in productivity (Jacinto *et al.*, 2013).

Water consumption scenarios

Water consumption scenarios were also explored up to the end of the century, not just for EPAL's system, but also for all the other sectors competing for this resource – water. The water consumption scenarios in the study area were obtained using population growth scenarios and land use scenarios, as well as those concerning the evolution of other parameters (namely technological development, climate change, policy change and consumption behaviours) (IPCC, 2007; Alcamo *et al.*, 2007; Kok *et al.*, 2009; Jacinto *et al.*, 2013).

To sum up, regardless of the scenario used, the results indicate that water consumption will decrease progressively up to the end of the century (Figure 9). These reductions are mostly due to the increase in efficiency of water use in all sectors and the reduction of the agriculture areas. These results are in accordance with known global studies. According to various authors, Portugal is among the group of countries that will reduce its water consumption over the next few decades, mostly owing to an increase in irrigation efficiency.

Notwithstanding, it is fundamental to bear in mind that although demand is on average less in any of the scenarios developed in this study and also in other studies, it may be more focused on the hotter months and, together with the extension of the hot and dry season (from May or even April up to September or October) may lead to problems of water availability during this period.

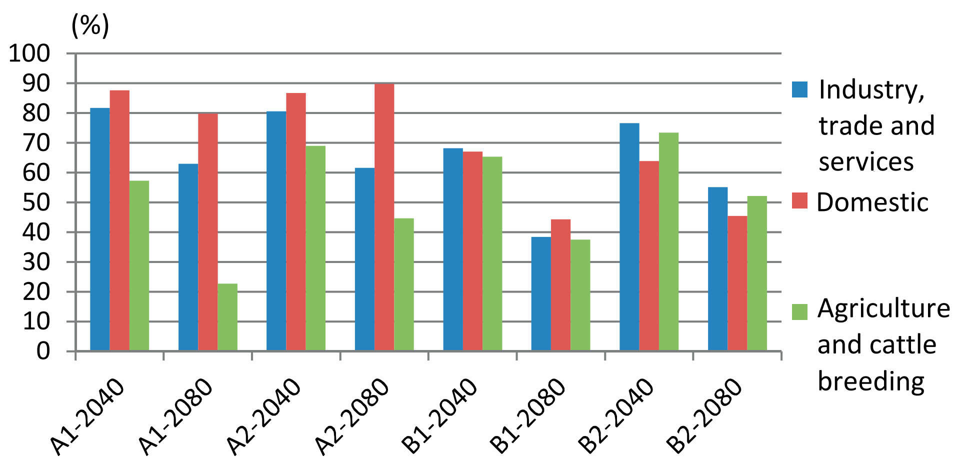


Figure 9 **Water consumption scenarios by sector for all the municipalities covered by EPAL for the years 2040 and 2080, in percentage change with regard to 2007**

3. Vulnerability assessment

Authors: Nuno Grosso, João Pedro Nunes, Paulo Diogo, João Nascimento, António Carmona Rodrigues and Maria João Cruz

3.1 Introduction

To assess climate vulnerability for each water source, water quantity and quality related vulnerabilities were considered separately. The overall value of climate vulnerability of each source was estimated as the highest vulnerability to any type of climate event taken individually.

The vulnerability to each type of climate event is considered to be the combination of the potential risks with the system's adaptive capacity (Figure 10), that includes the control measures (so-called by EPAL in their Water Safety Plan, WSP). The potential risk is calculated by multiplying the severity of a given event with the likelihood of its occurrence. Severity was assessed on a scale of 1 (low) to 3 (high); likelihood was assessed from 0 (zero) to 3 (high); adaptive capacity was assessed from 1 (low) to 3 (high).

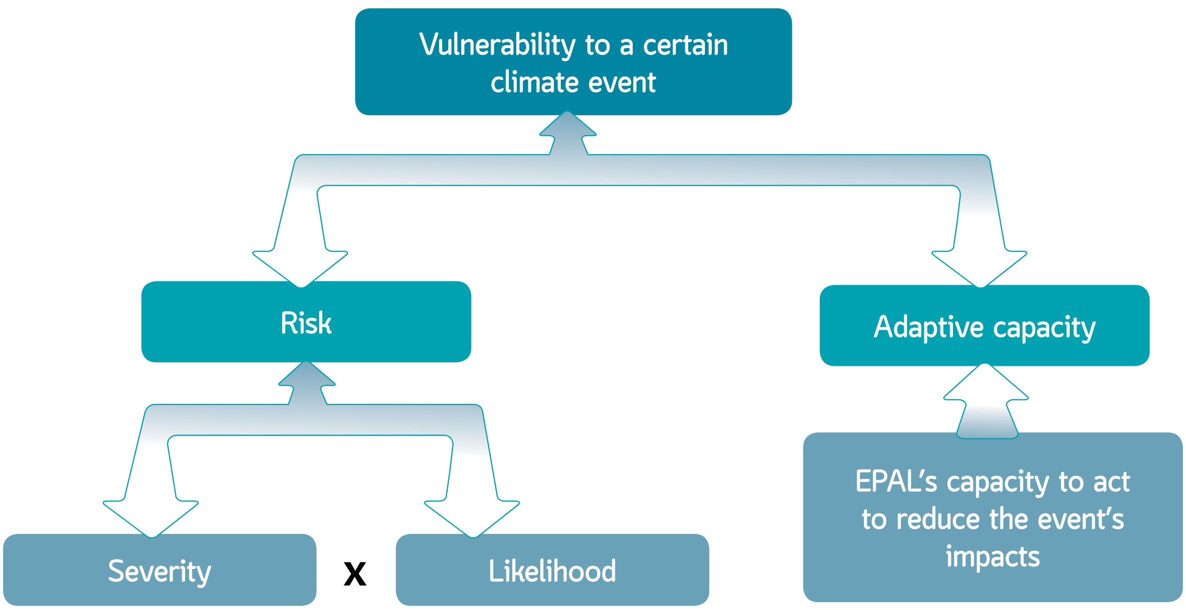


Figure 10 **Factors taken into account in assessing the vulnerability to a certain climate event at each of EPAL's water source**

The current climate vulnerabilities of the EPAL system were assessed according to the following:

1) Analysis of the observed data and identification of past climate events with impacts on EPAL's system;

2) Assessment of perceptions within EPAL about its current climate vulnerabilities;

3) Analysis of the climate risks identified in the WSP.

The future vulnerabilities of the EPAL system to climate variability and change were assessed based on estimated impacts on the water quality and quantity in the surface resources (Castelo do Bode and Valada-Tejo), including a more specific study that assessed the risk of salt-water intrusion in the Valada-Tejo abstraction point, and the main underground water sources (catchment at Lezírias, Ota-Alenquer aquiferous system and Olhos de Água spring). These impacts were assessed for the different climate periods taken into account: a) reference period: 1980-2009; b) future periods: 2010-2039, 2040-2069 and 2070-2099.

The study on surface water sources was based on the Soil and Water Assessment Tool, eco-hydrological model (SWAT, Neitsch *et al.*, 2011), according to which flow series to the Castelo do Bode reservoir and to the abstraction point of Valada-Tejo were obtained. In the case of Castelo do Bode, assessment of water availability was made through an analysis of the variation of hydro-metric levels at the reservoir. For this purpose a hydrological balance model was used, taking electricity generation and water supply as the main consumptions. Still concerning Castelo do Bode, the assessment of the impacts on water quality included the descriptors: total phosphates, nitrogen compounds (nitrates and nitrites) and total suspended solids. The CE-Qual-W2 (Cole and Wells, 2008), a bi-dimensional mathematical model for simulating the hydrodynamics and quality of surface water masses was used. This model was also used to assess the intrusion of salt-water in the Valada-Tejo abstraction area.

Statistical models were developed to study each underground abstraction points included in the EPAL system. These models were developed to determine the respective piezometric levels in each of the climate scenarios from the monthly precipitation or accumulated precipitation deviations (defined as accumulated deviation of precipitation in a certain month with regard to precipitation on that same month in a reference period).

