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EFECTOS DEL CAMBIO CLIMÁTICO EN LOS RECURSOS HÍDRICOS MEDITERRÁNEOS Y SUS IMPLICACIONES ECONÓMICAS

EFFECTS OF CLIMATE CHANGE IN MEDITERRANEAN WATER RESOURCES AND THEIR ECONOMIC IMPLICATIONS

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GENERAL INDEX

LIST OF SYMBOLS, ABREVIATIONS AND ACRONYMS

acuaMED	*Agua de las Cuencas Mediterráneas, S. A.* (Public coorporation Water of Mediterranean Basins)
AdapteCCa	*Plataforma de intercambio de información sobre impactos, vulnerabilidad y adaptación al cambio climático.* (Platform of information exchange on climate change impacts, vulnerability and adaptation).
AEMET	*Agencia Estatal de Meteorología* (Spanish National Meteorological Agency)
AGUA (Programa)	*Actuaciones para la Gestión y Utilización del Agua* (Actions for Water Use and Management)
AR4	Fourth Assessment Report (IPCC)
ARIDE	Assessment of Regional Impact of Droughts in Europe
CAP	Common Agricultural Policy
CE	*Comisión Europea* (European Commission)
CEDEX	*Centro de Estudios y Experimentación de Obras Públicas* (Centre for studies and experimentation on public works)
CEP	Council and the European Parliament
CGIAR	Consultative Group for International Agricultural Research
CHG	*Confederación Hidrográfica del Guadiana* (Guadiana River Basin Authority)
CHJ	*Confederación Hidrográfica del Júcar* (Júcar River Basin Authority)
CHS	*Confederación Hidrográfica del Segura* (Segura River Basin Authority)
CIRCE	Climate Change and impact research: the Mediterranean environment
CIS	Common Implementation Strategy (of the WFD)
Climate-ADAPT	The European Climate Adaptation Platform
CSOs	Civil Society Organisations
DMA	*Directiva Marco Europea del Agua* (Water Framework Directive)
DMG	Drought Management Guidelines
DMPs	Drought Management Plans
DSI	*Dirección General Estatal de Obras Hidráulicas, Turquía* (Directorate General of Hydraulic Works, Turkey)
EC	European Commission
ECCE	Assessment report of the preliminary impacts in Spain due to Climate Change
ECHAMs	Global Climate Model developed by the Max Planck Institute for Meteorology
EEA	European Environmental Agency
EEUU	*Estados Unidos* (USA)
EMMCW	Euro-Mediterranean Ministerial Conference on Water
ENPI	European Neighbourhood and Partnership Instrument

ENSEMBLES	Climate change and its impacts at seasonal, decadal and centennial timescales
EU	European Union
EUROLIMPACS	European project to evaluate impacts of global change on freshwater ecosystem
EUROSTAT	The Statistical Office of the European Union
EVREN S.A.	Evaluación de Recursos Naturales, S.A.
FAO	Food and Agriculture Organization
FHIMADES	*Fundación para el Desarrollo Socioeconómico Hispano-Marroquí* (Spanish-Moroccan Socioeconomic Development Foundation)
FP	Framework Programmes
FRMP	Flood Risk Management Plans
FYROM	Republic of Macedonia
GAP	*Güneydogu Anadolu Project* (Agricultural national Project, Turkey)
GDP	Gross Domestic Product
GEF	Global Environmental Fund
GHGs	Greenhouse gases
GMOs	Genetically Modified Organisms
HadCM3	Hadley Centre Coupled Model, version 3 (coupled atmosphere-ocean general circulation model)
HALT-JUCAR-DES	Halting Desertification in the Júcar River Basin
IDDRI	*Institut du Développment durable et des Relations Internationales* (Institute of Sustainable Development and International Relations)
IEA	International Energy Agency
IEMED	*Instituto Europeo del Mediterráneo* (European Institute of the Mediterranean)
INE	*Instituto Nacional de Estadística* (National Statistics Institute)
INTERREG	Interregional cooperation across Europe, Program
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
MAGRAMA	Ministerio de Agricultura, Alimentación y Medio Ambiente
MARM	Ministerio de Medio Ambiente Medio Rural y Marino
MDGs	Millenium Development Goals
MED EUWI	Mediterranean Component of the EU Water Initiative
MEDA	Financial Instrument of the Euro-Mediterranean Partnership (*Measures D'accompagnement*)
MEDROPLAN	Drought Management Guidelines and Examples of Application
MENA	Middle East and North Africa
MIRAGE	Mediterranean Intermittent River Management Project
MMA	Ministerio de Medio Ambiente
MS	Member States of the EU
NGOs	Non-Governmental Organisations
OECC	*Oficina Española de Cambio Climático* (Spanish National Office of Climate Change)
OECD	Organisation for Economic Co-operation and Development

OGMs	*Organismos Genéticamente Modificados* (Genetically modified organisms)
ONG	*Organización no Gubernamental* (NGO)
PAM	Parliamentary Assembly of the Mediterranean
PB	*Plan Bleu* (Blue Plan)
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PEV	*Política de Vecindad* (EU Neighbourhood Policy)
PIB	*Producto Interior Bruto* (Gross Domestic Product)
PMV	*Plan Maroc Vert* (Plan Green Morocco)
PNACC	*Plan Nacional de Adaptación al Cambio Climático* (Climate Change National Adaptation Plan)
PoM	Programme of Measures (of RBMPs)
PRODIM	Proactive Management of Water Systems to face drought and water scarcity in islands and coastal areas of the Mediterranean
PROMES	An atmosphere-ocean coupled regional model for climate studies of the Mediterranean region
PRUDENCE	Prediction of Regional Scenarios and Uncertainties for Defining European Climate change risks and Effects
RBMPs	River Basin Management Plans
RCM	Regional Circulation Model
RD	Royal Decree
RDI	Reconnaissance Drought Index
RegCM3	Third generation of the Regional Climate Model
SEDEMED	Dryness and Turning into a desert in the Mediterranean basin project
SEEA	System of Environmental-Economic Accounting (UN)
SEEA-Water	System of Environmental-Economic Accounting for Water (UN)
SEMIDE	*System Euro-Mediterraneen d'Information sur les Savoir-Faire dans le Domaine de l'Eau* (Euro-Mediterranean Information System on the know-how in the water sector)
SFG	Strategic Foresight Group
SIA	*Sistema Integrado de Información del Agua* (Integrated Water Information System)
SIMPA	*Simulación Precipitación-Aportación* (Precipitation-Contribution Simulation model)
SPI	Science Policy Interface
SRES	Special Report on Emission Scenarios
SWM	Strategy for Water in the Mediterranean
UE	*Unión Europea* (European Union)
UN	United Nations
UNDP-MAP	United Nations Development Programme - Mediterranean Action Plan
UNED	Universidad Nacional de Educación a Distancia
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UpM	*Unión por el Mediterráneo* (Union for the Mediterranean)
VUB	*Vrije Universiteit Brussel* (Free University of Brussels)

VWWF	V World Water Forum
WAMME	West African Monsoon Modeling and Evaluation project
WATCH	Water and Global Change project
WEI	Water Exploitation Index
WEI+	(revised) Water Exploitation Index
WFD	Water Framework Directive (2000/60/EC)
WS&D	Water scarcity and droughts
WTTC	World Travel and Tourism Council
XEROCHORE	Exercise to Assess Research Needs and Policy Choices in Areas of Drought project

LIST OF TABLES AND FIGURES

Chapter 1.

Chapter 2.

Chapter 3.1.

Chapter 3.2.

Chapter 3.3.

Chapter 3.4.

Chapter 3.5.

Chapter 3.6.

Chapter 5.

1 Introduction

1.1 Overview

The Mediterranean region presents a strategic location at the crossroads of three continents. Its climate has encouraged the settlement of peoples throughout history and a relevant socio-economic growth. However, pressures produced by the increase in population, tourism and urban development, mainly on the coastal areas, are causing serious environmental problems that affect its development. In addition, climate change effects are likely to increase these pressures, and pose important challenges for natural resources management. While being one of the richest regions in ecosystems, and considered one of the top biodiversity hotspots in the world (European Commission, 2009a), the Mediterranean area is at the same time one of the most vulnerable due to these pressures and closely related environmental problems as water scarcity, point-source and diffuse pollution, overexploitation of aquifers, deforestation, soil erosion and desertification.

Water is a catalyst for development, essential for almost all socio-economic activities and it is a vital natural resource for the environment. Yet, it is very unevenly distributed in space and time in the region, and not always managed wisely. Water is very scarce in a way readily accessible for human use, and has limited availability in the quality and quantity required for the different demands[1]. This makes it a limiting factor for economic activities, development and production of food and energy. The main water-related problems are being exacerbated by the effects of climate change, and extreme phenomena such as droughts and

[1] This thesis refers to concepts such as water demand (water withdrawn to be used) or water scarcity (lack of sufficient water for a specific use) according to their meanings in sectorial EU policy and their common use in international hydrological planning, which vary substantially from their economic definitions.

floods, increasing social and resource management problems, as well as conflicts among different sectors.

1.2 Climate change

Given the close relationship between water availability and weather phenomena, this thesis focuses on expected climate change impacts in the region and specifically in Spain. According to the IPCC report (IPCC, 2013), in the Mediterranean region the temperature rise linked to climate change will translate into a greater number of extreme events, an increase in their intensity, and a decrease in available water resources. Decreases in rainfall, increasing aridity and extreme droughts in southern Europe and the Middle East are expected (Dai, 2011), as well as changes in sea temperature and decreases in river flows. In Spain in particular, the conclusions of one of the first developed comprehensive studies, the *Preliminary General Assessment of the Impacts in Spain due to the Effects of Climate Change* (Ministerio de Medio Ambiente, 2005), in relation to water resources already pointed out towards: a) a general decrease of water resources and increased demand from irrigation systems, b) a reduction in contributions of up to 50% in semi-arid regions, c) an increase of their inter-annual variability d) demand management as a palliative option e) the need to improve and expand monitoring networks, research projects in this area and the importance of climate change impacts on water resources policy and regulations.

Already ten years ago, in 1995, it was estimated that 1,400 million people were living in conditions of water stress mainly in South West Asia, Middle East and in the Mediterranean region (Arnell, 1996, 2004). Thus, it is likely that declines in runoff estimates for the foreseeable future, will cause even higher rates of water stress due to decreasing availability.

Studies have progressed, and while they still present uncertainty and downscaling techniques are challenging, the predicted impacts continue to be similar. For instance, a more recent study published in 2011 by the CEDEX (Centro de Estudios y Experimentación de Obras Públicas, 2011), has fine-tuned impacts at the national level and predicts a generalised reduction of precipitation and water availability (near -5%, -9% and -17% during the periods 2011-2040, 2041-2070 and 2071-2100 respectively), with the greatest variability occurring in the Mediterranean coast and in the southeast of the country. In addition, the study predicts increases in temperature, evaporation and evapotranspiration, and decreases in groundwater recharge and runoff.

The effects of climate change will impact the availability and distribution of water resources, and because of this, food production, by impacting crops and livestock. Extreme weather events related to water, droughts and floods, will most likely aggravate, and will be important factors to consider in hydrological planning and water management to prevent shortages or minimise damages to people and goods. Furthermore, specific sectors, such as the agricultural one, will possibly present higher demands caused by the effects of temperature rise and evapotranspiration processes. As water becomes an increasingly scarce resource, coupled with a growing demand, climate change could affect management priorities in the distribution of resources (Estrela and Vargas, 2008).

As stated, some authors (Magnan et al., 2009) emphasize the uncertainty of climate models and hydrological data or CO_2 emissions, the unpredictability of the natural variability of climate, the lack of consistency in data and the wide margins of estimates on population growth and water consumption. Therefore, it seems necessary to develop more robust studies on climate change and for the predictions of expected impacts, as well as to invest more in adaptation strategies (UNEP/MAP-Plan Bleu, 2009). In any case, given the situation that the region presents, with fragile water balances, it is expected that any climate variability will generate relevant social and agricultural impacts.

Publications presented in this thesis approach these issues, provide recent references, data assessments, policy studies at the EU and national levels. They determine gaps in adopting climate change considerations in water management, and take specific approaches at the river basin level.

1.3 Policies addressed

There are several environmental policies at the EU level that aim at better protection and sustainable use of natural resources. The following chapters include just a small selection of these policies. Although there are references to the Nitrates Directive[2], the Common Agricultural Policy[3], the Habitats[4] and Birds Directives[5], among others, given their interlinkages, the focus lies on water and climate change policies. More precisely, the thesis focuses on those legislative tools that make the backbone of water protection such as the Water Framework Directive (WFD) 2000/60/EC.

The implementation of the WFD has made possible that EU Member states (MS) converge towards meeting quality and protection objectives. The Directive is innovative by setting the river basin as a single system for water management (although Spain has been applying this principle since the beginning of 20th century), aiming at good status of all waters, and establishing River basin management plans (RBMPs) as the main tools with programmes of measures to achieve that status. It is a policy that sets specific deadlines, and it is backed by mechanisms coupled with economic sanctions. Furthermore, the Floods Directive (2007/60/EC) complements this water protection objective by aiming to improve the management of flood episodes and reduce their risks, especially in water

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[2] Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.

[3] Policy born in 1962 to ensure food productivity at affordable prices in the EU and fair living of farmers. It has witnessed reorientation of goals, inclusion of new challenges, and numerous reforms, especially for its economic instruments http://ec.europa.eu/agriculture/50-years-of-cap/files/history/history_book_lr_en.pdf

[4] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

[5] Directive 2009/149/EC of the European Parliament and the Council of 30 November 2009 on the conservation of wild birds.

courses and in coast lines. It requires the mapping of areas with considerable risk and the development of management plans. In addition, the European Commission (EC) has funded several projects and studies to determine the effects of climate change on water resources and has published numerous papers and reports to establish the basis for policy on adaptation.

However, these policies are often developed considering water availability, and territorial characteristics very different from those present in Spain, which can be much more similar to the ones of neighbouring countries in the Mediterranean basin. Moreover, the fulfilment of the objectives of these policies seems more than uncertain due to old and emerging challenges. The EC developed a comprehensive assessment on the existing directives, their results, and the causes of not achieving the initially established goals for water quality, management and protection. This initiative, called Blueprint to Safeguard Europe's Water[6], which sets the year 2020 as the first horizon, focuses on four major areas: RBMPs developed under the WFD, a review of the European action against water scarcity and drought, the vulnerability assessment of water resources to climate change and other anthropogenic pressures, and a general fitness-check for EU water policy.

Nevertheless, recommendations and tools provided in the Blueprint are to be assessed in the upcoming RBMPs, which should be presented by MS by the end of 2015 and their data reported in March 2016. Furthermore, a revision of the WFD should take place in 2019, when the reasons for non-implementation and a possible review of the Directive’s text could take place. Also, in 2017 the Commission should report to the European Parliament and the Council on the implementation status of the EU Strategy on adaptation to climate change

[6] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; A Blueprint to Safeguard Europe’s Water Resources. COM/2012/673 final.

(European Commission, 2013). A greater effort of aligning water protection and climate adaptation goals, should, at this point, be considered and assessed.

The following figure 1 summarises the introduced problems based on the DPSIR (Drivers, Pressures, Status, Impact, Responses) framework developed by the EEA (European Environment Agency, 1999):

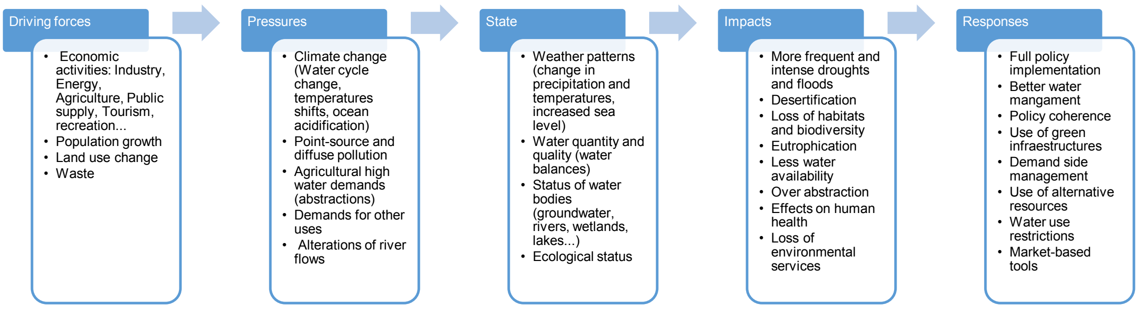

Figure 1. Summary of effects of economic activities and climate change impacts in water resources. Source: own elaboration based on the causal framework developed by the EEA (extended from previous OECD Works), that links society and the environment.