In order to offer greater robustness in ascertaining the future vulnerabilities of EPAL's system, a statistical analysis was made of the flow time series at different time scales (annual, seasonal, monthly and daily). The following different indicators were calculated:

1) Water Exploitation Index – WEI, defined as the ratio of abstraction of fresh water (for this study, current or future abstraction at each water source) and water availability in the long-term (represented by the estimated flows in the scenarios) (EEA, 2012), for surface abstraction points (Castelo do Bode and Valada-Tejo). The interpretation of this index allows identifying seasonal and annual periods of over-exploitation of the surface water resources in the EPAL system.

2) Water Deficit Index (Keyantash and Dracup, 2002) calculated for the different surface water resources, which allows detecting and characterising future drought periods by comparing with the flows during a critical reference period. For the purposes of this study the critical reference period picked was 2005, an historical drought.

3) Filling Index, for the different EPAL underground water sources, which compares the piezometric level during a given period with the difference between the maximum and minimum levels during a reference time series. Values of this index that are higher than 1, from 0 to 1 and 0 identify future piezometric levels higher than, equal to or lower than historic levels, respectively.

Concerning EPAL's consumptions, the reference value was defined as the mean consumption for the 2005-2009 period identified as the worst case scenario, taking into account the estimates of the socioeconomic scenarios developed for this project, which point towards a decrease in water consumption. Regarding hydroelectric power generation in the Castelo do Bode reservoir, it was assumed that the current annual water consumption levels would be maintained for the future by EDP, estimated at approximately 1,400 hm^3/year, according to the data provided by the utility company itself - a necessary assumption given the uncertainty of the future scenarios inherent to this type of water usage.

For calculating future vulnerabilities and bearing in mind the methodology described in this section, one must highlight that the future adaptive capacity values are considered to be unchanged with regard to the current ones. This is because this capacity will only be changed if the necessary adaptation measures are implemented. In the case of extreme climate events not modelled in scenarios (for instance, floods, forest fires), it was also assumed that future vulnerability will be the same as current vulnerability.

For each vulnerability assessment, current or future, an associated confidence assessment was made (IPCC, 2005). Confidence was assessed on a scale of 1 (limited confidence) to 3 (robust), through the joint analysis of:

1) Agreement – the level of coherence between the various sources used. In the case of current vulnerabilities this was assessed according to the agreement of the information collected. In the case of future vulnerabilities this depended on the coherence between scenarios A2 and B2 and between the different indicators used.

2) Evidence – the degree to which the data/observations support the result. In the case of current vulnerabilities, it would be high for events observed and low for events for which there are no observations, meaning that there are no data to support the conclusions. In the case of future vulnerabilities the evidence depends on the confidence on the models (model structure, input data and suitability for the impact under study).

The confidence associated with the total vulnerability in each origin was calculated as the mean value of the confidence associated with each of the events under consideration.

3.2 Current vulnerabilities

The current vulnerability assessment study in the locations of the Tagus river basin where EPAL has abstraction points led to the conclusion that the status of the water quality is considered good for all the water masses where EPAL currently abstracts water, except for the lower Tagus region, which includes Valada-Tejo. As for water availability, the assessment indicates a good level for all the water bodies where EPAL abstractions are located. The current water exploitation index in Valada-Tejo is lower than 1% and in Castelo do Bode it stands at around 9%. The water exploitation index for aquifers is lower than 30%, and it is only very high in the Tagus alluvial floodplains (higher than 50%).

In the past there have been several periods of drought in the study area (PGRH RA, 2011). The so-called "drought of 2005" was more intense than all the droughts recorded since 1940, in several places. In fact, "the analysis of the severity of drought from December 2002 to September 2006 period (46 months) shows that during 12 months more than 40% of the basin region suffered from extreme drought and for 17 months more than 40% of that area suffered from moderate, severe or extreme drought" (PGRH RA, 2011).

The Tagus has a long history of floods, since it is a river that is cyclically subject to this kind of phenomena (PGRH RA, 2011). However, these do not have a great impact on the quantity of water available for consumption; on occasion they may damage the abstraction infrastructure, stopping them from functioning properly.

The final result of the vulnerabilities of each source to each type of climate event is shown in the table below (Table 3).

CURRENT EPAL VULNERABILITY TO CLIMATE CHANGE	Water quality			Water quantity			Overall Climate Vulnerability
	Floods	Droughts	Forest fires	Floods	Droughts	Salt water intrusion	
Castelo de Bode	Low	Low	Low	Medium	Low	N/A	Medium
Valada	Medium	High	Low	Low	Low	Low	High
Valadas boreholes	Low	Low	Low	Low	Low	N/A	Low
Lezírias boreholes	Low	Low	Low	Low	Low	N/A	Low
Ota-Alenquer boreholes	High	Low	Low	Low	Medium	N/A	High
Olhos de Água spring	High	High	Low	High	High	N/A	High

Table 3 Summary of the current climate vulnerabilities of the different sources in the EPAL system. For each climate event and source the level of vulnerability is shown ("Low", "Medium" or "High") as well as the respective level of confidence ("Robust" , "Medium" or "Limited").

As for the current climate vulnerability, it was considered "Medium" for Castelo do Bode, determined by the highest vulnerability value attributed to floods, since there has already been an episode where the reservoir's pumping station was flooded due to a discharge after the maximum levels in the reservoir were reached.

Regarding the source of Valada-Tejo, total climate vulnerability is "High", mostly due to the water quality related vulnerability during the summer time. Every year during this season EPAL experiences problems resulting from the rise in temperature and the greater concentration of contaminants. This is because not only are the dry season flows naturally decreased, but these are also retained in the Spanish part of the basin area. These problems have led to adjustments in exploitation, both in terms of treatment and flows.

As for underground water sources, only the Ota and Alenquer boreholes show high climate vulnerability to floods due to the intense precipitation that can cause problems in terms of water quality. They also show medium vulnerability to droughts in terms of water availability (EPAL, 2006).

Lastly, the Olhos de Água spring hasn't been used for abstraction since 2011 because of water quality and quantity issues, since the water showed high levels of turbidity during high flow periods. For this reason the highest vulnerabilility class was attributted to this water source for most of the climate events.

3.3 Future vulnerabilities

Castelo do Bode

According to the results obtained, the annual flows to the Castelo do Bode reservoir should decline between 12% (scenario B2) and 5% (scenario A2) at the start of the century (2010-2039) and between 20% (B2) and 34% (A2) at the end of the century (2070-2099), when compared with the mean flow in the reference period (1980-2009, ≈1853 hm^3/year) (Figure 11). These decreases will be mostly concentrated in the autumn where, for example, in the 2070-2099 period, average flows will lower to levels similar to those of summer months, following the trends seen for precipitation. Another feature of the future annual flows series is the trend towards a reduction in its variability.

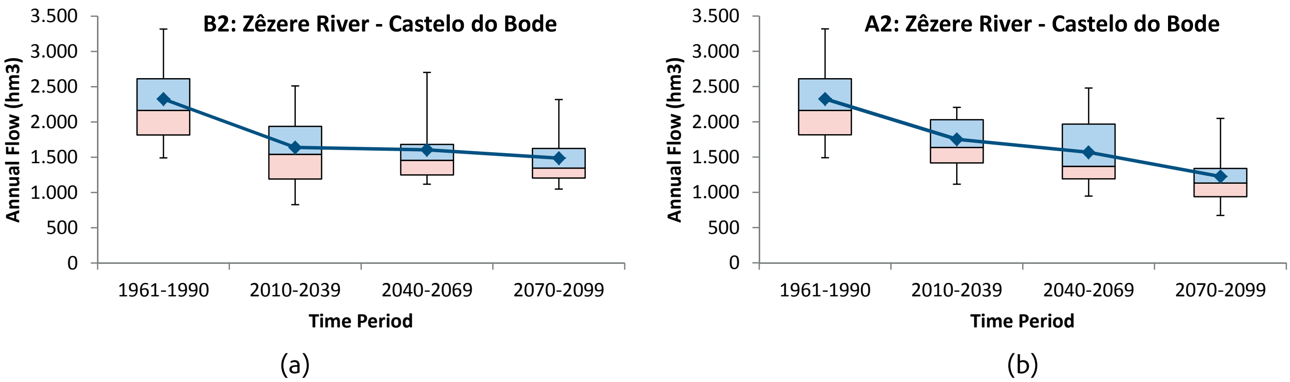


Figure 11 **Graph with boxes showing the variation of the annual flows to the Castelo do Bode reservoir according to the estimates of the SWAT model for scenarios B2 (a) and A2 (b). The points indicate the mean values; the lower border of each of the boxes corresponds to the threshold below which only 25% of data falls; the upper border of each of the boxes corresponds to the threshold below which 75% of data falls; the limits of the respective whiskers indicate the thresholds of 10% and 90% of data, respectively.**

Despite this trend of a reduction in the quantity of water available in the reservoir, EPAL's current consumptions at Castelo do Bode only account for about 13% of annual mean flows estimated for the 2070-2099 period, in the worst case scenario. Even in years of very small flow, this fraction increases to about only 25%.

However, when water consumption for EDP's hydroelectric power generation is included in the model, the water exploitation index rises significantly for all the periods under study (Figure 12). EPAL and EDP's consumptions, which currently account for about 85% of the Castelo do Bode's annual mean flows, will represent around 96% (2010-2039) and 118% (2070-2099) in scenario B2 and 90% to 140% in A2. This means that as of the mid-century, if EDP and EPAL's consumptions remain unchanged, they shall exceed mean flows, pointing towards the possibility of chronic water deficit situations in the reservoir.

Accordingly, maintaining the current consumption levels will become unsustainable and in the medium- to long-term may generate conflicts of interest between different water uses. Although the Water Act establishes that priority should be given to human supply in the event of a drought, this additional pressure should be taken into consideration in the analysis of future vulnerabilities as a factor of significant increase in the risk of water availability in the Castelo do Bode reservoir.

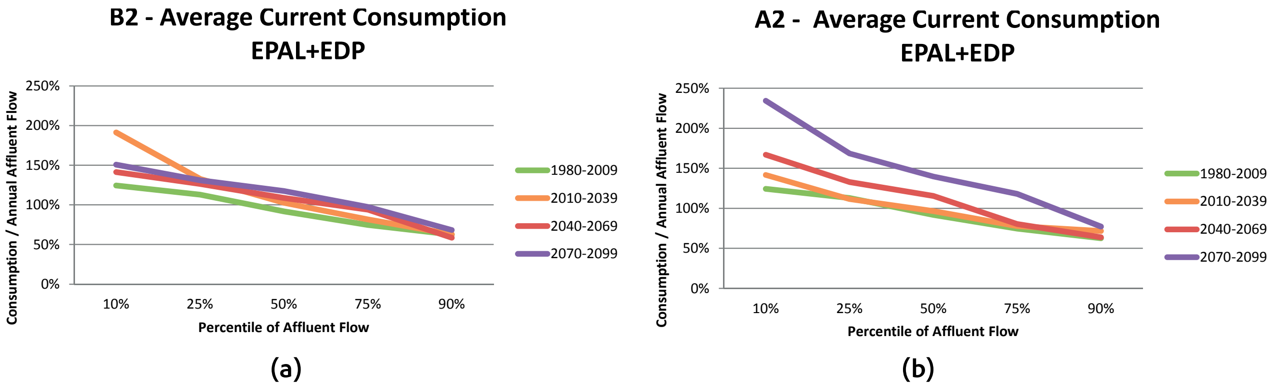


Figure 12 **Water exploitation values given by the WEI, estimated taking into account the joint consumption by EPAL/EDP for the percentiles of flows and for the different periods of the climate scenarios (a) B2 and (b) A2.**

At the same time, the severity of the drought should increase substantially (Table 4). This intensifying of the drought periods will be marked by:

1) A greater frequency of annual flows lower than those seen in 2005. In order to have an idea of the relevance of this potential impact, in the worst period, at the end of the century in scenario A2, the flow in 2005 shall be equal to the mean flow of that 30-year series;

2) A greater persistence, confirmed by the slight increase in the number of consecutive years with a flow lower than 2005;

3) An increase in their mean intensity with flows between 23 and 17% lower than those of 2005 in scenario B2 and between 21 and 20% in A2.

		Period			
Scenario	Indicator	1980-2009	2010-2039	2040-2069	2070-2099
A2	Frequency	1	4	6	17
	Persistence	1,00	1,00	6,00	2,83
	Intensity	0%	-21%	-30%	-20%
B2	Frequency	1	8	5	7
	Persistence	1,00	2,00	1,25	1,17
	Intensity	0%	-23%	-19%	-17%

Table 4 **Values of the different components of the Accumulated Water Deficit index for Castelo do Bode in the two climate scenarios, taking as the Reference Value (RV) the flow in the drought of 2005 (1182 hm^3). These components are: a) Frequency - Nº of years below the RV; b) Persistence – mean number of consecutive years below the RV and c) Average Intensity - % of months with flows lower than that of the reference year.**

The different indicators point towards a significant increase in the climate risk for the main water resource of the EPAL system, substantiated by the decrease in flows throughout the different climate periods and consequent decrease in the dam's average water levels, in addition to an intensifying of the severity of the drought periods. Notwithstanding, none of these indicators allow to conclude in an unequivocal manner the occurrence of disruption periods in water supply. Even so, Castelo do Bode's vulnerability has been classified as "high" in climate change scenarios. The main factor that led to this rating has to do with identifying situations of chronic flow deficit to the reservoir in the medium- and long-term, if the current joint consumption by EPAL and EDP remains unchanged. The confidence associated with this rise in climate vulnerability was deemed "Robust", since most of the models used have proved adequate to assess the impacts identified and both scenarios agree with regard to the change signal.

Regarding water quality parameters Total Phosphates (P_{Total}), NO_X, (nitrates e nitrites) and Total Suspended Solids (SST) were evaluated (Table 5). The interpretation of these results should focus on general trends to the detriment of the analysis of the value magnitude, although for NO_X information is provided on the approximation to the legal threshold. This limitation is mostly due to the difficulties encountered during the water quality model calibration and validation stage, associated with the used model's limitations with regard to the time scale under analysis (30-year periods), as well as the lack of sufficient field data that would allow a suitable coupling between the eco-hydrology model and the water quality models, particularly concerning P_{Total}.

Parameter	Trend
P_{Total}	Rise trend in the mean concentration from 0.014 mg/L in the reference period to 0.035-0.04 mg/L at the end of the century in both climate scenarios.
NO_X	Increase in the concentration in the climate scenarios to levels close to 1.2 mg/L at the end of the century with regard to the reference scenario, which registers values lower than 1 mg/L. Values significantly lower than the legal threshold set for nitrates (50 mg/L).
SST	Increase in the concentration, which varies from 4 mg/L as of October of the reference period to 10-12 mg/L in the months of December/January at the end of the century.

Table 5 Trends in estimated values for the different water quality parameters at the Castelo do Bode reservoir, for a two-year period, representing the average conditions of each of the 30-year periods in the two future climate scenarios (B2 and A2).

Generally an increase trend in concentrations for all the parameters under analysis has been observed, which stems from the combination of three factors: a) a decrease in flows; b) greater seasonal concentration of these flows (the most problematic period starts during the first precipitation in the autumn, which, due to the extension of the dry period, registers higher concentrations of pollutants); c) longer average times for retention in the reservoir (they vary on average from between 160 days for the reference period and 190 days at the end of the century, scenario A2). However, although the estimated values are indicative of a greater need for treatment, these may not become problematic given the current treatment capacity of the Asseiceira WTP. For this reason, the water quality vulnerability at the reservoir during drought periods has been kept as "Low". Notwithstanding, the confidence level has been lowered to "Medium" due to some restrictions found in the validation of the model to simulate total phosphates and, accordingly, in the assessment of the effective risks of a decrease in the water quality due to the eutrophication phenomenon.

Valada-Tejo

Future estimates for surface abstraction at Valada-Tejo (Figure 13) suggest a higher decrease of flows compared to Castelo do Bode. This is due to a greater dependence on the flows from Spain, which are more sensitive to climate change (Nunes *et al.*, 2013). Throughout the century the decrease in average flow will vary between 20% and 31% in scenario B2 and between 16% and 49% in scenario A2, in relation to the reference period (1980-2009). Seasonally there was a pattern similar to that mentioned for Castelo do Bode: more significant decreases during the autumn months, especially October, which will register values similar to the summer months, resulting in an extension of the dry period.