1.4 Spanish river basins

Many Spanish river basins face water shortages, persistent droughts, land degradation and overexploitation of water resources. And all these problems tend to be exacerbated by the effects of climate change. Mediterranean river basins in Spain, such as for instance the Júcar or the Segura river basins, are typical example of basins suffering the impacts of these phenomena, and having a major surface of semiarid areas (according to the UNESCO aridity index). They often suffer different extreme events such as floods and torrential rainfall events (or flash floods), while they present intensive water abstractions primarily for agricultural uses.

The updated RBMPs are still to be reported to the European Commission, and should provide an interesting opportunity to study the possible effects of climate change on water availability, the proposed technical measures, and to conduct their economic assessment. The publications presented in this thesis provide some insights from the preliminary draft RBMPs, assess the existing policies being implemented and the degree of their coherence.

1.5 Remarks and proposed solutions

This thesis provides an overview of the effects of climate change on water resources, both at regional and national levels and gives some examples of economic implications. The effects of climate change indicate the need to intensify certain measures already being implemented: saving and demand management measures, the use of non-conventional resources (desalination and wastewater reuse), ensure a sustainable use of groundwater, greater use of green infrastructure development, modernization of irrigation systems, as well as specific plans and measures to address floods and droughts management.

The thesis core chapter 3 is the result of assessed information, studies, data series, and main policies development. In addition, some of the most relevant research projects in the sector are mentioned. The author points out to existing policy, management and research gaps as well as social issues, and proposes solutions and recommendations.

Some of the pending issues in the water sector include the fully incorporation of climate change impacts on water planning, and better uptake of economic considerations in technical measures and adaptation processes. These aspects will be described in more detail in section 7.

As mentioned, there are also sectorial tools, such as Drought Management Plans (DMPs) that could be very useful to build on resilience. However, their implementation and integration into broader frameworks such as river basin management plans, or their interlinkage with relevant sectors as for instance land use remains limited (European Commission, 2012a; Vargas et al., 2014).

In view of the upcoming review of the WFD, specific recommendation are provided to improve its degree of implementation in Spain or the prioritisation of measures given the recent decreases of available budgets. Yet, one of the main obstacles to achieve better water protection and incorporate climate change effects lies on the lack of policy coherence. This problem has been stressed specifically for water and the Common Agricultural Policy, by the European Court of Auditors (European Court of Auditors, 2014).

2 Objectives

The thesis provides an introduction to water resources in the Mediterranean region providing some specific examples (e.g. Morocco and Spain), presents the main witnessed and expected effects of climate change in water resources, providing a specific assessment on drought impacts and management. Furthermore, the impacts of climate change in sectors directly linked to water, such as agriculture or land management, are evaluated at the national level. Finally, the thesis takes a closer look into EU policies, and their implications at the European and national levels.

An evaluation of various studies on the effect of climate change on water and European adaptation policies has been done, providing case studies, specific examples and introducing economic assessments.

More specifically, the established goals are:

a) Provide an introduction to water management in the Mediterranean region.

b) Develop an analysis of EU policies on water and climate change.

c) Analyse the effects of certain extreme events common in Mediterranean basins such as droughts.

d) Determine how previous experience in water management and planning may or may not represent a framework for adaptation to climate change effects.

e) Provide examples of policy gaps and recommendations to improve water protection policies in the future.

Some of the research queries or questions to which the thesis responds are:

What is the situation of Mediterranean countries regarding water resources status, access and policy? How will climate change impacts affect water resources in the EU, in the region and in Spain? What are the existing management tools to address climate change effects in water resources? Are EU policies sufficiently robust to pursue a common strategy, especially given the disparity between the availability of resources from one Member State to another? Are countries such as Spain prepared to develop sectorial adaptation plans that address climate change effects? Are economic considerations and impacts linked to water resources sufficiently considered?

2.1 Justification

The thesis will present an introduction to the problem of climate change and its effects on water availability and management, responding to the stated questions, based on available studies, hydrological data, and developed publications.

An introduction to the situation of water resources in the Mediterranean basin is provided given the similarities, in hydrological terms, of the riverine countries. This overview is provided to show also disparities in terms of access to water, policy and administrations consolidation, especially between EU and non-EU MS. Given the importance of water for the agricultural sector, and its varying effects in the different national economies, specific examples of agricultural programmes are provided.

Furthermore, a more specific analysis is done on droughts, due to the expected increase in intensity and frequency of drought episodes in the region due to climate change. The reason for this focus, is threefold: to address policy, economic and environmental aspects related to droughts. While there is no specific EU Directive to approach drought episodes, an important legislative process was carried out by the European Commission between 2007 and 2012, which included a specific communication, follow-up reports and studies at the EU and national levels, and an assessment of drought effects in achieving environmental protection objectives. The thesis, considers the specific example of DMPs in Spain, being one of the first existing cases in the EU, and their flexibility in adopting climate change predictions (Estrela and Vargas, 2012;

Vargas et al., 2014). As for economic considerations, some general aspects are provided as the overall valuation of water scarcity and drought costs at the EU level provided by the European Commission (European Commission, 2007). As it will be indicated, one of the findings highlights the limited integration of DMPs into RBMPs, and the need for a better harmonisation at the EU level.

The environmental acquis[7] at EU level is quite complete and incorporates not only specific sectoral policies, but also horizontal tools that help towards overall environmental protection, and integration of environmental considerations in different sectors and processes. One of the main pillars of water protection is the WFD (2000/60/EC), which aims to achieve good chemical and ecological status for all water bodies by 2015. The general objective of this Directive is to prevent and reduce water pollution, to promote sustainable water use, environmental protection, and improve aquatic ecosystems. In addition, and through complementary legislation and political initiatives, it also aims to mitigate the effects of floods and droughts.

It requires MS to produce River Basin Management Plans (RBMPs) as main tools to assess the status of waterbodies and the pressures on them, and set the required measures to protect and improve the water environment. However, it has been estimated that about half of EU surface waters are unlikely to reach a good ecological status in 2015 (European Commission, 2012b). Moreover, at the time of entry into force of this Directive, climate change impacts were unclear, and studies presented high uncertainties. Thus, it was recommended and agreed to incorporate climate change considerations in the second cycle of the Directive (RBMPs to be adopted in 2015) and thereafter, which degree of implementation is to be assessed.

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[7] The *Community acquis* or *acquis communautaire* or *EU acquis* refers to the group of legislation tools, legal acts and court decisions at the EU level.

Climate change considerations are quite recent compared to policy history, and have not been fully incorporated into water resources management practices. In this, sense, recommendations are provided into how and where to consider climate change impacts within the WFD cyclic nature, how to liaise with other sectors and policies, while taking also into account economic impacts and tools.

2.2 Methodology

The thesis includes a compilation of articles and publications in which the author had a relevant or main contribution, presenting the overall conclusions obtained, recommendations for policy makers and managers, and suggesting future lines of work.

To complete works, the author has developed a research process and a comparison of scientific studies, articles and management policies, which includes publications, studies, official governmental and EU sources, as well as results of the application of hydrological models and forecasts on the impacts of climate change. In addition, the thesis takes into account water balance exercises (using the System of Environmental-Economic Accounting for Water), and other works such as the use of specific water indicators by the European Environment Agency.

The steps that have been taken are described below and presented in chronological order. Also a summary table (table 1) is presented for the main characteristics of publications provided in chapter 3:

1. Assessment of the overall water picture in the Mediterranean basin: quantity, quality and availability aspects, main water consumptions per sector, contribution of agricultural practices to Gross Domestic Product, effects of climate change, extreme phenomena, policies and administrations, economic tools and environmental accounting, water related challenges, regional and neighbouring policies and strategies.

    1.1. Scale: the focus was established for the whole Mediterranean river basin.

1.2. Decisions: 15 countries were selected for the presentation of data assessment.

1.3. Sources: Summarised comparable tables were built using data sources from Aquastat (FAO), Eurostat and national sources.

2. Specific study on drought episodes and their main management tool: DMPs. An overall assessment is done on EU policies.

   2.1. Scale: it was set at the national level.

   2.2. Decisions: the use of DMPs was assessed more in-depth as management tools as well as the usefulness of the national drought indicator system.

   2.3. Sources: mainly national sources were used, such as modelling works from universities, national administration reports, and specific data from the Júcar River Basin Authority. Also, some figures at the EU level were provided from the EEA.

3. Assessment of climate change on water resources in Spain: availability and specificities, hydrological variabilities and trends, studies on modelling hydrological effects of climate change, implications for policy actions.

   3.1. Scale: the main scale used in the study is the national one. Specific examples were provided for river basins.

   3.2. Decisions: it was decided to highlight natural variability and trends, and the effects of using long and short data series, to show uncertainty in predictions and expected trends.

   3.3. Sources: the main data sources consulted were national official data repositories, and specific series for river basins were used (precipitation, runoff, streamflow).

4. A study on climate change at the national level is produced, incorporating the effects in water resources, but also in interlinked sectors such as agriculture and land planning.

   4.1. Scale: the chosen scale of study was the national one, although it also addressed EU scale by assessing European policy.

   4.2. Decisions: the focus on agricultural sector (and land management) was selected for being the one with the highest water demands at the national level. Specific considerations were provided for water accounting.

   4.3. Sources: mainly national official reports on emissions, mean precipitation values, and agricultural practices (water use, emissions).

5. An assessment of river basin planning is developed to assess its suitability and adaptability to climate change

   5.1. Scale: the scale was predominately set at the national level (as case study). Specific examples are included at the river basin level, and references to EU policy are provided.

   5.2. Decisions: It was decided to encompass the case study into the theoretical framework[8] of the whole book, based on a system approach that addresses local adaptation to climate change. It was decided to highlight the incorporation of climate change aspects in the national policy, and the assessment of sectoral tools (specific management plans).

   5.3. Sources: most of the data were obtained from national sources, river basin authorities, and draft RBMPs.

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[8] It is based on the assumption that the environment can be degraded by climate change effects, but also regenerated through effective adaptation strategies. It links adaptive capacity with adaptation and mitigation, with loops that provide feedback to the different processes (Stucker and Lopez-Gunn, 2015).

6. The final section provides a comparison between EU and national policy on water and climate change.

    6.1. Scale: The scale of study was set at the EU and the national levels (examples are provided for specific river basins).

    6.2. Decisions: it was decided to address, in addition to the assessment of policy implementation and policy coherence, emerging issues (e.g. nexus water-food-energy).

    6.3. Sources: data and information were obtained mainly from official reports of the European institutions (EC, EEA, Eurostat, Court of Auditors), and national sources (ministries, agencies, river basin authorities…). Also, scientific reports and articles were consulted, as well as recent EU-funded research projects.

The findings of publications determine if past experiences, especially in the development and implementation of management plans (for river basin, as well as droughts and floods), will allow, in a practical and feasible way, to implement policies for adapting to climate change in the water sector, and which economic implications will imply, taking into account the current national economic recession. The link between the stated research questions and the findings is described in section 5.

Table 1. Summary of the main topics covered by sector in all presented publications

Sections Chapter 3 Scale, main approaches per sector.	Scale	Water resources	Climate change	Policy	Economic	Social
3.1. Water in the Mediterranean Basin (*El Agua en la Cuenca mediterránea*).	Mediterranean basin (15 countries with greater focus in Spain).	- Availability and status. - Precipitation and renewable resources. - Water consumption. - Demands per sector (focus on agriculture). - Access to water.	- Main predicted effects. - Direct impacts on water resources. - Link to other sectors: food production.	- Policy existence and robustness of water administrations. - Regional strategies (Neighbourhood policy, N-S instruments, Union for the Mediterranean, WFD, MED EUWI).	- Water accounts. - Water pricing. - Cost-benefit of measures. - Main economic sectors: agriculture, industry and tourism. - EU financial instruments (ENPI).	- Regional conflicts (link to Arab Spring). - MDGs. - Public participation. - Information access. - Decentralisation of powers.
3.2. Drought Management Plans in the European Union. The case of Spain.	EU and national	- WS&D. - WEI. - Water imbalances. - Supply/Demand. - Non-conventional resources.	- Climate change effects (intensification of droughts, decrease of water availability). - Vulnerability and water stress. - Adaptation.	- WS&D EU communication. - WFD. - National legislation and DMPs.	- Pressures of coastal economic activities. - Overall economic impacts of droughts. - Compensations to farmers.	- Social and political conflicts (WS&D). - Consensus process (DMPs). - Public participation.
3.3. Impacts of climate change on water resources in Spain.	Spain (EU to lesser extent)	- Water imbalances - Scarcity - Runoff and precipitation - Overall demands	- Major projected impacts - Vulnerability issues - Uncertainty of models and trends - Intensification of impacts (droughts)	- Challenge: climate change integration at the national level. - National water regulation - WFD and RBMPs	- General socio-economic impacts of climate change	- Public awareness

3.4. The challenge of climate change in Spain: water resources, agriculture and land.	EU, national (some references to regional competences)	- Latest management shifts (desalination, demand management, modernisation of irrigation techniques) - Imbalances. - Over abstraction. - Major demands.	- Main predicted effects. - Direct impacts on water resources. - Link to other sectors: agriculture, land, and desertification. - Adaptation and mitigation.	- PNACC (emissions reductions commitments). - Sectorial plans and strategies (agriculture and water). - CAP. - National water regulations. - WFD.	- Climate change related costs (energy and food production). - Ecosystem valuation. - CAP cross-compliance.	- Political interests and links to water management. - Participative processes. - Public awareness. - Capacity building. - Coordination efforts.
3.5. Adopting the framework of river basin planning for climate .change adaptation in Spain.	EU, national, Spanish river basins (some references to regional and local level)	- WS&D. - Water planning. - Groundwater dependency. - Major water demands and abstractions. - Water infrastructures.	- Vulnerability. - (Spontaneous) adaptation. - Adaptation capacity. - Climate change scenarios.	- EU water and climate change policy. - Multilevel governance. - WFD, EU Blueprint Communication. - Adaptation planning. - Management tools (i.e. RBMPs and DMPs)	- Effects on economic sectors (energy, agriculture, tourism). - Resources needed for adaptation strategies. - Valuation of climate change measures in draft RBMPs.	- Role of society in building adoptive capacity. - Role of NGOs and CSOs. - Participative processes in decision making. - Climate health implications. - Public awareness.
3.6. Climate change policy and water resources in the EU and Spain. A closer look into the Water Framework Directive.	EU and national	- Water pollution. - WS&D. - Precipitation ranges. - Water planning. - Water efficiency. - Water-food-energy nexus.	- Major projected impacts (decrease river flows, saline intrusion, coastal subsidence, modification of habitats) - Vulnerability issues - Extreme phenomena (floods, heat waves).	- WFD - EU climate change policy. - CAP and Nitrates Directives. - Birds, Habitats Directives. - Water governance. - Science-policy interface.	- Market based instruments (block tariffs, pricing policies). - Cost-recovery. - Valuation of ecosystem services. - Water balances. - Harmful subsidies.	- Participative processes. - National conflicts. - Water security. - Social awareness. - Capacity building and training.

3 Publications

This section of thesis is a compilation of a series of publications in which the author had a major or relevant contribution. They provide an introduction to the issue of climate change and its effects on water availability and management, responding to the stated research questions, and pointing out in particular economic implications. Publications presented here are mainly based on recent research and technical studies, hydrological data, and policy developments at the EU and national levels.

3.1 Vargas-Amelin, E, 2011. **El agua en la cuenca mediterránea**, In J. M. López-Bueno (Ed.), El Mediterráneo tras 2011 (p. 200). Melilla: FHIMADES. p. 248.

This chapter provides an introduction to the situation of water resources in the Mediterranean basin, given the similarities, in hydrological terms, of the riverine countries. The chapter focuses on 15 Mediterranean countries, gives an overview of water resources major existing pressures, availability, and dependence by different sectors. It provides information on disparities in terms of access to water, policy development and administrations consolidation, especially between EU and non-EU MS. Given the importance of water for the agricultural sector, specific examples of agricultural programmes are provided, as well as figures on contribution to national GDPs.

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El agua en la región Mediterránea

Resumen

Este capítulo analiza la importancia de los recursos hídricos en la región, su estado y utilización y los principales retos a los que se enfrentan los países mediterráneos, especialmente del sur y del este, proporcionando ejemplos concretos. También resume algunas de las políticas o iniciativas internacionales más destacadas en materia de protección de aguas, así como la posible repercusión de las recientes revueltas sociales. Además, trata de resaltar aspectos pendientes, y establecer algunas líneas futuras clave hacia un desarrollo sostenible, no uno que no base su crecimiento económico en la sobreexplotación de los recursos naturales.

1. Introducción a la región mediterránea y a la importancia del agua

La región mediterránea, cuna de civilizaciones y religiones y situada en el cruce de tres continentes, cuenta con un suave y favorable clima que ha fomentado el asentamiento de pueblos a lo largo de la historia. También ha sido una región marcada por el comercio, las rutas de caravanas nómadas y los oasis como puntos de encuentro, intercambio y actividades económicas, así como los conflictos bélicos. La riqueza de sus ríos, como el Nilo, el Éufrates o el Tigris, y la aportación de sedimentos a sus llanuras de inundación, han propiciado a lo largo de los siglos el desarrollo de la agricultura y el asentamiento de civilizaciones, favoreciendo el aumento de la población en las zonas cercanas a los ríos y a la costa, donde, actualmente, gran parte de la población se concentra. Las poblaciones rurales han ido subsistiendo y desarrollándose mediante rotación de parcelas y aplicando históricamente técnicas de aprovechamiento del recurso. De hecho, acequias, canales y otras infraestructuras hidráulicas son comunes en el paisaje mediterráneo y de las primeras en ser registradas, como el primer acueducto "Aqua Appia", construido en el año 312 a.C. para el abastecimiento de agua en Roma, aunque , a pesar del nombre, fuera un canal subterráneo (Ruf y Valony, 2007; de la Peña, 2006). Desde alrededor del año 1000 a.C., también los "quanats" o galerías drenantes se han venido construyendo en el suroeste de Asia, en el Norte de África y en Oriente Próximo para aprovechar los recursos subterráneos, y siguen siendo utilizados, por ejemplo en España (MMA, 2006).

Actualmente, la presión producida por el aumento de población, el turismo o el desarrollo urbanístico, principalmente en el litoral, están produciendo graves problemas medioambientales que repercuten en el desarrollo social y económico de la región. Aun siendo una de las regiones más ricas en ecosistemas, es al mismo tiempo una de las más vulnerables en el mundo (EEA, 2010), debido a las mencionadas presiones socioeconómicas y a otros problemas ambientales como la deforestación, la erosión del suelo o la desertificación. Los problemas sociales en torno al uso y explotación de los recursos naturales en la región, y más concretamente del agua, son ampliamente conocidos.

Nos encontramos con una cuenca claramente dividida entre el norte y el sur y este[1]. El norte, enmarcado en una unión política y económica, la Unión Europea, con instituciones y competencias específicas, posee un claro marco legislativo que fomenta la competitividad de los mercados, trata de proteger su producción, reducir la dependencia externa de productos y energía, y regula la gestión y protección de los recursos naturales. Por otro lado, el sur y este, aun contando con potentes entidades como la Liga Árabe, estructuras que agrupan a Ministros de sectores específicos, o acuerdos económicos bi y multilaterales entre algunos países, carece de este marco unificador, especialmente en cuanto

1. El sur y este de la región mediterránea hacen referencia a los países ribereños del norte de África y del este del Mediterráneo: Marruecos, Argelia, Túnez, Libia, Egipto, Territorios Ocupados Palestinos, Israel, Líbano, Siria y Turquía, además de Jordania.

a legislación. El sector industrial sigue estando limitado, y su actividad económica depende más del turismo y la agricultura.

Han sido numerosas las políticas de acercamiento y colaboración entre norte y sureste, como la Política de Vecindad o Unión por el Mediterráneo, e importantes las iniciativas internacionales para fomentar una economía sostenible y una protección del medio ambiente, basándose en los Objetivos del Milenio, como se describirá más adelante.

En este contexto, y ante las recientes revueltas sociales en los países de Oriente Próximo y norte de África, el agua juega un papel esencial como motor de desarrollo, al ser un elemento necesario para la práctica totalidad de actividades sociales y económicas, así como para la protección y sustento de ecosistemas. Tanto en la agricultura, sector en el que se hace mayor hincapié en el presente capítulo, como en otros estratégicos como la industria o el turismo, el agua es un elemento indispensable para la producción. Al mismo tiempo, las actividades agrarias y ganaderas se asientan en gran parte de la superficie edáfica y de las masas de agua, produciendo importantes impactos en los ecosistemas. El agua, recurso natural vital, está distribuida de manera muy irregular espacial y temporalmente en la región. Es muy escasa en un estado directamente aprovechable y presenta una disponibilidad limitada en calidad y cantidad requerida por cada demanda[2], lo que le convierte en un factor limitante para la actividad económica, el desarrollo y la producción de alimentos.

La actual recesión económica, la volatilidad de los precios de los productos agrícolas en los mercados internacionales y la creciente disparidad entre países desarrollados y en vías de desarrollo son problemas globales de los que tampoco se salva la región mediterránea.

2. Aspectos generales cualitativos y cuantitativos del agua

La componente medioambiental, y en concreto la protección del agua, no ha sido una de las prioridades políticas en la región. Aunque empieza a haber iniciativas por parte de los gobiernos para concienciar a la población, asegurar la protección de ecosistemas, reducir vertidos, o mejorar la calidad de las aguas y

2. Conceptos como demanda o escasez de agua son utilizados en este capítulo de acuerdo con las acepciones correspondientes empleadas en la legislación sectorial comunitaria y su uso habitual en la planificación hidrológica en el ámbito internacional, difiriendo sustancialmente del significado económico de los mismos.

su gestión, será necesaria una mayor planificación y estrategias a largo plazo para asegurar una buena gestión del recurso y minimizar los impactos de fenómenos extremos, como las sequías, o evitar los estragos producidos por la escasez de agua. Tanto la recesión económica actual, como la ola de revueltas en el sur y este de la cuenca, no ayudarán probablemente a encaminarse en esta dirección, dado que se priorizarán otros asuntos como la seguridad, la estabilidad política, la salud o el comercio exterior, a pesar de su imbricación con el agua. Sin embargo, también los recursos hídricos podrían proporcionar una oportunidad para la colaboración, fomentando acuerdos técnicos y políticos e intercambios de información.

Disponibilidad y estado de los recursos hídricos

Un resumen de los principales datos relacionados con la disponibilidad de recursos hídricos y algunos aspectos económicos asociados vienen reflejados en la **tabla 1**. En general, los países de la región, y especialmente los del sureste, se caracterizan por una baja disponibilidad de recursos hídricos así como por la irregularidad en su distribución. En muchos casos, las lluvias se concentran en cortos periodos de tiempo, y las infraestructuras de control, gestión y almacenamiento son numerosas. A pesar de la notable irregularidad espacial y temporal, las precipitaciones anuales medias en la región son de unos 600 mm (FAO, Aquastat, 2011). En algunos países, sus zonas más húmedas cuentan con medias que exceden los 2.000 mm (norte de la Península Ibérica), mientras que otras desérticas y semiáridas cuentan con valores de 0 a 200 mm anuales, y representan una importante superficie. En Marruecos, la precipitación media anual varía de más de 750 mm en el norte del país, a menos de 150 en el sureste, y el desierto del Sahara representa el 84% de la superficie total de Argelia o el 95% de Libia (SEMIDE, 2005; FAO, 2005). La cantidad disponible por habitante varía también enormemente, y viene marcada en muchos casos por el desarrollo económico del país. Según crece la economía de un país, el consumo de agua por cápita también aumenta, aunque su disponibilidad pueda ser limitada. Como ejemplos, mientras que Francia cuenta con más de 3.000 m^3/año per cápita, la disponibilidad de recursos renovables en los Territorios Ocupados Palestinos es tan solo de 201 m^3/año/persona.

Históricamente, ríos como el Nilo, el Éufrates o el Tigris han sido de gran relevancia en el desarrollo de la región, aunque los dos últimos acaban en el Golfo Pérsico. 69 ríos desembocan en el Mar Mediterráneo, y en términos de caudal vertido, las principales aportaciones provienen del Ródano, el Po y el Nilo que contribuyen con casi la mitad del agua vertida que se estima en 8.100 m^3/s.

También hay contribuciones relevantes del río Ebro y de los ríos del este de la costa Adriática. La aportación proveniente de ríos del norte y este de África es bastante menor, a excepción del Nilo (Struglia *et al.*, 2004) y una pequeña proporción de ríos mediterráneos vierte en el Mar Muerto. Por otro lado, una gran parte de los ríos y acuíferos de la región son compartidos entre países vecinos (por ejemplo el acuífero Arsenica Nubia compartido entre Libia, Chad, Egipto y Sudan). De hecho, la mayor parte de la población mediterránea vive en cuencas transfronterizas, y el 90% del área de del sureste europeo se encuentra en cuencas internacionales (Ganoulis, 2004).

En el año 2000, la población de la región se estimaba en 450 millones de personas, de los cuales dos tercios se situaban en el sur del Mediterráneo, zona que en 1950 acogía solamente a un tercio de la población (PAM, 2011). Las desigualdades en los índices de natalidad, ligadas a los niveles de desarrollo, han marcado importantes diferencias entre los crecimientos poblacionales, pero se estima que la región podría alcanzar los 600 millones de habitantes en el año 2050 (Saverio Civili, 2010). Además, éstos seguirían concentrándose principalmente en zonas costeras y urbanas, que por lo general tienen menor disponibilidad de agua. Este es uno de los motivos por los que la práctica de la desalación de agua de mar se haya ido incrementando en la región y se esté utilizando como solución para abastecer crecientes urbes como se comenta más adelante. Ciudades como Estambul, El Cairo o el área metropolitana de París superan ya los 10 millones de habitantes, cifra que da una idea de la presión demográfica que sufre la región.

En la zona mediterránea son numerosas las presas, balsas de riego, canales y trasvases, e infraestructuras de regadío que se han usado durante siglos, aunque en muchos casos no son todo lo eficientes que podrían ser, y requieren de inversiones, mejoras y modernización para reducir pérdidas y fugas. También los países cuentan con canalizaciones diversas de distribución y abastecimiento, principalmente en las zonas urbanas, pero la situación varía mucho de un país a otro. Las infraestructuras de tratamiento y distribución no están totalmente implantadas, sobre todo en las zonas rurales, lo que produce problemas de acceso al saneamiento y agua potable, y, por tanto, sociales y de salud.

Los principales problemas a los que se enfrenta la región en relación a la calidad de los recursos hídricos son la contaminación difusa (prácticas agropecuarias) y puntual (vertidos urbanos e industriales principalmente), así como la falta de saneamiento y depuración. El aumento de los problemas de calidad de agua se traduce en eutrofización (acumulación de materia orgánica y descenso de O_2 disuelto), y disminuye la capacidad de dilución de los ríos.

También la degradación de humedales, la erosión del suelo, los vertidos de crudo al Mar Mediterráneo y el descenso de biodiversidad, cuentan entre los principales problemas medioambientales. Sin embargo, uno de los mayores retos al que hace frente gran parte de los países es la escasez de agua. La falta de este recurso tan preciado en enclaves estratégicos, como ciudades costeras o zonas agrarias, pone límites al desarrollo económico y social.

Los grandes problemas cualitativos del agua en los Estados miembros de la UE están siendo actualmente abordados mediante la Directiva Marco Europea del Agua (2000/60/CE o DMA), las directivas hijas (aguas subterráneas y sustancias prioritarias), y la Directiva 91/271/CEE sobre el tratamiento de aguas residuales urbanas. La DMA, por ejemplo, impone a los Estados alcanzar el buen estado de las masas de agua para el año 2015 mediante la implantación de Planes Hidrológicos de Demarcación Hidrográfica y Programas de Medidas específicos para hacer frente a los principales problemas hídricos, estableciendo estrictos objetivos ambientales. El no cumplimiento de las directivas, conlleva procedimientos de infracción y multas económicas a los países. La falta de un marco común sobre la protección de las aguas en el sur y este del Mediterráneo se está tratando de desarrollar en el seno de la Unión por el Mediterráneo, como se describe posteriormente.

Fenómenos extremos

Los fenómenos extremos, como inundaciones, lluvias torrenciales o sequías son comunes en la región. Las inundaciones son causantes de pérdidas humanas y millones de euros en materiales cada año. Pero al igual que estos fenómenos, los asociados a la falta de agua son también habituales, produciendo efectos menos inmediatos, pero no por ello menos graves. La *sequía* por un lado, caracterizada por ser un proceso climático lento, difícil de predecir, provocado por un aporte menor de recursos hídricos que en estado normal (principalmente debido al descenso de precipitaciones), se sucede en la región mediterránea causando importantes impactos socioeconómicos y ambientales. La *escasez de agua* por otro lado, está más ligada al efecto antrópico que al natural, y se define como el desequilibrio entre el agua disponible y las demandas existentes en condiciones sostenibles (CE, 2007; Estrela y Vargas, 2008). Esta escasez de agua, se podría decir que es característica y supone un problema más que frecuente en los países ribereños, produciendo importantes daños en la agricultura debido al descenso de producción en las cosechas, y dificultades para abastecer a las poblaciones principalmente en las zonas urbanas. De hecho, la escasez estructural hace que 180 millones de personas tengan una disponibilidad de 1.000 m^3 por año (por cápita) y 80 millones por debajo de los 500 m^3 (PB, 2009).

Sólo en los países de la UE, los impactos económicos de la sequía se han estimado en 100 billones de euros en los últimos 30 años. El impacto anual medio se ha duplicado entre el periodo 1976-1990 y 1991-2006, alcanzando un pico anual medio de 8,7 billones de euros en 2003 (CE, 2007).

Cambio climático

Dada la estrecha relación entre disponibilidad de recursos hídricos y los fenómenos meteorológicos, no hay que olvidar los impactos del cambio climático que se prevén en la región. Según el informe del IPCC (2007), en la región Mediterránea el aumento de la temperatura ligada al cambio climático prevé un mayor número de fenómenos extremos, un aumento en su intensidad, y una disminución de los recursos hídricos disponibles. Se prevén descensos en las precipitaciones, incremento de la aridez y de sequías extremas en el sur de Europa y en Oriente Próximo (Dai, 2010), alteraciones de la temperatura del mar, y disminución en los caudales. Concretamente, un aumento de 1,2 ºC para el año 2020 podría traducirse en una reducción de la disponibilidad de agua del 15% en el Líbano y en algunas zonas de Marruecos por encima del 10% (UN, 2009a). Si Arnell (1999; 2004) afirmaba que ya en 1995, 1.400 millones de personas vivían en condiciones de estrés hídrico principalmente en el suroeste asiático, Oriente Próximo y en la región mediterránea, presentando estas dos últimas zonas los porcentajes más elevados, las estimaciones de descenso de escorrentía, provocarán aún mayores índices de estrés al disminuir la disponibilidad de agua.

El efecto del cambio climático, afectará tanto a la disponibilidad como a la distribución de los recursos hídricos, y a su vez a la producción de alimentos al repercutir tanto en la producción de cosechas como en la de ganado. Las situaciones de escasez de agua y sequías se verán muy probablemente agravadas, y serán importantes factores a tener en cuenta en la planificación y gestión hidrológica. Esto se traducirá en mayores demandas por un recurso cada vez más escaso, lo que afectará a las prioridades gubernamentales (Estrela y Vargas, 2008). Sin embargo, también Arnell, y otros autores (IDDRI, 2009) destacan la incertidumbre de los modelos climáticos e hidrológicos o de los datos de emisiones de CO_2, la imprevisibilidad de la variabilidad natural climática, la falta de consistencia de datos para la región, así como los amplios márgenes de estimaciones en cuanto a crecimiento de las poblaciones y del consumo de agua. Se necesitará mayor robustez en los estudios de cambio climático y en los impactos esperados, para alentar a los gobiernos a invertir y desarrollar más en estrategias de mitigación, frente a las actuaciones presentes que se centran principalmente en la adaptación (PB, 2009). En cualquier caso, dada la situación que ya presenta la región con delicados balances hídricos, fuerte escasez de agua e índices de pobreza, está previsto que cualquier alteración climática genere impactos sociales y agrícolas destacados.

Los países mediterráneos deberán plantearse aspectos como la priorización de usos del agua, como por ejemplo para abastecimiento público o la producción de alimentos frente a la seguridad energética (IWMI, 2008). Las alteraciones climáticas afectarán tanto a la disponibilidad de agua como a la distribución y producción de cultivos, por lo que deberán tenerse en cuenta en las políticas agrarias, energéticas e hídricas, apoyándose en estructuras horizontales que coordinen las actuaciones.

3. Principales políticas de gestión del agua

Instituciones, competencias y gestión

La administración hidráulica en la región presenta cierta complejidad, ya que las competencias se reparten, y a veces solapan, entre diferentes entidades, pero dista mucho entre un país y otro y especialmente entre los comunitarios, que comparten una legislación común, y el resto.

En la mayor parte, los países cuentan con estructuras centrales que marcan directrices y políticas a desarrollar en ámbito regional o de cuenca hidrográfica. Habitualmente, se cuenta asimismo con legislación específica tanto para el aprovechamiento como la protección de las aguas, aunque, como se ha comentado, en el caso de los países de la UE con la DMA y la Directiva 271, existe además un sistema de infracciones económicas en caso de que el Estado miembro incumpla los objetivos y plazos marcados.