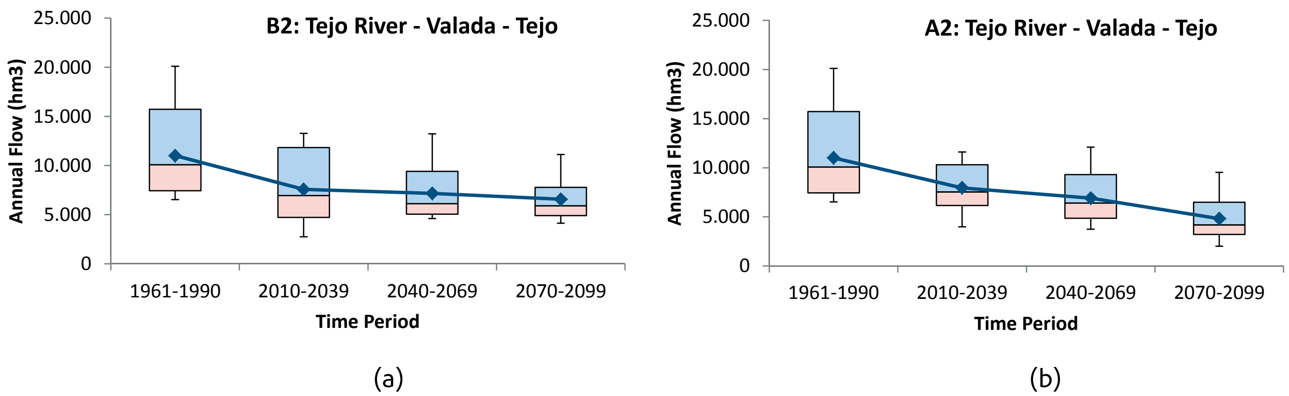


Figure 13 Graph with boxes showing the variation in annual flows to the Valada-Tejo section according to estimates of the SWAT model for scenarios B2 (a) and A2 (b). The points indicate the mean values; the lower border of each of the boxes corresponds to the threshold below which only 25% of data falls; the upper border of each of the boxes corresponds to the threshold below which 75% of data falls; the limits of the whiskers indicate the thresholds of 10% and 90% of data, respectively.

Despite these reductions, the annual flows to the Valada-Tejo source at the end of the century will still be twice the amount needed for EPAL. Even for an extreme minimum flow at the end of the century, EPAL's needs represent values of around 2.5% of annual flows.

However, to more adequately assess this resource's resilience to climate change it would be necessary to assess the hydrometric level data associated with these flows, since the minimum abstraction level is the main restriction on the continued use of this source. Nevertheless, calculating the hydrometric water level became unviable due to the unavailability of a flow curve that could translate the estimated flows into water heights, as well as the impossibility of a realistic estimate of potential future morphological changes that could occur in the river section in question. To partially overcome this restriction, the trends of daily flows were analysed (Figure 14), leading to the conclusion that the most severe impacts are associated with the extreme maximum and mean flows.

In fact, for scenario B2 the maximum and mean flows will decrease throughout the century in between 18% (2010-2039) to 37% (2070-2099) and 34% to 42%, respectively. In scenario A2 these reductions are even more pronounced and will vary between 9% and 49% and 28% and 65%. In relation to the days with the lowest flow (10 percentile), the decrease is less marked and will vary from between 12% and 9% in B2 and 2% and 23% in A2. In addition, there is a significant variability of daily flows, especially in the second half of the period being analysed in scenario A2. Although these reductions in the size and variability of daily flows represent an increased risk of interruptions in abstraction at Valada-Tejo, this risk can be partially limited due to the lesser impact registered with regard to minimum flows.

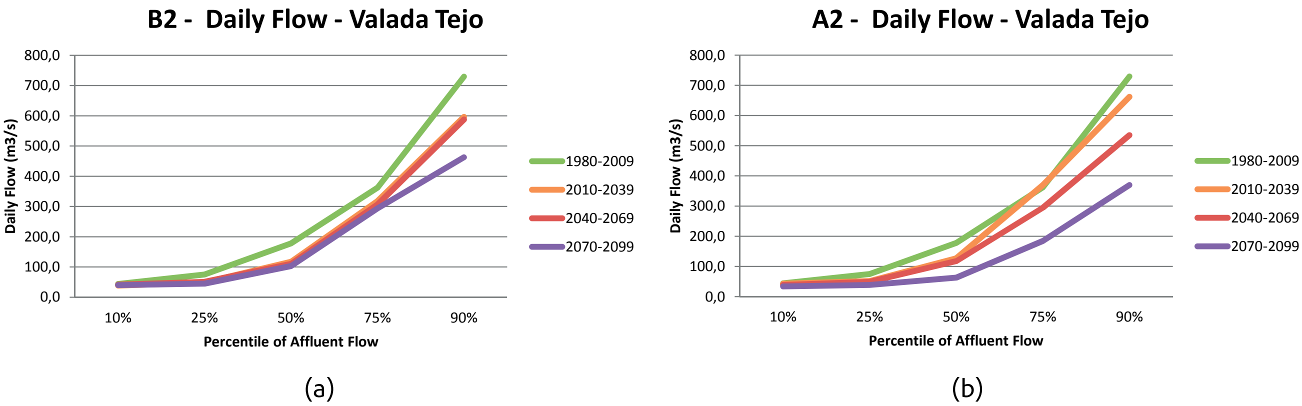


Figure 14 **Values of daily flow to the Valada-Tejo source for the different percentiles of flow and periods for climate scenarios (a) B2 and (b) A2.**

The periods of drought in the catchment area for the abstraction of Valada-Tejo show very similar characteristics (frequency, persistence and intensity) in terms of time distribution and magnitude to those presented for Castelo do Bode. The analysis of these periods, as shown in Table 6, allows us to conclude that in general the drought periods, when compared to 2005, will be more frequent, more persistent and of greater intensity, contributing in this way to an increase in the risk and therefore vulnerability of this resource to these types of phenomena.

		Period			
Scenario	Indicator	1980-2009	2010-2039	2040-2069	2070-2099
A2	Frequency	1	4	4	14
	Persistence	1,00	1,00	1,33	2,80
	Intensity	-6%	-9%	-26%	-26%
B2	Frequency	1	7	2	3
	Persistence	1,00	2,33	1,00	1,00
	Intensity	-6%	-27%	-28%	-16%

Table 6 **Values of the different components of the accumulated Water Deficit Index for the Valada-Tejo source and for the different periods and climate scenarios under analysis, taking as the Reference Value (RV) the flow in the drought year of 2005 (4404 hm^3).**

Combining the information given by the different indicators and the opinion of members of the project team and EPAL, the vulnerability value of this resource to droughts was increased from "Medium" to "High". This assessment was done in spite of the restrictions in setting with precision the likelihood of occurrence of shortages in supply in the different climate scenarios, which led to a decrease in the confidence to "Medium".

Different scenarios were simulated using the CE-QUAL-W2 model to describe the evolution of the intrusion of saltwater. The assumptions of each of the simulated scenarios took into account: a) different river flows upstream which varied from an average flow in future scenarios up to extreme minimum flows; b) a successive rise of the average sea level up to a maximum of 3.5 m; c) an increase to double the amount of the salt values in the Tagus estuary, downstream from the abstraction point and; d) the creation of a navigation canal in the Tagus river. The main objective of these scenarios was to simulate extreme situations that would enable the definition of a threshold as of which the increase in salt in the Valada-Tejo abstraction point could jeopardise the supply of water from this source. This threshold can be reached with salt levels of about 0.5 ppt, amounts that are indicative of brackish water.

From a general analysis of results we can claim that the salt threshold considered here is only reached in: a) situations of more than 10 consecutive days without any river flow from upstream; b) scenarios of change in the bathymetry of the Tagus river downstream from the abstraction point in order to render it navigable, together with scenarios of double salt levels and an upstream flow lower than the levels envisaged in the climate scenarios (10 $m^3.s^{-1}$); c) scenarios of a rise in the average seal level as of variations greater than 1 m (above that the values foreseen in the climate change scenarios).

These scenarios correspond to conditions with a very small probability of occurring individually or jointly. Accordingly, and despite this source's low capacity to adapt, we have decided to maintain the Valada-Tejo abstraction point's vulnerability as "Low". The confidence level was considered to be "Robust", since all the most representative scenarios are consistent.

Underground water sources

The vulnerability assessment for underground water origins was conditioned by the restrictions inherent in the estimate of the reference piezometric levels. In fact, the calibration and validation of the empirical models were done using a series of short-term piezometric values (from 4 to 8 years), which might not encompass the variability of all the processes that contribute to the variation in piezometry of a certain source.