Para la gestión, se cuenta normalmente con varios Ministerios ligados a las competencias de aguas (agricultura, medio ambiente, alimentación, bosques…), existiendo en algunos casos, una entidad principal y con competencias exclusivas en gestión y planificación de recursos hídricos y obras hidráulicas como un Ministerio de Recursos Hídricos o agencia estatal. Por ejemplo, en Turquía existe el DSI o la Dirección General Estatal de Obras Hidráulicas. En un importante número de países se aplica la gestión por cuenca hidrográfica, fomentada desde diversos foros internacionales y respaldad por sólidas políticas (DMA), respetando así los límites naturales y contando con administraciones hidráulicas específicas, como agencias de agua o confederaciones. Es el caso de Argelia, Marruecos, Turquía, España o Francia, y Líbano para la cuenca del Litani. Este tipo de gestión aborda directamente las necesidades y los problemas de los sistemas hidrológicos e integra más fácilmente a las distintas partes interesadas, como los usuarios, en la toma de decisiones (Iglesias *et al.,* 2006). Juntas de gobierno, asociaciones de regantes, cooperativas, y otras asociaciones, así como ONG o comunidades de vecinos juegan también un importante papel en la gestión y protección del recurso. Sin embargo, en la mayor parte de los casos, los procesos participativos, la consideración de alegaciones por parte de colectivos o su implicación directa en la toma de decisiones a la hora de gestionar el agua no están suficientemente recogidos. De hecho, en la gran parte de los casos, la gestión centralizada deja poco margen para la participación pública. También la coordinación con otras instituciones, ministerios y agencias cuyas competencias están directamente ligadas al agua (agricultura, cambio climático, desarrollo rural y territorial) es mayoritariamente insuficiente o está fragmentada, y el cumplimiento y aplicación de la legislación es débil (Ferragina, 2009).

La mayor parte de los recursos de agua dulce y aguas subterráneas en la región mediterránea se comparten entre países vecinos. Y aunque se ha avanzado en la cooperación internacional entre países, y existen numerosos tratados y acuerdos, los conflictos por el uso del recurso están bien documentados. Algunos ejemplos se identifican en el Río Nilo (compartido por 10 países), el Río Jordán y el Éufrates, el lago Tiberíades (lago Kineret o Mar de Galilea) de Siria que se anexionó Israel en la guerra de 1967, el río El Kebir entre Líbano y Siria o el Orontes entre Líbano, Siria y Turquía. En el caso del río Nilo, fue Egipto el primer país en controlar mediante grandes infraestructuras su caudal, tanto para ampliar las zonas de regadío como para evitar daños por inundaciones no controladas. Sin embargo, Sudán y Uganda han comenzado a construir presas para abastecer sus demandas, entrando en conflicto con el superpoblado y cada vez más demandante de agua Egipto, creándose una situación de posibles futuros conflictos (Fairén Le Lay, 2008).

La creciente población y el desarrollo económico vienen acompañados de una mayor necesidad de agua para cubrir las demandas. No obstante, la disponibilidad es limitada, y no en todos los casos su explotación está justificada, al menos teniendo en cuenta criterios de sostenibilidad. Hasta ahora, las políticas se centraban en incrementar los recursos disponibles, pero poco a poco, los países de la región están cambiando hacia una de gestión de la demanda y considerando cada vez más la importancia de los ecosistemas, del tratamiento de las aguas usadas o de los costes que supondrán a largo plazo la sobreexplotación de acuíferos. Algunas iniciativas orientadas a ajustar la demanda al abastecimiento incluyen medidas no estructurales, como la colaboración intersectorial, la concienciación ciudadana o los incentivos económicos para hacer un uso racional del agua (VWWF, 2009). Las administraciones hidráulicas están, por tanto, logrando progresivamente un mayor control y regulación de los recursos, mejorando las redes de medida, el control de extracciones, así como las técnicas de tratamiento y saneamiento. Por ello, se espera que los siguientes pasos se centren en gestionar mejor este control y las demandas de los diferentes sectores, reduciendo pérdidas en los sistemas, sensibilizando a la población, modernizando infraestructuras y técnicas de regadío, priorizando usos y estableciendo actividades socioeconómicas en las zonas más óptimas para cada caso.

Algunos aspectos que deberán reforzarse en los próximos años incluyen el desarrollo legislativo en materia de aguas y su cumplimiento, el fortalecimiento institucional y de procesos participativos de partes interesadas y la coordinación entre autoridades competentes tanto dentro de los países como en el ámbito transfronterizo.

Herramientas económicas y contabilidad ambiental

Las administraciones hidráulicas se basan en diferentes herramientas para sufragar los gastos relacionados con la construcción y el mantenimiento de infraestructuras de almacenamiento y abastecimiento. Sin embargo, el sentimiento generalizado de que el agua es un bien común natural y que, por tanto, debiera ser gratuito, ha afectado notablemente a la tarificación y las decisiones de asignarle un precio al agua. De hecho, continúa siendo una de las mayores discusiones en foros internacionales (Foros Mundiales del Agua o Conferencias Ministeriales). En gran parte de los países mediterráneos, las tasas por el uso del agua se aplican principalmente a los sectores urbanos e industriales, subvencionando su coste en la agricultura para favorecer la actividad económica de las zonas rurales, la producción de alimentos y su exportación. Además de cánones, tarifas, e impuestos sobre el uso del recurso, otras herramientas como los mercados de agua se han fortalecido en los últimos años, favoreciendo el intercambio de derechos y la compra-venta de volúmenes entre usuarios.

Por otro lado, se lleva insistiendo en la necesidad de incorporar aspectos ambientales en las cuentas nacionales desde los años 60, y ya en los años 70 se planteó la manera de integrar indicadores que tuvieran en cuenta la degradación del medio natural (UN, 1994; Nordhaus y Tobin, 1973). A pesar de que han pasado muchos años, todavía son pocos los gobiernos que verdaderamente han implantado una contabilidad ambiental que podría resultar de gran utilidad a la hora de estimar el valor real de recursos naturales y sus servicios, compararlos a otros bienes materiales ampliamente integrados en el mercado (como la madera o los minerales), y determinar el impacto humano sobre los mismos. En el caso del agua, las externalidades de su explotación y uso, la contaminación de las masas de agua, o la valoración de los servicios que proporcionan (valor intrínseco, paisaje, servicios ambientales), son rara vez integrados en los sistemas de contabilidad económica, aunque en algunos casos se utilizan cuentas satélite. Éstas, vinculadas a los sistemas de cuentas nacionales, complementan la información disponible, pero no interfieren directamente en el cálculo de indicadores macroeconómicos como el PIB, ni sobrecargan o distorsionan el sistema central, pero proporcionan información ampliada y específica.

El agua, plantea importantes problemas a la hora de ser valorada: fluye a través del territorio sin fronteras definidas, lo que ya plantea problemas de propiedad y de autorizaciones de uso y aprovechamiento; hay una gran cantidad de administraciones que la gestionan, y sectores que la utilizan, alteran y contaminan; y la contabilización precisa de extracciones, vertidos, o incluso de su disponibilidad (masas de aguas subterráneas) es compleja. Como se ha indicado, en muchos países, y al igual que el aire, se percibe como un bien universal que debiera ser accesible por todos de manera gratuita. Esto plantea graves problemas a las administraciones hidráulicas que deben hacer frente a los gastos de extracción, tratamiento y distribución. En España, por ejemplo, el precio unitario del agua (cociente entre ingresos por servicios —abastecimiento, alcantarillado y depuración y el volumen de agua consumido-hogares, servicios e industria—) para 2005 era de 1,02 euros/m^3 (0,67 euros/m para suministro y 0,35 euros/m para alcantarillado y depuración) (INE, 2008). Sin embargo, este precio no recoge por ejemplo los costes de degradación del medio ambiente por su extracción y contaminación, ni tampoco contempla su papel como factor esencial en ecosistemas.

El aumento de la población, y por tanto de la demanda de agua, en todos los países mediterráneos requerirá de mayores inversiones en tratamiento y reutilización, medidas de ahorro y el incremento del uso de recursos no convencionales, como la desalación, repercutiendo en importantes costes económicos que deberían reflejarse en el valor del agua. El uso de cuentas satélite del agua en los países mediterráneos, podría suponer una herramienta estadística para determinar cómo las actividades económicas producen impactos que afectan al medio ambiente. A su vez, ayudaría a desarrollar y respaldar políticas que frenaran los daños ecológicos y ayudaran a asegurar una gestión integrada y sostenible del agua a través de estudios de coste-beneficio de medidas y obras, estudios de impacto ambiental o de recuperación de costes por los servicios del agua, además de concienciar a la población del valor intrínseco de un recurso tan vital.

Principales sectores económicos

La agricultura continúa siendo el sector más demandante de agua, con una media en el mediterráneo del 64% (PB, 2009). Aunque existen dos agriculturas principales, la del cereal de secano y la de regadío donde predominan los frutales y las hortalizas, es importante destacar que se ha ido desarrollando la economía de la región apoyándose cada vez más en una agricultura especializada y de regadío, cuyo despegue se da principalmente en el siglo XIX y XX (Ruf y Valony, 2007). Aceituna, cítricos, dátiles, hortalizas y cereales, forman parte del paisaje tradicional agrícola mediterráneo, y la exportación de estos productos supone una importante parte de la economía para muchos países.

Cuadro de texto 1.
El Proyecto GAP en Turquía (Güneydoğu Anadolu Projesi)
El proyecto GAP o del sureste de Anatolia en Turquía, el mayor proyecto regional del país y cuyo plan director se elaboró en 1989, tiene por objeto el desarrollo de una serie de actuaciones en esa región menos favorecida para fomentar el desarrollo rural y aumentar la producción agraria, creando puestos de trabajo y convirtiéndose en un centro exportador. Cubre una zona de 75.000km^2, y se centra principalmente en aumentar la zona de regadío y la producción hidroeléctrica en las cuencas de los ríos Eufrates y Tigris, aunque también incluye actuaciones para la mejora de infraestructuras urbanas y rurales, la educación y la sanidad. El programa de recursos hídricos incluye la construcción de 22 presas y 19 plantas (7 y 4 construidas respectivamente en 2001) y contempla canales e infraestructuras de regadío en un área de 1,7 millones de hectáreas. El enclave principal es la presa de Ataturk con una capacidad de 84,4 millones de m^3. El presupuesto total del proyecto es de 32 billones de dólares, de los que ya se han invertido 14,8 con importantes aportaciones del Banco Mundial, UNEP, UE y gobiernos europeos entre otros (a).

La irrigación inapropiada así como el uso excesivo de fertilizantes y la extracción abusiva de agua han provocado importantes problemas de salinización del suelo en la región y de contaminación difusa, por lo que se han puesto en marcha tanto programas de ahorro de agua y buenas prácticas agrarias como de reforestación. Otros problemas asociados incluyen la reducción de caudales aguas abajo, que afectan principalmente a Iraq y Siria, países con los que el gobierno Turco ha desarrollado acuerdos de cooperación y asignación de volúmenes principalmente desde la cuenca Dicle-Firat (b).

Cuadro de texto 2.
El Plan Marruecos Verde (Plan Maroc Vert —PMV—)
El plan presentado en 2008, establece las principales líneas estratégicas para la agricultura en Marruecos hasta el año 2020, basado en dos pilares: el económico y el social. Sus principales objetivos incluyen mejorar la producción y exportación, la modernización del sector, aumentar las inversiones privadas, contribuir al PIB nacional y crear puestos de trabajo, desarrollando entre 1.000 y 1.500 proyectos con una inversión de 10-15.000 millones de Dirhams anuales. El plan define un marco de libre comercio para la exportación de productos, la reforma institucional del Ministerio de Agricultura y Pesca (creación de una agencia para la puesta en marcha del plan), e incluye como prioridad mejorar las condiciones sociales en el medio rural y reducir los índices de pobreza. Las acciones clave son la reconversión, la intensificación y la diversificación de cultivos. Se pretende, por ejemplo, transformar extensiones de cereal poco productivas en cultivos destinados a la exportación que generen mayores ingresos (el tomate o la fresa) reforzando el comercio en el mercado de la UE, e introduciéndose en nuevos como EE.UU o China. En relación a los recursos hídricos, el Plan plantea la tarificación del agua, especialmente en las explotaciones privadas, un mejor aprovechamiento de la misma, y el delegar progresivamente su gestión en las Oficinas Regionales Agrícolas (c) (d).

La UE está liberalizando cada vez más el comercio agrícola con Marruecos en base al Acuerdo de Asociación en vigor desde el año 2000 y enmarcado en la Política de Vecindad. Su objetivo último es el establecimiento de una zona de libre comercio, para lo cual, entre otros aspectos, se ha venido actualizando su Protocolo agrícola. Actualmente, éste se encuentra en proceso de renovación (a falta de ratificación por el Parlamento Europeo) y supondrá un paso más en la liberalización de determinadas producciones mediante la ampliación de los contingentes de entrada de algunas frutas y hortalizas y la reducción de aranceles, aumentando la competitividad con los productos de los Estados miembros y favoreciendo así los acuerdos económicos con el país (e). Esto a su vez, está generando conflictos de intereses y rechazo por parte de países como España, Italia o Portugal, cuyas asociaciones agrarias denuncian el impacto económico producido, por ejemplo, por la entrada del tomate marroquí en el mercado, para el que, según afirman, se incumple los contingentes y el sistema de precios de entrada pactados.

La industria es otro de los sectores que contribuye de una manera importante al desarrollo económico de los países. El sector agroalimentario, la producción de metales, cemento o textil, entre otros, generan puestos de trabajo y exportaciones y contribuyen de manera significativa a los niveles de PIB nacionales. Se espera que el sector industrial y la producción de productos manufacturados aumenten progresivamente, más aun con los cambios sociales y las aperturas de las economías del sur y este de la región. Sin embargo, el sector también viene acompañado de impactos ambientales, y en el medio hídrico los vertidos de aguas no tratadas, producen importantes aportes de contaminantes, materiales en suspensión o metales pesados.

El agua es también necesaria para la producción, en la refrigeración de plantas, así como una fuente de energía en la región, ya que la hidroeléctrica cubre porcentajes no despreciables de abastecimiento en algunos países (en 2009, representó el 7,3% de la generación eléctrica española, MARM, 2009, mientras que en Turquía representó el 18,72% en el año 2006, y el 12,40 en Egipto en 2007, IEA 2011). Las extracciones, las recurrentes sequías y el consecuente descenso en los caudales de los ríos, hacen que la producción en las plantas hidroeléctricas se esté viendo comprometida.

Otro sector que juega un papel relevante en la región es el turismo, acogiendo un 30% del total global. En 2007, por ejemplo, se registraron 275 millones de turistas, siendo la región número uno en destinos turísticos. El sector genera miles de puestos de trabajo, ayuda en el desarrollo de regiones menos favorecidas y además fomenta el intercambio social y cultural. La contribución total de viajes y turismo al PIB de los países mediterráneos se estima en 895,3 billones de dólares para 2011 (un 10,9% del PIB total), previendo su aumento en un 2,5% para el año 2021. Además, el sector alberga el 4,5% del total de puestos de trabajo (WTTC, 2011). Los desplazamientos y las estancias se concentran en la mayor parte de los casos durante el verano, por lo que la demanda de agua tiene lugar en la época del año de mayor escasez en el mediterráneo. El turismo, es por tanto en muchos casos la razón por la que nuevas fuentes o aportaciones de agua se conviertan en necesarias de manera concentrada espacial y temporalmente. Según los medios de comunicación, las revueltas sociales y la inestabilidad política en la región, están ya teniendo impactos sobre la distribución del turismo, y los países de la franja norte se están viendo favorecidos en detrimento del descenso producido en el resto.

Retos ambientales e hídricos

Como se ha mencionado, el agua es necesaria para cualquier actividad económica, aunque la agricultura sigue siendo su principal demandante y cobra un papel protagonista en la región utilizando la mayor parte de la misma. Otros sectores como la industria o el turismo, también consumen agua y producen importantes impactos en el medio natural. Y aunque la escasez del agua podría considerarse uno de los principales problemas, la región se enfrenta a muchos otros impactos ambientales, producidos en gran parte por la actividad humana. La producción agraria o el desarrollo industrial, llevan parejos la contaminación de los recursos hídricos, la erosión del suelo o los vertidos. Las actividades agrarias, en las que se sustenta en gran parte la economía de la región, requieren de importantes aportes de fitosanitarios, que producen graves problemas de contaminación difusa, tanto en aguas superficiales como subterráneas, siendo estas últimas aún más frágiles debido a los lentos procesos de recarga. Estos problemas de contaminación hídrica producen, a su vez, impactos económicos negativos: mayor necesidad de depuración en los cursos de aguas superficiales, aplicación de tratamientos a la hora de utilizar aguas subterráneas especialmente para abastecimiento de poblaciones, o incluso imposibilidad de aprovecharlas debido a los altos contenidos de nitratos y fosfatos. Cuando los recursos económicos o humanos para tratar y depurar las aguas son insuficientes y se siguen produciendo extracciones, los pesticidas y fertilizantes pueden provocar problemas de salud, tanto por el consumo directo del agua, como por la contaminación de hortalizas.

La sobreexplotación de acuíferos para abastecimiento urbano produce generalmente intrusión marina en los acuíferos costeros, y algunos acuíferos fósiles no renovables están siendo explotados sin posibilidad de recargarse de manera natural, como ocurre por ejemplo en Egipto, en el Sistema Acuífero de Piedra Arenisca de Nubia, y en Libia (Foresight, 2011, FAO 2011). La disminución de extensiones de humedales y lagos y la pérdida de sus funciones naturales, las mortandades de peces o el incremento de la desertificación son también problemas comunes a los países de la región.

Ciertos cultivos altamente demandantes de agua (algodón, arroz, maíz o remolacha) están produciendo progresivamente una mayor demanda en zonas que ya de por sí tenían un desequilibrio hídrico o incluso sufrían escasez de agua. Esta situación incrementa a su vez la competencia entre los diferentes sectores consumidores de agua. La utilización del agua para regar mayores extensiones de cultivo se traduce en un descenso de los caudales naturales lo que produce impactos en los ecosistemas acuáticos (como por ejemplo humedales), o conflictos sociales al disminuir la disponibilidad del recurso aguas abajo (en una parte del cauce lejos del lugar de la extracción).

Otros problemas ambientales, incluyen la introducción de especies invasora y agresivas, no autóctonas en la región, que reducen la biodiversidad de los campos, desplazan y afectan a especies animales, alteran ecosistemas y provocan empobrecimiento y erosión de los suelos, así como el posible riesgo de la utilización de organismos genéticamente modificados (OGMs). Respecto a estos últimos, aún debe realizarse una evaluación más profunda entre sus beneficios (resistencia a plagas y a las sequías por ejemplo) frente a sus posibles impactos (efectos tanto en fauna como en flora en contacto o contaminación de campos biológicos) donde la opinión pública ejerce una importante influencia. Asimismo, la contaminación local del aire es habitual debido a la quema de residuos de la mayor parte de los cultivos tradicionales (aunque el aporte de nutrientes es mucho menor que si los residuos se dejaran descomponer de manera natural). También la desprotección del suelo tras la quema acelera la erosión, favoreciendo la desertificación y el descenso de producción en tierras de cultivo.

A pesar de todas estas externalidades, la agricultura y el sector agroalimentario siguen siendo una actividad económica de gran relevancia en los países de la región, empleando a un alto porcentaje de la población activa (**Tabla 2.** Turquía, Túnez, Siria, Marruecos, Egipto o Argelia) y proporcionando servicios ambientales y paisajísticos rara vez valorados. Cabe mencionar que algunos ecosistemas utilizados principalmente para la producción de alimentos presentan un alto valor ecológico debido a su biodiversidad. Además, en muchos ecosistemas agrarios en la cuenca mediterránea los altos niveles de biodiversidad se han adaptado a la prácticas agrarias existentes durante miles de años, por lo que es posible la producción de alimentos mientras se mantienen la biodiversidad y los servicios de los ecosistemas (Foresight, 2011). La utilización de ciertas prácticas agrarias, la expansión de la agricultura biológica y la mecanización en las zonas más aptas, podrían lograr un uso más racional tanto de agua como de suelo y fitosanitarios, reduciendo externalidades al mismo tiempo que conservando los beneficios del sector.

Expectativas y mejoras en la gestión de los recursos hídricos

Existen diferentes mejoras en los procesos de utilización y gestión de los recursos hídricos, que pueden aplicarse para asegurar el suministro a los principales usos, e idóneamente de manera sostenible, y mejorar la competitividad de la agricultura en la región. En este sentido, la tarificación del agua y los aspectos tecnológicos serán clave en los años futuros. Tanto la mejora en las técnicas de cosecha, como el aumento y modernización de infraestructuras, especialmente en el regadío, se podrán traducir en una mayor eficiencia en la producción y un menor uso del agua, logrando costes económicos y energéticos aún más bajos. Estas mejoras incluyen la modernización de sistemas de riego, la reutilización del agua y el uso de otros recursos no convencionales que deberán ir acompañadas de una política de precios adecuada.

En relación a los recursos no convencionales, algunos países producen ya importantes volúmenes que son utilizados principalmente en el sector turístico o en el abastecimiento urbano en el caso de la desalación, y para la agricultura en el de reutilización de aguas usadas. España, con una producción cercana a los 700 millones de m^3 anuales en 2009, se sitúa actualmente ya como el cuarto país en producción de agua desalada del mundo por detrás de Arabia Saudí, Estados Unidos y los Emiratos Árabes (MARM, 2009). Argelia, también se sitúa en el Mediterráneo como importante productor de agua desalada, con unos 109,5 millones de m^3 al año, valor que tras la finalización de once plantas desaladoras se podría multiplicar por ocho (PB, 2009). También en Israel es ésta una práctica extendida y se produce actualmente 450 millones de m^3 al año de agua desalada, siendo el objetivo del gobierno producir 750 para el año 2020 y hacer frente a la escasez de agua (FAO, 2011; MAE, 2005). En cuanto a la reutilización, países como Turquía, Siria o España producen importantes volúmenes que son usados en su mayor parte para el regadío (2.770, 1.364 y 1.012 millones de m^3 al año respectivamente) (FAO, 2011; SIA 2011). Como todo tratamiento asociado al agua, tanto la reutilización como la desalación requieren de técnicas especializadas que presentan costes energéticos y posibles problemas ambientales asociados principalmente a la descarga y tratamiento de residuos (lodos residuales y salmuera) y a las emisiones de CO_2. En los últimos años, se ha avanzado en el uso de nuevas tecnologías para la reducción de costes y energía requeridos, y en el desarrollo de estudios para evaluar los posibles impactos ambientales mediante dispositivos de difusión y vertido al mar, y fomentar el uso de tecnologías de desalación basadas en energías renovables, como la solar o la eólica.

Por otro lado, se necesitarían infraestructuras adicionales de distribución de agua, así como sistemas de almacenamiento en algunos países (que además, en el caso de las presas, minimizarían los impactos de inundaciones, por su papel laminador). Por ejemplo, en el caso de los Territorios Ocupados Palestinos, se ha planteado la construcción de pequeñas presas en *wadis* (o ramblas), que permitiría el almacenamiento de agua de lluvia, la cual suele concentrarse en cortos periodos de tiempo con escasa posibilidad de ser aprovechada.

También la rotación de cultivos y otras técnicas previamente descritas, minimizarían los impactos producidos principalmente en los recursos hídricos, el suelo y el aire, y reducirían las externalidades de la producción agraria. En la práctica totalidad de los países mediterráneos, el tratamiento de las aguas residuales es insuficiente o inexistente, por lo que deberá abordarse para reducir los problemas de calidad que afectan tanto a ríos como al Mar Mediterráneo.

Asimismo, la mejora de almacenamiento, procesamiento y transmisión de información, homogenización de bases de datos a escala regional (mediante estructuras existentes como el Sistema Euromediterráneo de Información sobre el Agua, SEMIDE), nacional y de cuenca, promovería su acceso por parte del público general promoviendo la concienciación social. El avance e implantación de sistemas de alerta temprana que minimicen impactos de fenómenos extremos, la teledetección para prever sequías o contabilizar extensiones de cultivos, y otras tecnologías serán clave a la hora de optimizar la utilización del agua y paliar, en la medida de lo posible, los impactos derivados de los fenómenos extremos. Otros aspectos importantes, serán el fortalecimiento institucional (por ejemplo, mediante cursos técnicos de formación) y la mejora de los marcos legales en la gestión y protección del agua. Por último, las cuentas satélite, como se ha mencionado, permitirían a los gobiernos mediterráneos mejorar la metodología y la valoración del daño ambiental, y enlazar los indicadores de rendimiento económico de la producción agraria con los índices de presión sobre el medio ambiente.

4. Políticas e iniciativas internacionales y recientes revueltas sociales

Ha habido políticas e iniciativas económicas y ambientales que se han lanzado en los últimos años para mejorar la cooperación en la región, fomentar el comercio e intercambio de bienes o movimiento de trabajadores entre las dos orillas, o proteger los recursos naturales, de gran importancia para la estabilidad política y social en la región. Tanto la transferencia e intercambio de conocimiento y aspectos técnicos como las ayudas e inversiones internacionales en los países en vías de desarrollo han tenido notables repercusiones en la construcción de infraestructuras, modernización de las prácticas agrarias, y mejora en el acceso a agua potable y saneamiento básico.

Los problemas hídricos han sido identificados en el ámbito político principalmente en el marco de las conferencias ministeriales, y discutidos ampliamente durante las reuniones de carácter más técnico de los Directores del Agua de las administraciones de los países ribereños que se vienen produciendo de manera periódica desde 1997. Y aunque se ha avanzado en la búsqueda de soluciones a problemas hídricos comunes, son muchos los aspectos prácticos y ambientales quedan todavía por abordar.

Conflictos por el uso del agua y el territorio

Los conflictos sociales en torno al uso y explotación del agua en la región son conocidos, y las tensiones por el recurso continúan siendo altas particularmente en Egipto, Malta, Siria, Libia e Israel (PB, 2009). Probablemente, el caso más destacado es el de Israel y los Territorios Ocupados Palestinos, ya que en numerosos conflictos bélicos los objetivos militares han sido el control del agua y explotaciones agrarias, puentes, potabilizadoras, canales y otras infraestructuras asociadas a los recursos hídricos. La mayor parte del agua que se disputa es la del acuífero de montaña de Cisjordania y los recursos del Río Jordán. En términos económicos, y en comparación con el coste de agua desalada, la estimación del valor de los 150-350 m^3/año que se extraen del acuífero y se distribuyen es de unos 30-70 millones de dólares al año, cifra que no llega ni al 0,1% del PIB israelí o palestino (Fisher *et al.,* 2005). El acuerdo de cesiones mínimas de agua aseguradas por parte de Israel a los Territorios Ocupados Palestinos, o el incremento de recursos no convencionales (desalación y reutilización) fácilmente proporcionaría la garantía de recursos requerida y una mayor estabilidad política en la zona.

Contrariamente al pesimismo generalizado sobre la posibilidad de llegar a acuerdos fructíferos y beneficiosos para las diferentes partes en la región Mediterránea, algunos sectores ven precisamente en el agua una oportunidad y un instrumento de cooperación e intercambio de información que promueva la paz y la estabilidad en la región. Los países de Oriente Próximo se enfrentan a problemas comunes y a una escasez de agua cada vez más aguda, por lo que el agua y el medio ambiente pueden ser críticos para el desarrollo regional y la *re-*

siliencia de las poblaciones frente a los impactos del cambio climático. Además, se vienen planteando posibles soluciones a corto y medio plazo, como la creación de comités conjuntos técnicos y políticos que promuevan una gestión integrada del agua por cuenca, la cooperación entre las partes implicadas, el intercambio de datos o la investigación, basándose en principios políticos comunes y protocolos para la restauración y protección de las aguas. Esta cooperación, con perspectiva ecológica y sostenible, aseguraría una gestión conjunta de los recursos, disminuiría la posibilidad de destrucción de infraestructuras en momentos de conflicto y atraería inversiones internacionales más fácilmente (SFG, 2011).

Por otro lado, en relación a las tierras, la región Mediterránea cuenta con una mezcla de extensas producciones agrarias, con otras de menor tamaño, fragmentadas y gestionadas localmente y en cooperativas. En algunos casos, hay conflictos por el uso y la titularidad de tierras, así como por el derecho al uso del agua en las zonas cultivables. En este contexto, la gestión centralizada de las aguas puede entorpecer el desarrollo y la lucha por la autosuficiencia de regiones o entidades locales.

Las Metas del Milenio y el acceso al agua potable

En el marco de las Naciones Unidas, se aprobaron en el año 2000 las conocidas Metas del Milenio a alcanzarse en el año 2015, con objeto de asegurar el desarrollo humano, luchar contra la pobreza y generar mayores oportunidades para beneficiarse de la economía global. Han sido recientemente revisadas en la Cumbre de 2010, aprobando un marco acelerador para facilitar su cumplimiento (UN, 2009a). En relación al agua, el objetivo 7 trata de garantizar la sostenibilidad del medio ambiente, y más concretamente la meta 10 establece reducir a la mitad el porcentaje de personas que carece de acceso sostenible al agua potable y al saneamiento básico. Mientras que en los Estados miembros de la UE el acceso al saneamiento y al agua potable está prácticamente asegurado al 100%, no sucede lo mismo en todos los países de la región. Según el informe de UN sobre desarrollo en los países árabes (2009b) se han realizado importantes esfuerzos por abastecer a las poblaciones con agua potable, traduciéndose en un cambio de un 83% en 1990 a un 85% en 2004, y alcanzándose el 86% en las zonas del Magreb y Mashreq. A pesar de este progreso significativo, existe todavía diferencias entre el acceso a agua potable en el ámbito rural y el urbano (ver **tabla 2**), por ejemplo en países como Marruecos, Túnez, Argelia o Siria. Además, en el caso de Libia el acceso en zonas urbanas también está limitado.

No solo la escasez de agua y el acceso a recursos limpios son los problemas a los que se enfrenta la región; también, como se ha explicado, la contaminación del agua, principalmente por fertilizantes, pesticidas, vertidos de aguas residuales sin depurar o contaminantes emergentes, como medicamentos, amenaza el acceso a agua limpia y la seguridad humana. Cabe destacar que la gestión y tratamiento de aguas, así como la capacidad de inversión en depuración, entre los países del sur y este de la región son muy reducidos. Las medidas de tratamiento de agua son insuficientes, y por otro lado, se estima que una buena parte del agua en las redes de abastecimiento en ciertos países supera los niveles recomendados de arsénico, nitratos, amonios, fluoruros y sales afectando a la salud de las personas.

Horizonte 2020

Una de las iniciativas lanzadas para afrontar estos problemas de contaminación es el Horizonte 2020, que viene reflejada en la Comunicación de la CE al Consejo y al Parlamento, *Establecer una estrategia medioambiental para el Mediterráneo* que proporciona apoyo a los países ribereños para hacer frente a las emisiones industriales y a los vertidos de aguas residuales provenientes de zonas urbanas con el objetivo de reducir la contaminación del Mediterráneo (EC, 2006). Para descontaminar el Mar Mediterráneo en el año 2020, la iniciativa se centra en cuatro elementos principales: (1) proyectos que reduzcan las fuentes de contaminación más significativas (industrias, vertidos y desechos municipales), (2) medidas de fortalecimiento institucional (creación de administraciones ambientales que desarrollen legislación en la materia), (3) utilización de los fondos de investigación de la CE para intercambiar conocimientos medioambientales relevantes sobre el Mediterráneo y (4) desarrollo de indicadores que analicen el éxito del Horizonte 2020. Esta iniciativa se dirige a los países asociados definidos bajo la Política de Vecindad (PEV), y destaca la utilización de su herramienta financiera *European Neighbourhood and Partnership Instrument* (ENPI), para llevar a cabo su objetivo, catalizando esfuerzos e inversiones adicionales provenientes de instituciones internacionales.

La Política de Vecindad y la Unión por el Mediterráneo.

Los intentos de acercamiento desde la UE a países ribereños han sido importantes en los últimos años. El Proceso de Barcelona de 1995, o Asociación Euromediterránea de los 15 países de la Unión y 12 países del sur del Mediterráneo o la Política de Vecindad (PEV) (EC, 2003) son prueba de ello. Los objetivos de ambos ejemplos han estado más bien centrados en aspectos como democracia y derechos humanos, seguridad y defensa, cuestiones económicas y financieras, como creación de una zona de libre comercio, o actividades culturales, dejando en un segundo plano, al menos inicialmente, los aspectos medioambientales. Aunque la Declaración de Barcelona mencionaba la necesidad de conciliar la actividad económica con la protección medioambiental, y reconocía el abastecimiento de agua como una cuestión prioritaria, estos aspectos sólo formaban una pequeña parte de los objetivos. Con la nueva “etiqueta” UpM, se relanza y amplía el Proceso de Barcelona en la cumbre de París de julio de 2008 tras más de una década de existencia y con duras críticas sobre su éxito. Diferentes autores han opinado que el Proceso de Barcelona no obtuvo los resultados esperados, entre otros aspectos, por la falta de implicación de la sociedad civil y de definición de cooperación con Estados Unidos, la necesidad de una mayor relación entre el Proceso y la PEV, así como de reforzar la cooperación entre los países, mejorar loa colaboración sociocultural o minimizar los conflictos existentes (Fernández y Youngs, 2005; Jerch *et al.*, 2005). En 2008, se trata de reimpulsar los trabajos centrándose en los ejes de descontaminación del mar, plan solar mediterráneo, implicación de actores financieros, y refuerzo de los lazos existentes en la región y se decide crear su Secretariado en la ciudad de Barcelona. Es decir, se introducen importantes retos, teniendo ahora más en cuenta, aspectos medioambientales, claramente interconectados con los socioeconómicos.