For these reasons, the discussion of the results that follows largely concerns the definition of general piezometric trends for each of the sources. In addition, low levels of confidence were associated with the future vulnerability classes defined, thereby reflecting the uncertainty associated with the scarce data available.

The analysis of the estimated piezometric levels for both climate scenarios and the Filling Index values, which relates those levels with the historical maximum and minimum ones of the series under observation, shows similar trends for the main underground water sources in the EPAL system: Ota, Alenquer and Lezírias (see Figure 15 for an Alenquer borehole, as an example). There is a relative stabilisation of the piezometric levels of the first two periods of the climate scenarios, with piezometric values within the historical maximum and minimum levels and a significant downward trend in the last period.

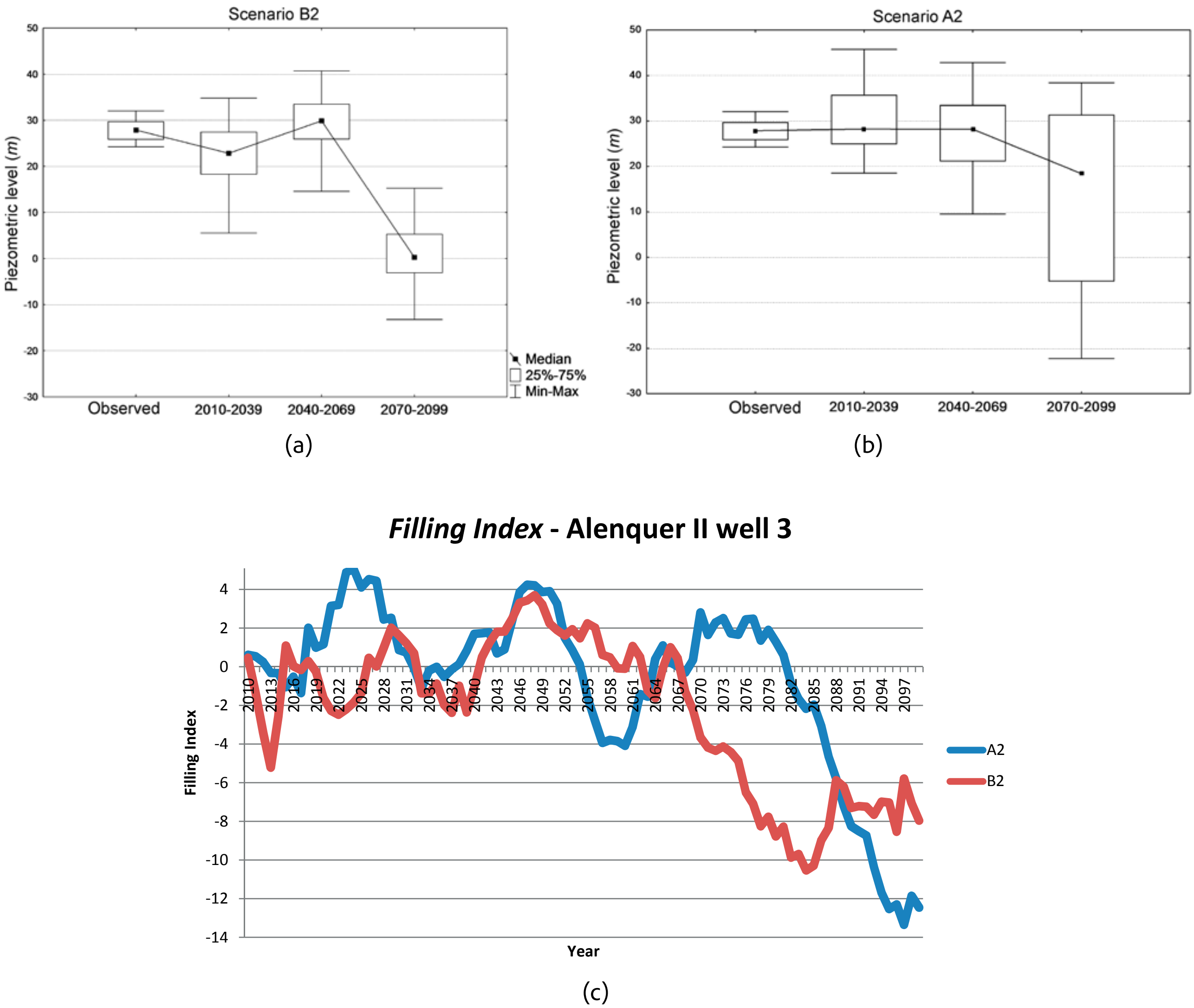


Figure 15 **Graph with boxes with the variation of the piezometric levels at the well 3 of Alenquer II source for the different climate scenarios (a) B2 and (b) A2. The points indicate the mean values; the lower border of each of the boxes corresponds to the threshold below which only 25% of data falls; the upper border of each of the boxes corresponds to the threshold below which 75% of data falls; the limits of the whiskers indicate the thresholds of 10% and 90% of data, respectively. The bottom part of the figure shows (c) the evolution of the annual Filling Index for this source.**

The Alviela stream is the only source whose behaviour is different to that of the remaining underground sources, with less difference between the piezometric levels and the historical levels. However, as of mid-century, there is a decrease in those levels, as well as a decrease in their variability. This apparent lower sensitivity of the Alviela stream to variations in precipitation in the climate scenarios may be out of synch with the current high vulnerability to droughts, in accordance with information gathered in the WSP and from EPAL experts.

Faced with the uncertainty associated with the developed empirical models and following a precautionary logic in defining climate vulnerability the high vulnerability to droughts of the Alviela stream has been maintained in Table 7. For the remaining underground water sources, despite the resilience seen for drought years, especially in the Tejo-Sado aquifer system, where the Lezírias sources are contained, the vulnerability to drought went up from "Low" to "Medium", due to the increase trend of piezometric levels identified for the end of the century. However, this increase in vulnerability should be weighted together with the limited confidence associated with these results.

The attempt at establishing an empirical relation between the different estimated climate parameters in climate scenarios (temperature and precipitation) and water quality parameters that result from the water-rock interaction in the different underground sources was inconclusive in most cases. The low correlations found may be related to the complexity of the hydrogeochemical processes that influence water quality in an aquifer, as well as the uncertainty associated with simulating anthropogenic activities.

Future vulnerability matrix for the EPAL water sources

Table 7 presents the vulnerabilities of the different EPAL sub-systems. Its analysis allows identifying a generalised increase in vulnerability to drought, determined by a reduction in flows or piezometric levels in all the water sources. This greater vulnerability is further heightened by an increase in the severity of the drought periods which, in the future and according to both scenarios, will become more frequent, persistent and intense. Among the sources affected by a high future vulnerability to drought, Castelo do Bode and Valada-Tejo take on a particular significance, since they represent approximately 90% of the total volume of water collected in the supply system. Despite the restrictions verified in reproducing the concentrations of certain water quality parameters, namely in underground water sources, an increase in the vulnerability of the different abstraction points associated with a significant decrease in water quality is not expected.

FUTURE EPAL VULNERABILITY TO CLIMATE CHANGE	Water quality			Water quantity			Overall Climate Vulnerability
	Floods	Droughts	Forest fires	Floods	Droughts	Salt water intrusion	
Castelo de Bode	Low	Low	Low	Medium	High	N/A	High
Valada	Medium	High	Low	Low	High	Low	High
Valadas boreholes	Low	Low	Low	Low	Medium	N/A	Medium
Lezírias boreholes	Low	Low	Low	Low	Medium	N/A	Medium
Ota-Alenquer boreholes	High	Low	Low	Low	Medium	N/A	High
Olhos de Água spring	High	High	Low	High	High	N/A	High

Table 7 Summary of future climate vulnerabilities of the different sources of the EPAL system. The level of vulnerability ("Low", Medium" or "High") is given for each climate event and each origin, as well as the respective confidence level ("Robust" , "Medium" or "Limited").

4. Adaptaclima-EPAL Project – Current and future challenges

Authors: Vanessa Martins, Basílio Martins, Ana Luís, Lília Azevedo, Tiago Capela Lourenço and David Avelar

4.1 Current challenges

As shown in the previous chapter, EPAL's water supply system currently presents high resilience to climate events. The current vulnerability of the system's various sources in terms of quality or quantity of water supplied is, in most cases, low for occurrences of events such as droughts, floods, forest fires or saltwater intrusion.

In the situations where the vulnerability was classified as "Medium" or "High", EPAL has already carried out a series of actions in order to improve the system's adaptive capacity, thereby contributing to a reduction in vulnerability and to an increase in resilience.

Castelo do Bode

The only current relevant vulnerability identified at the Castelo do Bode abstraction point is the possibility of the pumping station being flooded due to the floodgates discharges. The measures already adopted included placing equipment at a higher level and outside of the flood area.

The fact that the vulnerability to the remaining climate events is "Low" stems from a combination of the Castelo do Bode reservoir's natural features with a range of actions implemented by EPAL over the last few decades.

The reservoir's features allow for it to retain a volume of water that can respond to severe drought periods like the one that occurred in 2005, and also allow for good water quality by the abstraction tower, since any possible contaminants will be deposited throughout the way, from their entry into the reservoir up to the abstraction point. Furthermore, this reservoir is part of a river basin that is completely located on Portuguese territory (and is therefore not dependent on flows from Spain) and also its main land use is forestry, thereby safeguarding the quality of the water from accentuated diffused or topical contamination.

Finally, this sub-system has a series of features that further reinforce its low vulnerability: the fact that water can be abstracted at three different depths, in the abstraction tower; and the fact that all the water abstracted here is treated at the Asseiceira Water Treatment Plan, which is equipped with treatment processes that are able to deal with a potential deterioration in water quality at the reservoir.

Valada-Tejo

With regard to abstraction from the Tagus River in Valada, the main vulnerability (identified as "High") has to do with the poor raw water quality during periods of drought, which can lead to interruptions in water abstraction from this source. The already ongoing adaptation measure is the rehabilitation and reformulation of the treatment processes at the Vale da Pedra WTP, in order to deal with algae blooms, resulting from the eutrophication process caused by low water levels in the river and high temperatures, associated with wastewater discharges upstream from the collection point.

Current vulnerability in terms of water quantity was considered "Low", not only because the amount collected by EPAL at the section of the Tagus River merely corresponds to 1% of the volume passing through, but also because EPAL has implemented two important measures: the construction of a spur on the opposite bank in order to counteract the effect of the river silting up and the ensuing diverting of the flow to outside the abstraction station (a situation that has occurred in the past); as well as the setting up of oscillating masts (photo 1) that have been operating since 2003 in order to allow water being collected from lower levels.

Underground sources: Olhos de Água, Ota, Alenquer, Valadas and Lezírias

For the Ota and Alenquer sources, current vulnerability was considered "High" with regard to water quality during floods and "Medium" with regard to water quantity during droughts. These results are backed by historical data and by studies carried out for this purpose when the EPAL Master Plan was elaborated in 2006 (EPAL, 2006). However, as an adaptation measure, EPAL's response has included reducing the contribution of these sources to the overall calculation of water collected in the system. This measure was taken to the extreme in the case of the Olhos de Água spring: given its high vulnerability with regard to water quantity and quality, the option was to cease exploiting this water source.

The Lezírias abstraction points are the least vulnerable ones, since they are exploited at depths of 250 m and 500 m (and are therefore less sensitive to pollution), and are located in the largest aquifer of the Iberian Peninsula, the Tejo-Sado aquifer.

photo 1 **Oscillating masts system at the Valada-Tejo abstraction station**

4.2 Future challenges

As shown in previous chapters, the study of future scenarios points towards an increase of the vulnerability of water quality and quantity at EPAL sources by the end of the century.

Therefore, and in order to ensure the resilience of the supply system required to fulfil EPAL's mission, several adaptation measures have been analysed. This analysis, under the Adaptaclima-EPAL project, had two phases: (i) structuring the problem of adaptation; and (ii) assessing the solutions.

The first phase sought to define the main objectives and constraints in adapting the company, to provide an assessment of current and future vulnerabilities and to identify, define and describe a wide range of available potential options and adaptation measures. These individual options and measures were assessed in the second phase with regard to climate change scenarios and the main vulnerabilities identified. A set of recommendations to support EPAL's decision-making process were listed.

The adaptation measures to climate change deemed relevant for EPAL were categorised into general adaptation measures, namely:

a) Alter water supply;
b) Alter water demand;
c) Strengthen in-house processes and competences;
d) Alter institutional relations with other agents;
e) Ensure water quality;
f) Ensure the protection of the sources and other infrastructures.

Castelo do Bode

The greatest future vulnerability of EPAL's main water source is the possibility of shortage of water during a drought. The measures selected for Castelo do Bode fit within the options of "alter institutional changes with other agents" and "alter water supply" (Table 8).

TABLE 8 Adaptation measures deemed relevant for the Castelo do Bode water source

Option	Measure	Reasoning	Status
Alter institutional changes with other agents	Promote formal cooperation agreements in the joint management of resources and infrastructure that explain the objectives of adaptation and the requirements in terms of climate and non-climate information.	Setting critical limits is of high importance for using the reservoir, through an agreement with EDP, in order to ensure abstraction volume, control of discharged flows and to avoid conflicts of use during a drought.	Under way
Alter water supply	Construction of a system for harnessing the bottom discharge from the Castelo do Bode reservoir for gathering water. Using the existing transport and treatment infrastructure.	Ensure the continuity of abstraction, not just during a drought but also in the event of the dam level lowering due to maintenance works, acting as an alternative to the existing abstraction tower.	Under way

Valada-Tejo

The main vulnerabilities of Valada-Tejo, the source on the Tagus River, are water quality and quantity in the event of an extreme drought. The adaptation measures selected for this source fit in with the "ensure water quality", "alter water supply" and "alter institutional relations with other agents" (Table 9)

TABLE 9 Adaptation measures deemed relevant for the Valada-Tejo water source

Option	Measure	Reasoning	Status
Ensure water quality	Modify or resize the current WTP, including any amendments to treatment processes.	This measure responds to the current vulnerabilities associated with water quality problems at times of drought and with the capacity to respond to future problems related to the worsening of current vulnerabilities.	Under way
Alter water supply	Expand the structure of the spur located in the Tagus River next to the Valada-Tejo collection point.	Respond to two of the forecast vulnerabilities (reduction in average annual flow and worsening of the severity of droughts). Its main advantage is that of promoting greater temporary retention and redirecting the water at the collection point.	To be implemented
Alter institutional relations with other agents	Promote cooperation agreements for the joint planning and management of resources (land use, forests, fire prevention) that directly or indirectly influence EPAL's water sources or operations.	Respond to all of the current vulnerabilities (reduction in water quality associated with times of drought and contaminants' run-off) and future vulnerabilities (reduction in average annual flow and worsening of the severity of droughts).	To be implemented
	Promote cooperation agreements for sharing knowledge and information on decision-making processes in situations of extreme events (forest fires, floods, drought).	Respond to all of the current vulnerabilities (reduction in water quality associated with times of drought) and part of the future vulnerabilities (reduction in average annual flow).	To be implemented

Underground sources

The adaptation measures selected for these sources fall under the following options: "alter water supply", "ensure water quality", "alter water demand" and "strengthen in-house processes and competences" (Table 10).

TABLE 10 Adaptation measures deemed relevant for the underground water sources

Option	Measure	Reasoning	Status
Alter water supply	Increase the possibilities of transferring water between the EPAL sub-systems by building new transport/distribution infrastructure.	Potential response to all the main current and future vulnerabilities (significant reduction in piezometric levels and issues relating to water quality).	Under way
Ensure water quality	Support and promotion of the development of legislation and/or regulations that increase the role of protection of EPAL water sources (protection perimeters, land use, pollution sources).	Strengthen effective compliance with the law in force.	To be implemented
Alter water demand	Measures that reduce the current minimum water loss level in the EPAL system.	Response to the current and future vulnerability related to the need to reduce losses at the wholesale system, as it has already been achieved in the retail supply in Lisbon.	To be implemented
Strengthen in-house processes and competences	Invest in applied science studies and projects that can fill in any specific knowledge gaps and expand knowledge of adaptation to and mitigation of climate change.	Respond to the current and future vulnerability related to the significant reduction of piezometric levels. The main advantage is the improvement of knowledge of the aquifers in question, as well as modelling their development in climate change scenarios.	To be implemented

As previously mentioned, some of the adaptation measures are already under way. For the remaining identified measures, the strategy adopted has been one of implementing them as and when they become necessary or timely, instead of defining a rigid timeline for implementation.