El objetivo de la PEV, por otra parte, ha sido el crear una zona “amiga y segura” ampliada (Europa junto con países del sur y del este) con fuertes lazos económicos, y se basa precisamente en la integración económica, y en el intercambio de productos, principalmente agrícolas, y servicios. Aborda superfluamente aspectos medioambientales, mencionando la protección medio ambiental principalmente ligada a la eficiencia económica, y sólo hace referencia específica al agua, en relación a la cooperación transfronteriza y la seguridad.

Por otro lado, la experiencia de un marco de política común en la materia (DMA) y los avances logrados en los Estados miembros hacia una gestión integrada del agua han querido compartirse con el resto de países mediterráneos. La Componente Mediterránea de la Iniciativa Europea del Agua (MED EUWI) y el Proceso Conjunto MED EUWI y Directiva Marco del Agua (Joint Process DMA) han sido prueba de ello, al diseñar programas orientados al agua, que facilitaran la coordinación entre proyectos, hicieran más eficiente el uso de fondos, y mejoraran la cooperación para implantar más adecuadamente los proyectos.

Además, ya relanzada la Unión por el Mediterráneo en 2008, (agrupando a 43 países, además de a la Liga Árabe, la Comisión Europea y Libia como observador) y durante la celebración de la Conferencia Ministerial Euromediterránea del Agua, celebrada en Jordania en diciembre de ese año, se marcan los inicios de crear una Estrategia del Agua a largo plazo en la región con la idea de aprobarla durante el primer semestre de 2010 bajo la presidencia española del Consejo de la UE. Tal y como establecía la Declaración de Jordania, se debía hacer frente a los problemas relacionados con el cambio climático y las necesidades ambientales, utilizando enfoques integrados considerando todos los tipos de gua, conservando la calidad del agua y evitando su futuro deterioro o encontrando un balance entre la cantidad de agua requerida y su disponibilidad (escasez). Incluía objetivos que pudieran ser medidos con vistas a lograr crecimiento económico, prosperidad social, acceso al agua y protección ambiental entre otros, además de desarrollar herramientas tecnológicas en este campo.

Tras la creación de grupos técnicos, respaldados por los máximos responsables en materia de aguas de los países de la región, reuniones y procesos participativos con colectivos sociales entre julio de 2009 y marzo de 2010, se elaboró el borrador de la Estrategia para el Agua en el Mediterráneo (Strategy for Water in the Mediterranean —SWM—). Habría significado un punto de partida y un documento base para coordinar acciones y optimizar fondos y proyectos hidráulicos en la región con criterios y objetivos comunes centrados en gobernabilidad, saneamiento, gestión de la demanda y de fenómenos extremos como inundaciones y sequías. Sin embargo, los conflictos en Oriente Próximo y el bloqueo político asociado, afectaron directamente a las relaciones entre los países, especialmente entre Israel y la Liga de Países Árabes. Por ello, la IV Conferencia Ministerial Euromediterránea que se celebró el 13 de abril de 2010 en Barcelona finalizó sin acuerdo alguno, a pesar del respaldo generalizado al contenido de la SWM. La oposición por parte de Israel y Turquía a dos referencias de carácter político (territorios ocupados y la Convención de Naciones Unidas sobre los Usos de los Cursos de Agua Internacionales de 1997) desencadenaron el desacuerdo. Además, en enero de 2011, el Secretario General de la Unión por el Mediterráneo, el jordano Ahmad Masa'deh, dimitía aludiendo el cambio de condiciones bajo las que aceptó el cargo y la falta de recursos económicos. Los vicesecretarios del Secretariado con sus diferentes carteras, incluyendo la de medio ambiente y agua dirigida por la Autoridad Nacional Palestina, continúan actualmente con los trabajos (Secretariado UpM, 2011).

La falta de respaldo político, el consecuente freno de los trabajos técnicos, la escasez de recursos económicos fijados por la CE o de compromiso por parte de los países miembros de la UpM, han hecho que buena parte de estas iniciativas internacionales en materia de aguas hayan quedado sin implantarse.

Instrumentos de financiación y recursos

Han existido diferentes instrumentos económicos, como los fondos MEDA (12.000 millones de euros para el periodo 1995-2007) o el programa INTERREG desde los cuales se han financiado actuaciones medioambientales e hídricos. A partir de 2007, el instrumento MEDA se transformó en el ENPI con un presupuesto de 11,1 billones de euros para Europa del Este, Cáucaso y Mediterráneo (Argelia, Egipto, Israel, Jordania, Líbano, Libia, Marruecos, Autoridad Palestina, Siria y Túnez) (ENPI, 2011). Sin embargo, el porcentaje de fondos destinados específicamente a actuaciones en agua es reducido y difícil de cuantificar, ya que los fondos se destinan a planes nacionales o regionales que incluyen diferentes sectores, no solo el medioambiental.

También las organizaciones no gubernamentales, organismos, redes y entidades regionales han jugado un papel calve en fomentar la gestión integrada de los recursos hídricos en la cuenca mediterránea, aunando esfuerzos, proporcionando recursos, fomentando sinergias entre proyectos e iniciativas y promoviendo el fortalecimiento institucional. Estas entidades han desarrollado proyectos y organizado conferencias con objeto de intercambiar experiencias, mejorar la gestión del agua, catalizar inversiones, lanzar actividades de investigación y mejorar la cooperación entre países. En muchos casos, se ha contado con apoyo institucional y financiero proveniente del Programa de Medio Ambiente de Naciones Unidas (UNEP-MAP), UNESCO, del Banco Mundial o del Global Environmental Fund (GEF) entre otros.

A pesar de ello, los esfuerzos e iniciativas tanto de administraciones como colectivos se han desarrollado a menudo de manera desagregada e incluso solapándose. Ha faltado un marco común que estableciera bases y criterios comunes para las iniciativas y proyectos centrados en la materia, lanzara planes de acción con objetivos claros y concretos, ayudara a focalizar inversiones y estableciera metas con marcos temporales. La SWM podría haber jugado este papel, y quizá lo adquiera en un futuro cercano, teniendo en cuenta el progresivo acercamiento de los países árabes.

Actualidad

Las revueltas populares en el Magreb y Oriente Próximo acontecidas en el presente año 2011 han estado marcadas por la pobreza, las desigualdades sociales, la oposición a regímenes totalitarios y un creciente deseo de las poblaciones de libertades individuales y mayor apertura hacia el exterior, donde las nuevas tecnologías y el intercambio de información han sido elementos clave. Las revueltas comenzadas en Túnez y extendidas a Egipto, Yemen, Jordania, Siria, Arabia Saudí, Argelia, Marruecos o Bahréin, cuentan ya con la caída de varios presidentes. Aunque los países occidentales han centrado la discusión sobre el control de otros recursos como el petróleo o el gas, en un futuro cercano el control por los diferentes sectores económicos cobrará importancia, y el agua seguirá siendo un elemento relevante en la agenda política.

En muchos casos, la falta de productos básicos o el incremento de sus precios iniciaron las revueltas. Por ejemplo, en el caso de Marruecos, y para apaciguar las protestas, el gobierno anunció un mayor apoyo y subvención a productos como el azúcar, el aceite o el trigo, y los hidrocarburos, así como la compra de toneladas de cereales para evitar su escasez en los mercados mediante el existente Fondo de Compensación, que para el presente año cuenta con 1.500 millones de euros. El Fondo trata, principalmente, de impedir que el aumento de los precios de productos de primera necesidad repercuta en los consumidores (El País, 2011).

Las posibles trasformaciones derivadas de las revueltas pueden ser numerosas, incluyendo cambios de gobiernos, mayor democratización y apertura económica hacia mercados internacionales y reformas legislativas y políticas. Estos cambios sociales, políticos y económicos a medio y largo plazo pueden alterar de manera importante el peso de sectores destacados, como el turismo, la industria o la agricultura. En ese momento, la autosuficiencia en producción de alimentos y el deseo por participar en mercados internacionales podrían entrar en conflicto.

Por otro lado, la posible apertura de las economías de los países podría traducirse en una mayor colaboración entre países y el establecimiento de acuerdos para el aprovechamiento conjunto y la protección de recursos naturales y masas de agua que asegurara tanto el desarrollo agrario de ciertas regiones, como el abastecimiento a poblaciones, dotando de responsabilidades y derechos a las partes implicadas, y apoyando de nuevo las actuaciones en el marco de la UpM y su Estrategia sobre el agua.

Y en todos estos cambios, el agua, continuará siendo un factor limitante para la agricultura o el desarrollo urbanístico e industrial, por lo que jugará un importante papel, y su buena gestión o las medidas que aseguren su uso racional y protección a largo plazo serán esenciales para fomentar un desarrollo sostenible en los países mediterráneos.

5.Conclusiones

El suave clima mediterráneo ha favorecido a lo largo de los siglos el asentamiento y crecimiento de civilizaciones. Actualmente, la presión poblacional, turística, urbanística e industrial en el litoral costero produce graves impactos medioambientales. El agua es un potente motor de desarrollo para la región y mantiene importantes actividades económicas como la agricultura, la industria o el turismo. Los principales problemas ligados a ella incluyen su escasez, distribución irregular, la alta contaminación puntual y difusa, los conflictos entre sectores demandantes, regiones y países, y la sobreexplotación de acuíferos, que además produce intrusión marina en zonas costeras. Estos problemas se ven agravados por las sequías, las inundaciones, y el cambio climático, incrementando los problemas sociales y de gestión.

Existe una clara diferencia en cuanto a desarrollo económico, marcos institucionales y la importancia económica de la agricultura entre el norte y el sur y este de la región. En relación a las externalidades ambientales de la actividad agraria, cabe destacar el uso de pesticidas y fitosanitarios que contaminan las masas de agua en una región que carece a menudo de las requeridas infraestructuras de tratamiento, saneamiento y reutilización. Asimismo, la transformación de zonas naturales de alta biodiversidad, la extracción incontrolada de recursos hídricos de cauces y acuíferos en las zonas más áridas y costeras, son algunos de los problemas presentes.

Las administraciones hidráulicas, que en muchos casos gestionan el agua a escala de cuenca hidrográfica, han logrado progresivamente un mayor control y regulación de los recursos mediante el control y las infraestructuras, aunque falta la aplicación de herramientas económicas que permitan sufragar más los gastos de construcción y mantenimiento y promuevan la concienciación sobre el uso racional del agua y su valor intrínseco. También se ha avanzado, aunque de manera insuficiente en aspectos de saneamiento y acceso a agua potable o en el tratamiento de aguas residuales. Se espera que los siguientes pasos se centren en la gestión de la demanda, reduciendo pérdidas en los sistemas y sensibilizando a la población. La modernización de infraestructuras y técnicas de regadío, así como el uso de recursos no convencionales y la priorización de usos, fomentando las actividades socioeconómicas en las zonas más óptimas y adaptadas para cada una, serán por tanto parte del futuro de los países mediterráneos. Sin una adecuada gestión del agua, y sin lograr minimizar los impactos socioeconómicos y ambientales de la escasez del agua y las sequías, el intercambio de productos agrícolas y el desarrollo sostenible de la región estarán comprometidos.

Será clave también la coordinación técnica entre los países del norte y del sur y este, para intercambiar conocimiento sobre las experiencias positivas alcanzadas y analizar los logros y deficiencias en la aplicación de políticas como la DMA. Por otra parte, el trabajo técnico, en la medida de lo posible, deberá desligarse de los conflictos políticos que puedan surgir durante el Proceso de Paz de Oriente Próximo, y entre Israel y la Liga de Países Árabes.

Las Administraciones hidráulicas en la región deberán ser capaces de aplicar la legislación ambiental y en materia de aguas existentes, exigir su cumplimiento, y controlar tanto la aplicación de pesticidas, como la contaminación puntual y difusa de las masas de agua para evitar altos costes ambientales a largo plazo. En estos procesos, la descentralización y los procesos participativos tendrán que reforzarse. Además, en algunos países donde el marco legal sea más débil, su desarrollo y el fortalecimiento institucional serán aspectos relevantes, así como la estrecha colaboración con otros sectores y políticas (relacionadas por ejemplo con el cambio climático y de desarrollo territorial).

Se deberá fomentar la conservación de la actividad agraria allá donde sea más beneficiosa tanto por sus efectos económicos como sociales y ambientales y conservar y generar puestos de trabajo en zonas rurales marginales para evitar éxodos y aglomeraciones en las zonas urbanas, donde la creciente población requerirá aún más servicios mínimos, alimentos, energía y agua. Sin la aplicación de buenas prácticas agrarias, los costes ambientales y sociales de la agricultura, contrarrestarán sus posibles beneficios económicos y sociales. Las políticas agroalimentarias deberán, además desarrollarse y coordinarse estrechamente con otros sectores como la industria, la energía, la gestión del agua, el desarrollo territorial, los servicios de los ecosistemas y la biodiversidad.

Los habitualmente llamados recursos no convencionales, como la desalación de agua de mar o aguas salobres o la reutilización de aguas usadas han visto incrementado su uso en los últimos años y se prevé un aumento del volumen de agua obtenida mediante estas técnicas. Los principales obstáculos, como externalidades ambientales, el coste de su producción, o el alto consumo energético están siendo abordados mediante nuevas tecnologías y el uso de energías renovables, como la solar.

La aplicación de instrumentos económicos, aunque a menudo escasos en comparación con otros sectores, y las iniciativas de redes y colectivos sociales han sido notables, pero se han desarrollado de manera desagregada, a menudo solapándose y sin objetivos comunes.

Ha habido importantes acercamientos de la CE a los países mediterráneos no comunitarios por intereses de cooperación económica y de seguridad, e intentos de transferencia de políticas y criterios de protección ambiental. Los aspectos ecológicos y concretamente aquellos en materia de agua no han sido siempre una prioridad a pesar de su importancia para la economía y producción de alimentos, aunque vienen en parte reflejados en las metas del milenio o la Política de Vecindad, pero sobre todo en el Horizonte 2020 y en la Estrategia para el Agua en el Mediterráneo de la UpM. La Estrategia podría haber representado el hilo conductor con bases y criterios comúnmente aprobados para gestionar y proteger el agua a medio y largo plazo con hitos temporales concretos. Su importancia recae en el hecho de que sin un adecuado enfoque en la gestión de los recursos hídricos no se logrará alcanzar ciertos objetivos regionales como: crecimiento económico, prosperidad social, equidad en el acceso al agua y eficiencia de su uso, o la protección medioambiental.

Las revueltas vividas en los países de sur de la cuenca mediterránea y en Oriente Próximo afectarán a las estructuras gubernamentales y podrían fácilmente traducirse en reformas legislativas y económicas. En estos futuros cambios, el agua, como factor esencial para el desarrollo económico, así como su gestión y protección podrían tener un papel relevante en la agenda política de la región.

Tabla 1. Resumen de disponibilidad y aprovechamiento de recursos hídricos en países mediterráneos seleccionados (Fuentes: FAO; INE; MARM; EUROSTAT).