In fact, bearing in mind the investment associated with implementing most of the adaptation measures, carrying them out will only be justified as the climate changes become more harmful. Furthermore, the measures the company may adopt and incorporate in its planning processes must respond to other requirements of improvement of the system (e.g. risk management), where security of supply and increase in resilience to climate change are just one more aspect to take into account. Lastly, the joint effort of the various entities and agents of the Tagus River basin with a view to adapting to climate change represents evident economies of scale and better end results.

Accordingly, EPAL's strategy for the development of future actions for adapting to climate change includes defining and monitoring indicators that will enable the actions to be implemented in phases or modules, faced with the potential effects of climate change as they become more serious and when closer to vulnerability thresholds identified as unacceptable.

4.3 Indicators and decision-making

The series of indicators identified includes variables for all of the EPAL water sources and refers to both water quality and quantity. Table 11 presents examples of indicators applicable to the Castelo do Bode reservoir.

TABLE 11 Examples of climate change monitoring indicators for the Castelo do Bode water source

Indicator	Scope of application
SPI 12 months	Provides information on the development of drought episodes with impacts on the hydrometric levels of the larger reservoirs. It is calculated based on the precipitation observed during the time period in question. Values of this indicator for the Lisbon and Tagus Valley area are available on the Instituto Português do Mar e Atmosfera website (Portuguese Atmosphere and Sea Institute - IPMA - www.ipma.pt). Based on this indicator one can also withdraw information on the length and scale of droughts.
Accumulated water deficit	Analyses i) No. of years below the annual flow value, ii) Mean number of consecutive years below annual average flow and iii) Mean intensity (% below annual flow). It provides information on how the extreme drought situations are progressing in terms of duration, persistence and scale, by comparing the flows in a given time scale with the flows for the same time scale during a reference period (typically a historical year of drought).
Average and minimum abstraction hydrometric levels	A direct indicator of the sustainability in the short, medium and long-term of the abstraction levels as well as of the consequences of extreme drought on the different sources. It incorporates information in consumption and flows.

4.4 Stakeholder relations

The relation and cooperation with stakeholders and potential for creating synergies through cooperation is likewise relevant in EPAL's successful adaptation.

The great number and complexity of stakeholder relations were taken into account in the Adaptaclima-EPAL project, from a perspective of combining efforts in order to obtain and share information, to manage assets and to carry out integrated investments – with obvious advantages and the possibility of co-benefits from the synergies and economies of scale; and also a perspective of regulation, control and coordination of activities, anticipating or managing potential crises and mediation thereof to influence public policy to become more in tune with the requirements of adaptation to climate change. Among the various stakeholders of EPAL, included in the project through the various meetings and workshops held, are municipalities upstream and downstream of the EPAL system, the Agência Portuguesa do Ambiente (Portuguese Environment Agency), the Entidade Reguladora dos Serviços de Águas e Resíduos (Water and Waste regulator), the Direção Geral de Saúde (Directorate-General for Health) and the electricity utility EDP-Energias de Portugal.

In general, all the entities showed great interest in the study and highlighted the potential benefits of sharing the acquired knowledge. An important adaptation measure has come up – the setting up of an agreement between EPAL and EDP – Energias de Portugal for the joint management of the Castelo do Bode reservoir.

It should be noted that 80% of the selected adaptation measures require the intervention of at least one agent foreign to EPAL. This result reflects the high level of complexity inherent in the process of adaptation to climate change, and highlights the need for collaboration between the different outside agents.

In line with the National Strategy for Adaptation to Climate Change, the Adaptaclima-EPAL project indeed represents an example of sharing information and creating synergies between different entities, which takes on particular relevance in a context of rationalising financial resources and aligning measures that do not generate antagonism, ambiguity or overlap of the options taken.

5. Adaptaclima-EPAL Project: What the team has to say

The Adaptaclima-EPAL project main objectives were the development of models to assess the potential impacts of climate change on EPAL system in order to reduce its future vulnerability and the identification of potential opportunities. This project comprised several challenges to the research team, particularly in terms of the sequential integration of models with different spatial and temporal scales, of the creation of useful indicators that could be incorporated and monitored by EPAL and of the elaboration of a strategy for adaptation that can be effectively adopted by EPAL. Therefore, the project has been a rewarding experience for the researchers involved as it has allowed the development of innovative scientific knowledge in a highly applied context. **[Research Team]**

When the GAC (Group for Climate Change) was set up at EPAL, we enthusiastically accepted the challenge of monitoring the knowledge acquired in studies on climate change, namely the Adaptaclima-EPAL project, and disseminating it within the company. Step by step, task by task, from workshop to workshop, the contact with the many research teams involved enabled the GAC members to take on new knowledge about climate change, as well as sharing with those teams the concrete reality of a water supply company like EPAL. This was particularly crucial in the "Vulnerability Assessment" and "Adaptation" stages. The Adaptaclima-EPAL project came to its end, culminating in the Project Final Conference in July 2013. However, this "end" merely represents the start of a new cycle in which climate change takes on a preponderant role in decision-making on planning EPAL's supply system. **[GAC]**

FILIPE DUARTE SANTOS EPAL has shown great leadership in Portugal; it is one of the major public service companies that decided to adopt an adaptation to climate change strategy in the medium- and long-term. It must now implement this strategy, bearing in mind that adaptation is a process subject to ongoing assessment and renewal.

MARIA JOÃO CRUZ The Adaptaclima-EPAL project is simultaneously innovative and applied, by cross-referencing the scientific knowledge of the most renowned research groups on climate change in Portugal, with EPAL's technical know-how of their needs and operation. The creation of mechanisms to enhance the dialogue between researchers and EPAL, both through the creation of the GAC and the Project Monitoring Committee, and through workshops involving a wider range of EPAL experts, proved critical to produce scientific results that are relevant and applicable in the context of this company. Examples of these results are the definition of adaptation measures and indicators which make it possible to monitor the effects of climate change on the system and to identify action moments.

ANTÓNIO CARMONA RODRIGUES In a world where uncertainty and risk management are increasingly present when managing water resources, the Adaptaclima-EPAL project is surely one of the most in-depth studies carried out on national soil and one of the most interesting ones I've taken part in. I was especially involved in studying saltwater intrusion in the downstream part of the Tagus River as a consequence of sea level rising. I believe that one cannot highlight enough the sense of EPAL's responsibility in promoting this study. The company shows that it is still at the front line of global enterprises and that it not only provides a service of excellence, but also cares about being at the forefront of being prepared for future challenges.

PAULO ALEXANDRE DIOGO The increasingly greater evidence on the development and impact of climate change on water resources are testament in themselves of the importance of the Adaptaclima-EPAL project, which is undoubtably one of the most enticing projects in which I've taken part. I've been especially involved in studying the evolution of saltwater intrusion in the Tagus River and the water quality and availability at Castelo do Bode reservoir. The work carried out was an excellent opportunity to be associated with a multi-disciplinary work team, which resulted in an effective application of research and scientific knowledge to EPAL's decision-making requirements. Owing to the project's approach, and the way in which it was conducted, this initiative by EPAL is certainly a benchmark in scientific research applied to water resource management, not just at national level, but also internationally.

TIAGO CAPELA LOURENÇO (...) The knowledge acquired in an active cooperation with some of the most experienced Portuguese universities in this field throughout the Adaptaclima-EPAL project provided EPAL with a set of scenarios, options and adaptation measures that will allow the company to have a more robust decision-making process and to be better prepared for current and future climate change challenges. In addition to being innovative in Portugal, this project places EPAL on a restricted list of water supply companies that have this type of knowledge and have included this new perspective in their planning. This project's scientific and practical relevance, as well as the main contributions to EPAL and the populations served by the company were a strong motivation for those who research the problem of climate change.

JOÃO PEDRO NUNES For me the Adaptaclima-EPAL project was an excellent opportunity to take the methods and knowledge developed as part of the fundamental research on hydrology and apply them to solving a concrete problem posed by EPAL. The project enabled me to better understand the areas in which hydrology is not yet capable of fully answering EPAL's questions, which played an important part in setting my fundamental research priorities for the coming years.