País	Población (millones habitantes)	Área (Km^2)	Precipitación media (mm/año)	Recursos hídricos renovables, totales internos (km^3/año)	Recursos hídricos renovables totales por cápita (km^3/año)	Superficie cultivada (1.000 hectáreas)	Consumo de agua en la agricultura	Consumo de agua en la industria	Capacidad de almacenamiento de presas (millones m^3)	Aportación de la agricultura al PIB y población activa en el sector	
Argelia	34,3	2.381.740	89	11,3	339,5	8.424	65%	13%	5.676	11%	23%
Egipto	73,4	1.001.450	51	1,80	702,8	3.422	86%	65%	169.000	16,8%	31%
España	43,8	504.782	650	111,50	2.506	17.300	60%	21%	55.586	2,6%	4,04%
Francia	62,0	549.190	867	200,00	3.401	19.331	12%	69%	9.917	2%	3,8%
Grecia	11,1	131.960	652	58	6.667	3.225	89%	2%	11.770	4%	12,4%
Israel	6,7	20.770	435	0,78	254	392	58%	6%	-	1,8%	2,2%
Italia	59,6	301.340	832	182,5	3.210	9.768	44%	36%	8.430	1,8%	4,2%
Jordania,	5,7	88.780	94	0,68	161	270	64,9%	4%	275	3%	9,8%
Líbano	4,1	10.450	661	4,50	1.074	286	59%	11%	228	6%	2,6%
Libia	5,6	1.759.540	56	0,60	113	2.150	83%	2,9%	385	9%	5%
Marruecos	31	446.550	346	29,00	971	9.283	87%	2,8%	16.904	18%	33%
Siria	19	185.180	252	7,13	1.403	5.742	87%	3,5%	19.654	20%	25,8%
Territorios Ocupados Palestinos	4,1	6.020	402	0,812	201	218,2	45%	6,9%	0	9,5%	10%
Túnez	10,1	163.610	207	4,19	482	5.041	75%	3,8%	2.512	12,9%	23%
Turquía	73,2	783.560	593	227	2.800	26.606	73,8%	10,7%	651.000	9%	42,6%

Tabla 2. Porcentaje de población con acceso a agua potable en países mediterráneos seleccionados (Fuente: FAO).

País	Recursos renovables por cápita (m^3/año)	Población rural abastecida	Población urbana abastecida
Argelia	473	80%	92%
Egipto	859	97%	100%
España	2.506	100%	100%
Francia	3.439	100%	100%
Grecia	6.667	100%	100%
Israel	254	100%	100%
Italia	3.210	100%	100%
Jordania	161	91%	99%
Libia	113	68%	72%
Líbano	1.074	100%	100%
Marruecos	971	56%	99%
Siria	1.403	83%	95%
Territorios Ocupados Palestinos	201	88%	94%
Túnez	482	60%	94%
Turquía	2.800	95%	98%

Referencias

Arnell, N. W., 1999. Climate change and global water resources. Global Environmental Change, 9 (1999) S31-S49.

Arnell, N. W., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. Global Environmental Change, 14 (2004) 31-52.

CE, Comisión Europea, 2007. Comunicación de la Comisión al Parlamento Europeo y al Consejo. Afrontar el desafío de la escasez de agua y la sequía en la Unión Europea. COM (2007) 414 final.

Dai, A., 2010. Drought under global warming a review. Advanced review.

De la Peña, J.M., 2006. Diferencia del Concepto de Obra Pública Actual y en la Roma Clásica. Ingeniería Civil, nº 141, CEDEX Ministerio de Fomento.

Estrela T., y Vargas, E. 2008. Los Problemas del Agua, Una visión global sobre los recursos hídricos disponibles. La Desalación en España, Cap.1. Aguas de las Cuencas Mediterráneas, S.A. (Acuamed). DL M-27347-2008.

EEA. European Environmental Agency. State of the environment report No 1/2010. Chapter 7: environmental challenges in a global context. ISBN: 978-92-9213-114-2

Fairén Le Lay, V., 2008. Crónicas del agua. Vida Científica. Colaboraciones en Ciencias de la Naturaleza. Serie: Problemas del Medio Ambiente. Parte 3. Facultad de Ciencias UNED.

Fernández, H.A., y Youngs, R., 2005. Proceso de Barcelona: balance de una década de Asociación Euromediterránea. Real Instituto Elcano de Estudios Internacionales y Estratégicos. Área: Mediterráneo y Mundo Árabe- ARI nº 137/2005.

Ferragina, E., 2010. Focus: Water Policy in the Mediterranean: An Overview. IEMED.

Fisher, M.F., y Huber-Lee, A., 2005. Liquid assets. An economic approach for water management and conflict resolution in the Middle East and beyond. Together with Amir I., Arlosoroff S., Eckstein Z., Haddadin M.J., Jayyousi A.F., Shamir U., and Wesseling H. Resources for the future press.

Foresight, 2011. The future of Food and Farming. Executive Summary. The Government Office for Science. London.

Ganoulis, J., 2004. Water resources management and environmental security in Mediterranean transboundary river basins. In: Linkov, I. ed (2004) "The role of Risk Assessment in Environmental Security and Emergency Preparedness in the Mediterranean Region". Kluewer, Amsterdam.

IDDRI, Institut du développement durable et des relations internationales, 2009. The Future of the Mediterranean. From Impacts of Climate Change to Adpatation Issues. SciencesPo.

Iglesias A., Garrote, L., Flores F., Moneo, M., 2006. Challenges to manage the risk of water scarcity and climate change in the Mediterranean. Water resources manage. Springer Science.

IPCC, 2007. Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IWMI, International Water Management Institute, 2008. Water implications of biofuel crops: understanding tradeoffs and identifying options. Water policy brief. Issue 30.

Jerch M., Lorca A., Escribano G., 2005. De Barcelona a Luxemburgo: la política euromediterránea. Política Exterior nº107.

MAE, 2005. Ministère des Affaires Étrangères. Dossier du Service pour la Science et la technologie. L'Eau en Israël. Ambassade de France en Israël. Services de Coopération & Action Culturelle.

MARM, 2009. Perfil Ambiental de España. Informe basado en indicadores (NIPO 770-09-185-7).

MMA, 2006. Ministerio de Medio Ambiente. Secretaría General Técnica. *Las galerías drenantes del Sureste de la Península Ibérica. Uso tradicional del agua y sostenibilidad en el Mediterráneo español.* Hermosilla, J. ISBN: 8483203707.

Nordhaus, W.D. y Tobin, J., 1973. "Is Growth Obsolete?" en Economic Growth, Fiftieth Anniversary Colloquium V, NBER, New York.

PB, UNEP/MAP-Plan Bleu, 2009. State of the Environment and Development in the Mediterranean. UNEP/MAP-Plan Bleu, Athens.

Ruf, T., y Valony, M.J., 2007 Les contradictions de la gestión intégrée des ressources en eau dans l'agriculture irriguée méditerránéenne. Synthèse, pression sur les resources et développement durable. Cahiers Agricultures vol. 16, nº4, julliet-août 2007.

Saverio Civili, F., 2010. La contaminación de origen terrestre en el Mar Mediterráneo: estado actual y perspectivas. Anuario IEMed del Mediterráneo. Med2010. ISSN 2013-3812.

SEMIDE. System Euro-Mediterraneen d'Information sur les Savoir-Faire dans le Domaine de l'Eau, 2005. Local Water Supply, Sanitation and Sewage, Country report, Morocco.

SFG, Strategic Foresight Group, 2011. The Blue Peace, Rethinking Middle East Water.

Struglia, M.V., Mariotti, A, and Filograsso, A. 2004. River Discharge into the Mediterranean Sea: Climatology and Aspects of the Observed Variability. Journal of Climate. Volume 17.

UN, 2009a. UN Millennium Development Goals Report 2009. United Nations, Geneva.

UN, 2009b. Arab Human Development Report 2009. Challenges to Human Security

in the Arab Countries.
UN, 1994. Manual de Contabilidad Nacional, Contabilidad Ambiental y Económica Integrada.
WTTC, World Travel & Toursim Council. 2011. Travel and Toursim Economic Impact, Mediterranean.
VWWF. V World Water Forum, 2009. Regional Document, Mediterranean. ISBN 978-605-60848-1-2.

Cuadros de texto

(a) Olcay Ünver, I.H., 2001. Southeastern Turkey: Sustainable Development and Foreign Investment. GAP Regional Development Administration, Prepared for the OECD-China Conference on FDI in China's RegionalDevelopment.
(b) OECD (2008), Environmental Performance of Agriculture in OECD countries since 1990, Paris, France
(c) Embajada del Reino de Marruecos en Madrid, 2008. Boletín Quincenal del Departamento Económico, Informaciones económicas y comerciales de Marruecos. N° 04 B-2008.
(d) Agence Marocaine de Développement des Investissements, 2011. http://www.invest.gov.ma
(e) European Union External Action. http://www.eeas.europa.eu/morocco/association_agreement/index_en.htm

Legislación mencionada y otros documentos

Declaración Ministerial, 2008. Euro-Mediterranean Ministerial Conference on Water, 22 December 2008, Dead Sea, Jordan.
Directiva del Consejo 91/271/CEE Sobre el tratamiento de las aguas residuales urbanas.
Directiva 2000/60/CE del Parlamento Europeo y del Consejo de 23 de octubre de 2000 por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas (DO L 327, 22.12.2000).
Estrategia para el Agua en el Mediterráneo. IV Conferencia Ministerial Euro-Mediterránea sobre el Agua. Barcelona, 2010. Versión Pre final.
EC, 2006. Communication from the Commission to the Council and the European Parliament. Establishing an Environment Strategy for the Mediterranean. COM(2006) 0475 final.
EC, 2003. Communication from the Commission to the Council and the European

Parliament. Wider Europe-Neighbourhood: A New Framework for Relations with our Eastern and Southern Neighbours. COM(2003) 104 final.

Páginas web

El País. www.elpais.com 2011. Especial 2011 el año de las revueltas. Una ola de cambio.

ENPI, 2011. http://www.enpi-programming.eu/wcm/index.php

FAO, 2011. Food and Agriculture Organization of the United Nations. Aquastat: http://www.fao.org/nr/water/aquastat/data/query/index.html

IEA, International Energy Agency. OCDE. http://www.iea.org/stats/index.asp. Energy Statistics and Balances.

PAM, 2011. Parliamentary Assembly of the Mediterranean. http://www.apm.org.mt/

Secretariado UpM, 2011. http://www.ufmsecretariat.org/en/

SIA, 2011. Sistema Integrado de información del Agua. Libro Digital del Agua. Ministerio de Medio Ambiente y Medio Rural y Marino, España. Datos de 2009. http://servicios2.marm.es/sia/visualizacion/lda/

Tablas

Tabla 1. Elaboración propia, datos de FAO, Aquastat 2011 (datos 2005 y 2008) http://www.fao.org/nr/water/aquastat/main/indexesp.stm. INE, 2011. Instituto Nacional de Estadística www.ine.es (datos 2008), MARM, 2011. Ministerio de Medio Ambiente y Medio Rural y Marino www.marm.es. EUROSTAT, 2011 (datos 2007) http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home

Tabla 2. Elaboración propia, datos de FAO, Aquastat 2011 (datos 2005 y 2008) http://www.fao.org/nr/water/aquastat/main/indexesp.stm.

3.2 Estrela, T., Vargas, E., 2012. **Drought Management Plans in the European Union. The case of Spain**. Water Resources Management. 26, 1537–1553.

This article provides a specific analysis on droughts, due to the expected increase in intensity and frequency of drought episodes due to climate change. The article addresses policy instruments, economic and environmental aspects related to droughts. While there is no specific EU Directive to approach drought episodes, an important legislative process was carried out by the European Commission between 2007 and 2012, which included a specific communication, follow-up reports and studies at the EU and national levels, and an assessment of drought effects in achieving environmental protection objectives. The article, considers the specific example of DMPs in Spain and their main repercussions for water management.

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Drought Management Plans in the European Union. The Case of Spain

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Abstract Water is a strategic resource for the economic, social and environmental development. However, water scarcity and droughts are current challenges to this growth, as it is reflected in European Union (EU) water policies, and in national and regional growing initiatives. In addition, these water related issues could worsen by climate change effects, adding pressure to already water stressed areas. This paper presents a general overview of drought management in the European Union, reviews scientific and technical advances, the status of implementation of policy tools and focuses on drought management plans. It analyses the specific case of Spain, a country characterised by presenting a high irregularity in temporal and spatial distribution of water resources and numerous areas affected by water scarcity and droughts. Details are presented on the National Drought Indicator System and drought management plans approved in 2007 in Spain, which represent strategic tools with positive results in drought warning and impact mitigation respectively.

Keywords Drought · Water scarcity · Environment · Drought management plans · European Union · Spain

1 Introduction

Drought is a natural hazard that results from a deficiency of precipitation from expected or normal, which can translate into insufficient amounts to meet the water demands of human

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activities and the environment. Although by itself is not a disaster, whether it becomes one depends on its impacts on society and environment (Wilhite and Buchanan-Smith 2005).

The impacts produced by droughts are numerous. These phenomena can impede populations receive a minimum water supply, affect crop yields and environmental ecosystems or increase pressures among users, among other problems. They can be exacerbated when occurring in regions already presenting low water resources levels, with imbalances between the available resources and the water demands (European Environment Agency 2001). In addition, it is expected that climate change will produce negative direct impacts on the available water resources in the most vulnerable European Union (EU) regions (IPCC 2007).

There are relevant EU policy tools such as the Water Framework Directive 2000/60/EC (European Parliament and Council of European Union 2000) or a specific Communication on water scarcity and droughts entitled "Addressing the challenge of water scarcity and droughts in the European Union" from the European Commission to the European Parliament and Council in 2007. In addition, a policy review on water scarcity and droughts is currently being carried out to be integrated into the "Blueprint to safeguard European Waters" (an EU policy response to recent water challenges, related to the EU 2020 Strategy and the Resources Efficiency Roadmap).

The Water Framework Directive establishes a legislative framework for Community action in the field of water policy, introducing a new perspective from a modern view of water policy to all Member States of the European Union and aiming at improving and protecting the status of water bodies along Europe, with specific environmental objectives for 2015. The WFD also provides general criteria to consider drought impacts in the status of water bodies.

The EC communication responds how to address water scarcity and drought issues and has triggered different technical and political initiatives to mitigate their impacts. This communication highlights that water saving must become the priority, lists possible measures to cope with water scarcity and droughts, and recommends shifting from a risk/emergency to a planned drought management approach, shift that has become evident in other areas such as the United States (Wilhite et al. 2000). The importance of public participation in the decision making process for an adequate water scarcity and drought management has been stressed, and drought management plans have been identified as useful tools to achieve this objective in the European Union.

Spain is an EU country characterised by presenting a high irregularity in temporal and spatial distribution of water resources, and numerous areas already affected by water scarcity and frequent droughts (Ministerio de Medio Ambiente 2000). The gained experience through policies implementation, the new applied tools and technologies as the drought management plans, and the implication of the users and other interested parties in Spain, are allowing to better predict and manage these situations by applying agreed criteria to minimize the long-term socio-economic and environmental impacts produced by droughts (Ministerio de Medio Ambiente, Medio Rural y Marino 2008).

The objective of this work is to revise the scientific and technical advances and the status of implementation of the recent policies and actions on drought management carried out by the European Union, focusing on the development of drought management plans and analysing the case of Spain, where drought management policies have shifted from risk/management actions to a planned approach in the last years. An innovative aspect to be highlighted is the link between the national drought indicator system and the actions to be taken in the drought management plans developed for all the Spanish river basins as well as the experience gained during their application for the severe 2004–2008 drought.

2 Water Scarcity and Droughts in the European Union

2.1 Problem Assessment

Water scarcity and droughts, wrongly used interchangeably, are different concepts linked to permanent and temporary situations respectively. Water scarcity is defined as a situation where insufficient water resources are available to satisfy long-term average requirements (European Commission 2007a). At least 11% of the population and 17% of the European territories are affected by water scarcity (European Commission 2007b). Cyprus, Belgium, Spain, FYROM, Malta and Italy show the lowest water availability when comparing their water exploitation index (WEI) (European Environment Agency 2005). This index is obtained as the percentage of mean annual total demand for freshwater with respect to the long-term mean annual freshwater resources and shows, in principle, to which extent the total water demand puts pressure on water resources (Fig. 1). However, it must be taken into account that this index has much more sense when is represented at the river basin scale especially in those countries where there is an irregular spatial distribution of resources and demands. Values of this index corresponding to large European river basins taken from European Environment Agency (2005) are shown in Fig. 2.