LUIS RIBEIRO Groundwater has a capacity of resilience that makes it a key component in the context of climate change adaptation strategy. This study showed that the aquifers explored by EPAL should be managed in an integrated manner with the superficial water sources so that likely recharge reductions are accompanied by an optimal exploitation of groundwater resources especially in periods where the superficial water sources are scarce.

ANA MARGARIDA LUIS Climate change is a concern which companies like EPAL cannot overlook. The results of the Adaptaclima-EPAL project, namely the indication of future scenarios and respective potential impacts on the quality and quantity of water at EPAL's sources are important inputs for the company's long-term strategic planning, thereby contributing to the sustainability of fulfilling its mission. In my understanding, the path taken over roughly the last three years in strict interaction between science and industry is as important, if not even more so, than the results obtained, since the knowledge generated, shared and placed within EPAL's GAC (Group for Climate Change), which have accompanied this project, enabled the development of skills and critical sense that will remain in time.

GAC Team (from left to right) **Lília Azevedo, Alexandre Rodrigues, Vanessa Martins, Ana Luís, Basílio Martins and Paula Aprisco**

REFERENCES and BIBLIOGRAPHY

- Alcamo, J. , Florke, M. and Marker, M. 2007. Future longterm changes in global water resources driven by socio-economic and climatic changes. Hydrological Sciences Journal, 52: 247— 275. http://dx.doi.org/10.1623/hysj.52.2.247.
- CIESIN, 2002. Country-level Population and Downscaled Projetions. Center for International Earth Science Information Network http://www.ciesin.columbia.edu/datasets/downscaled.
- Chandler, R. 2010. GLIMCLIM - Generalized linear modelling for daily climate time series, User Guide. London: University College London.
- Cole, T.M. and Wells, S. A. 2008. CE-Qual-W2: A two-dimensional,laterally averaged, Hydrodynamic and Water Quality Model,Version 3.6," Department of Civil and Environmental Engineering, Portland State University, Portland, OR.
- Collins, M., Booth, B. B. B., Harris, G. R., Murphy, J. M., Sexton, D. M. H., and Webb, M. J. 2006. Towards quantifying uncertainty in transient climate change. Climate Dynamics, 27(2-3), 127–147. doi:10.1007/s00382-006-0121-0
- EPAL, 2006. Revisão do Plano Diretor de Desenvolvimento do Sistema de Producão e Transporte da EPAL. Consórcio ENGIDRO, Estudos de Engenharia, Lda. / ProSistemas, Consultores de Engenharia, S.A. / Procesl – Engenharia Hidráulica e Ambiental, Lda.
- EEA, 2012. Towards efficient use of water resources in Europe. European Environmental Agency, Agencia Europeia do Ambiente , Copenhagen, Denmark.
- IPCC, 2005: Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties. Intergovernmental Panel on Climate Change (IPCC), Geneva,Switzerland.
- IPCC, 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 Parry, M.L., Canziani O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds), Cambridge University Press,Cambridge, United Kingdom and New York, NY, USA. 976 pp
- IPCC, 2014. Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Working Group II - Impacts, Adaptation, and Vulnerability (http://www.ipcc.ch/report/ar5/wg2/).
- Jacinto, R., Cruz, M.J and Santos, F.D. 2012. Water use scenarios as a tool for adaptation to climate change of a water supply company. Drinking Water Engineering and Science, 5, pp. 265-289. doi:10.5194/dwesd-5-265-2012.
- Keyantash, J. and Dracup, J. A. 2002. The Quantification of Drought: An Evaluation of Drought Indices. Bull. Amer. Meteor. Soc., 83, pp. 1167–1180.
- Kok, K., Vliet, M., Barlund, I., Sendzimir, J. and Dubel, A. 2009. First ("first-order") draft of pan-European storylines - results from the second pan-European stakeholder workshop. SCENES Deliverable 2.6. Wageningen Universitiy, Wageningen.
- Neitsch, S. L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. 2011. Soil and Water Assessment Tool, theoretical documentation, version 2009. Texas Water Research Institute Technical Report No. 406. Texas A&M University System, College Station, Texas, U.S.A

- Nunes, J. P., Seixas, J. and Pacheco, N. 2008. Vulnerability of water resources, vegetation productivity and soil erosion to climate change in Mediterranean watersheds. Hydrol. Process., 22(16),3115 - 3134.
- Nunes, J. P. and Seixas, J. 2011. Modelling the impacts of climate change on water balance and agricultural and forestry productivity in southern Portugal using SWAT. In Shukla, M. K.(ed.): Soil Hydrology, Land-Use and Agriculture. Measurement and Modelling. CABI, Wallingford, U.K. pp. 366 - 383.
- Nunes J.P., Diogo P.A., Ribeiro L., Grosso N. and Cruz M.J. 2013. A multicompartment modeling frame-work to study the impacts of climate change on the Lisbon water supplies. In: Roebeling PC, Rocha J (eds) TWAM2013 International Conference & Workshops Proceedings. University of Aveiro, Aveiro, Portugal.
- Nunes, J. P., Seixas, J. and Keizer, J. J. 2013. Modeling the response of within-storm runoff and erosion dynamics to climate change in two Mediterranean watersheds: a multi-model, multi-scale approach to scenario design and analysis. Catena, 102, pp. 27-39.
- PGRH RA, 2011. Plano de Gestão da Região Hidrográfica do Tejo, Avaliação Ambiental Estratégica - Relatório Ambiental. Ministério da Agricultura, Mar, Ambiente e Ordenamento do Território, Lisboa. 359pp.
- Pires, V., Silva, A and Mendes, L. 2010. Risco de Secas em Portugal Continental. Territorium 17, pp. 27-34.
- Pulquerio, M., Garrett, P., Santos, F. D. and Cruz, M. J. 2014. On using a Generalized Linear Model to downscale daily precipitation for the center of Portugal: an analysis of trends and extremes. Theoretical and Applied Climatology. DOI 10.1007/s00704-014-1156-5.
- Rounsevell, M.D.A., Reginster, I., Araujo, M.B., Carter, T.R., Dendoncker, N., Ewert, F., House, J.I, Kankaanpaa, S., Leemans, R., Metzger, M.J., Schmit, C., Smith, P. and Tuck, G. 2006. A coherent set of future land use change scenarios for Europe, Agriculture, Ecosystems & Environment, Volume 114, Issue 1, Scenario-Based Studies of Future Land Use in Europe, May 2006, Pages 57-68,ISSN 0167-8809, DOI: 10.1016/j.agee.2005.11.027.
- Santos, F.D. 2012. Alterações Globais, desafios e riscos presentes e futuros. Fundação Francisco Manuel dos Santos, Lisboa.
- SIAM, 2002. Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures - SIAM Projet. Santos, F., K. Forbes and R. Moita (editors). Gradiva, Lisboa, 401 pp.
- SIAM, 2006. Alterações Climáticas em Portugal. Cenários, Impactes e Medidas de Adaptação. Project SIAM II. Santos, F. and P. Miranda (editores). Gradiva, Lisboa, 506 pp.
- Vuuren, D.P. van, Smith, S. J. and Keuwan, R. 2010. Downscaling socioeconomic and emissions scenarios for global environmental change research: a review. John Wiley & Sons, Ltd, volume 1, pp.393-404. http://onlinelibrary.wiley.com/doi/10.1002/wcc.50/abstract.
- Wilby, R. L., Charles, S. P., Zorita, E., Timbal, B., Whetton, P. and Mearns, L. O. 2004. Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods (pp. 1–27).

2 3

6

SISTEMA DE ABASTECIMENTO DA EPAL 1) Captação de Valada-Tejo, 2) Recinto de Vila Franca de Xira, 3) Rio Tejo em Valada (captação e esporão), 4) Recinto dos Olivais, Laboratório Central, 5) ETA de Vale da Pedra, 6) Captação dos Olhos de Água, 7) Captação de Castelo do Bode, 8) ETA da Asseiceira

EPAL WATER SUPPLY SYSTEM 1) Valada-Tejo intake, 2) Vila Franca de Xira site, 3) Tagus River section in Valada (intake and spur), 4) Central Laboratory at Olivais site, 5) Vale da Pedra WTP, 6) Olhos de Água intake, 7) Castelo do Bode intake tower, 8) Asseiceira WTP

8