Droughts, on the other hand, represent relevant temporary decrease of the average water availability and even if it is a concept apparently easy to interpret, the absence of a precise

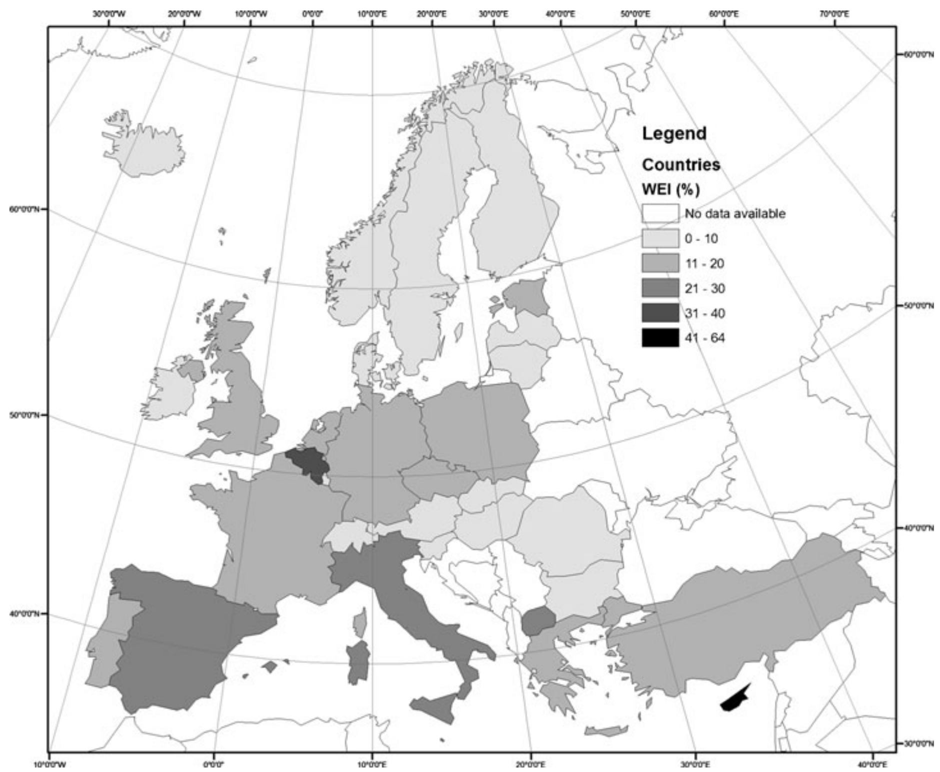

Fig. 1 Water exploitation index in European Union (elaborated with data taken from European Environment Agency web page)

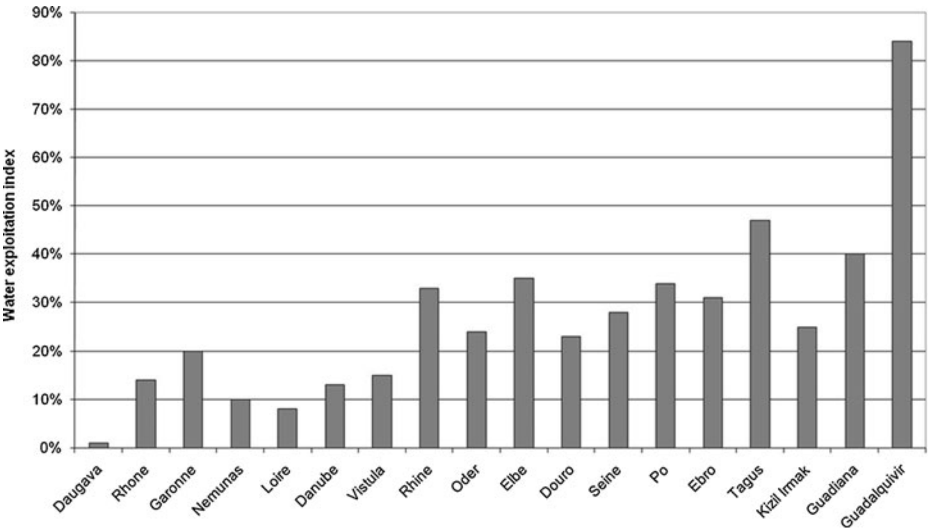

Fig. 2 Water exploitation index in large European river basins for 2000 year (elaborated with data taken from European Environment Agency 2005)

and universally accepted definition of drought adds to the confusion as to whether a drought exists and, if it does, its degree of severity (Wilhite and Buchanan-Smith 2005). According to the European Commission droughts refer to important deviations from the average levels of natural water availability and are considered natural phenomena (European Commission 2007b). Drought is thus a climatic cyclic phenomenon, it is difficult to predict and can produce severe socio-economic and environmental impacts, interfering with urban supply, impacting other water uses and affecting vulnerable aquatic ecosystems. However, the duration and related impacts of droughts can greatly vary from region to region and among countries. While in countries lacking water storage infrastructures, directly dependant on rainfall to supply water demands, a decrease in rainfall during some months or weeks can become a drought, in others, droughts can extend for years producing major impacts.

Drought episodes have been occurring repetitively in Europe for the past centuries. Nowadays, these episodes might not be as dramatic as in the past when a strong dependency on localised agriculture translated into devastating famines. During the Middle Ages, Western Europe suffered famines due to harvest failures produced by drought episodes, which in some occasions counted with millions of deaths (United Nations Development Programme 1994). More recently, and during the past 30 years, drought events have regularly occurred in the European Union. The duration, affected population and area, greatly vary throughout this period, but severe events have occurred on annual basis affecting more than 800.000 km² of the EU territory (37%) and 100 million inhabitants (20%) in 1989, 1990, 1991 and 2003 (European Commision 2007b).

Furthermore, water scarcity and droughts could worsen by climate change effects increasing the area and population living under water stress. Changes in precipitation and temperature lead to changes in runoff and water availability, affecting water related ecosystems, water requirements for crops, as well as populations' needs. Runoff is projected with high confidence to decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics, due to decreases in rainfall and higher rates of evapotranspiration. There is also high confidence that many semi-arid areas, as the Mediterranean Basin, will suffer a decrease in water resources due to climate change (IPCC 2007). The European Environment Agency (2005) states in "The European Environment—State and outlook 2005" that temperatures in Europe could rise by 2–6°C this century and that the expected impacts include water shortages, more extreme weather, marine species migrations and economic losses.

2.2 Scientific and Technical Advances

Important efforts both in the scientific and technical field in relation with droughts have been or are being carried out by different researchers in Europe. Several research projects funded by the European Union show significant and useful results to better manage water scarcity and droughts such as ARIDE, SEDEMED, WAMME, PRODIM, MEDROPLAN, WATCH, MIRAGE, XEROCHORE and others. These projects increase the knowledge on droughts in different research areas and regions providing additional tools and experiences for policy makers and water managers. Risk management approaches and drought management plans are now being developed in Europe and therefore scientific approaches to risk evaluation including characterization of drought episodes, development of risk indicators, identification, selection and prioritising of measures to alleviate the effects of droughts or analysis of the role of economic instruments for risk mitigation are needed (Iglesias et al. 2009). Some relevant methodologies and findings of selected projects are described below.

The severity of droughts is represented by drought indexes, which have been developed during the last century to detect, monitor and assess drought events. Different indexes have been proposed by various researchers in the fields of meteorology, hydrology, agriculture or water exploitation systems. Lloyd-Hughes and Saunders (2002) present a high spatial resolution and multi-temporal climatology for studying the incidence of drought in Europe during the 20th century, based on monthly values of the well known Standard Precipitation Index (SPI) calculated on a 0.5°grid across the whole Europe for the period 1901–99. Alvarez and Estrela (2003) develop a methodology for regionalisation and identification of droughts at a pan European scale in the framework of the ARIDE project, delimiting regions with a homogeneous climatic behaviour and identifying drought events for the XXth century from monthly rainfall data series. Bordi et al. (2009) provide an analysis of trends in drought and wetness for the whole Europe using monthly precipitation data and applying the SPI. Other new drought indexes, as the Reconnaissance Drought Index (RDI) based on the precipitation to potential evapotranspiration ratio (Tsakiris et al. 2007 and Vangelis et al. 2011) have been applied in Europe. This index was initially proposed in the framework of MEDROPLAN project and was improved during the implementation of PRODIM project. Although in some cases RDI behaves in a similar way as the SPI, it is more sensitive and suitable in cases of a changing environment.

Drought monitoring and forecasting are essential tools for implementing appropriate mitigation measures to reduce negative impacts of droughts. SPI has been extensively used for describing and comparing droughts among different time periods and regions with different climatic conditions, however, limited efforts have been made to analyse the role of the SPI or similar indexes for drought forecasting. In addition, Cancelliere et al. (2007) provide, under the research activities of MEDROPLAN project, two methodologies for the seasonal forecasting of SPI.

Information on regional drought characteristics can be very helpful for adequate water resource management. Hisdal and Tallaksen (2003) introduce a method to calculate the probability of a specific area to be affected by a drought of a given severity and thereby return periods could be assigned to historical drought events. Tallaksen et al. (2009) examine drought propagation at the catchment scale using spatially aggregated drought characteristics as part of the WATCH project, illustrating the importance of catchment processes in modifying the drought signal in both time and space in the Pang catchment, United Kingdom. Vasiliades et al. (2011) assess hydrological droughts by using a water balance derived drought index within an operational context at subwatershed scale at the Pinios river basin in Greece.

A key aspect of drought management plans is to establish an adequate link between basin drought status and the management actions to be taken. Garrote et al. (2007) develop a methodology to link operational drought indicators to policy management actions in regulated water supply systems in the Tagus River Basin Drought Management Plan in Spain. Basin status is described by a drought indicator system that includes variables like precipitation, streamflow, reservoir inflow, reservoir storage or groundwater piezometric levels and the basin policy consists on a catalogue of management actions, ranging from enforcing demand reduction strategies to establishing priority of uses to allocate scarce water or approving emergency works. Rossi et al. (2005) set a conceptual framework for a proactive approach to drought mitigation, by proposing a methodology to assess alternatives that takes into account economic, environmental, and social impacts of different measures. Preferred alternatives are selected based both on the scores of each alternative with respect to the selected criteria and on the capability to reach the consensus among stakeholders. Andreu and Solera (2006) propose, in the framework of the of WAMME and SEDEMED projects, a methodology for the analysis of water resources systems which aim is the design and planning of operational measures that would avoid or mitigate the negative effects of droughts in the Júcar River basin District in Spain.

As a relevant policy science action, one of the main objectives of the MEDROPLAN research project must be highlighted, which consists on developing guidelines for drought preparedness plans and setting up a network for drought preparedness in Mediterranean countries. The Drought Management Guidelines published by MEDROPLAN (2007) provide Mediterranean countries with a framework to prevent and/or minimize the impacts of droughts, promoting a risk based preparedness and mitigation approach.

Research addressing water scarcity and droughts is covered by the XEROCHORE Support Action 7th Framework Programme that aims at establishing the state of the art of drought related policies and identify research gaps on various drought aspects (climate, hydrology, impacts, management, and policy) and steps to take in order to fill them. Networking is developed with close links to on-going initiatives, e.g. the European Drought Centre and relevant research projects which include drought components such as the WATCH, CIRCE and MIRAGE projects (Quevauviller 2011).

2.3 Political and Technical Responses

Due to the obvious and repetitive related problems, the Council of Ministers of the European Union (EU) launched a policy request to assess the gravity of water scarcity and droughts in Europe in March 2006. The European Commission (EC) responded by an impact assessment developed through Member States and the European Environment Agency feedback. Furthermore, a specific working group was created in 2007 within the Common Implementation Strategy (CIS) of the Water Framework Directive (WFD). This working group which has been led by Italy, Spain, and France (Fig. 3), has assessed technical needs and contributed with technical documents to find common mitigating measures.

Fig. 3 Scheme of the common implementation strategy of the Water Framework Directive, for the period 2010–2012

After the drafting and discussion process within stakeholder groups, the Communication of the European Commission (2007a) to the Council and European Parliament was issued on July 2007. As previously commented, this communication sets a series of recommendations and establishes the need for a European Strategy based on national and EU measures. It recognises the importance of both problems, and the need for undertaking European actions to use and reform, whenever necessary, the existing tools: Common Agricultural Policy, Water Framework Directive, financing mechanisms and emergency assistance. The communication underlines that water saving must become the priority, and that all possibilities to improve water efficiency must be explored prior to increasing supply. In addition, it states that policy-making should be based on a clear water uses hierarchy established through participative approaches. The communication lists possible measures to cope with water scarcity and droughts, recommends the development of drought management plans, supports establishing a European drought strategy, considers using European funds when suffering prolonged droughts, and proposes establishing a European drought observatory.

The European Commission (2011) in the third Follow up Report to the Communication on water scarcity and droughts in the European Union gives further details on the extent of water scarcity and droughts in the EU and the measures which are being put in place to address both situations. According to this report most Member States have not yet implemented national legislation in terms of water efficiency standards in buildings or water using devices, though some aspects are included in the River Basin Management Plans. Also it is highlighted that many Member States face non-authorised water abstractions which affect water availability and that a better control is required. On the other hand, activities to integrate water scarcity and droughts into sector policies have been undertaken by several Member States, in particular efforts to reduce water consumption and adaptation to climate change. Most Member States (except United Kingdom, Spain and Belgium) do not envisage setting up water markets to address water scarcity. Other relevant point highlighted in the report is that the prototype of the European Drought Observatory has been developed providing for the continuous monitoring of drought indicators across Europe. In 2010, the first tests for meteorological drought forecasting were performed with national, regional and local services including the Drought Management Centre for South East Europe and the Observatory for Sustainability in Spain.

Although drought management plans and risk management approaches have been applied in other regions of the world since years ago, as in United States of America (Martin 1991;

Pirie et al. 2004) or Australia and South Africa (O'Meagher et al. 1998), they are not being implemented in EU countries until very recent dates. Member States participating in the water scarcity and droughts working group in collaboration with the European Commission elaborated in 2007 the technical report "Drought Management Plan Report, including agricultural, drought indicators, and climate change aspects" coordinated by Spain (European Commission 2007c). Its main objective is to serve as a useful tool to elaborate drought management plans (DMPs), supplementing River Basin Management Plans (RBMPs) - according to the Water Framework Directive article 13.5-, providing general criteria, structures, and recommended measures. This guidance document can help EU Member States, and other countries, to mitigate and prevent drought effects by minimising socio-economic and environmental impacts. It provides technical recommendations to establish useful indicator systems to declare drought statuses. In addition, it establishes measure types,—revision or strategic, operative, organizative, follow-up and recovery-, in accordance with the indicators status, consistent with RBMPs. Last, it relates direct issues clearly affected by droughts (agriculture and groundwater) and considers possible consequences of climate change.

Recent works within the CIS of the Water Framework Directive are focusing on further developing water scarcity and droughts indicators that could be commonly used by Member States, and on a policy review and assessment of the EU related strategy to be integrated into the "Blueprint to safeguard European Waters" (an EU policy response to recent water challenges, related to the EU 2020 Strategy and the Resources Efficiency Roadmap).

3 Droughts in the Water Framework Directive

Droughts are considered in different parts of the Water Framework Directive (WFD), which has among its main purposes to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater, which contributes to mitigate the effects of floods and droughts.

The directive is very demanding in the fulfilment of environmental objectives. However, the temporary deterioration of the status of water bodies shall not be in breach of the WFD requirements if this is the result of circumstances of natural cause or "force majeure", as prolonged droughts, when some conditions have been met. Also, the WFD establishes the possibility of supplementing River Basin Management Plans (RBMPs) with detailed programmes and plans to deal with particular aspects of water management. In this case, Drought Management Plans can be considered as relevant additional tools to cope with the effects of prolonged droughts and ensure the WFD's implementation. As it is summarized in Estrela et al. (2006): a) droughts constitute an exemption from certain WFD requirements, b) the declaration of a drought situation must be defined in the RBMP, adopting adequate indicators, c) measures to be adopted in drought situation must be incorporated in the programme of measures of the RBMPs and d) the plan, once updated, will summarize the effects of droughts and applied measures.

The WFD provides general criteria to consider drought impacts in the status of water bodies. However, Member States are facing some challenges in the application of these criteria. For instance, there is no clear detailed common definition of prolonged drought, just a general common understanding, and although there is room for using supplementary tools to the RBMPs, such as drought management plans, the relationship between both tools is still unclear and to be defined. Furthermore, climate change effects will very likely affect drought and management approaches, increasing the difficulty of Member States for supplying basic demands while protecting water quality and ecosystems.

4 Water Resources Management in Spain

Spain is characterised by presenting an irregular temporal and spatial distribution of water resources and a fragile balance between water resources and demands. Although national mean values reflect enough available resources for all uses, a regional approach shows water scarce areas aggravated by drought episodes.

Spain presents an average precipitation of approximately 670 mm/yr, varying from 2.200 mm in northern areas to 120 mm in south-eastern ones, has a population of 44,7 million inhabitants (year 2006), which mainly concentrates in urban (cities of Madrid, Barcelona, Valencia, Sevilla, …) and coastal areas. The coastal economic and tourist development (mainly in the Mediterranean side), coupled with highly productive agricultural areas, translates into a higher demand of water in areas where this resource is scarce, and often during lower availability periods, e.g. summer time. Approximate distributions of water demand per sectors are 68% for irrigation, 13% for urban uses, 14% for refrigeration and 5% for industrial purposes (Ministerio de Medio Ambiente 2000).

There is a clear unbalance of water availability in Spain between northern, central and south-eastern areas (Ministerio de Medio Ambiente 2000). The high variability, uneven distribution of water and its scarcity throughout the territory, more persistent in the Mediterranean regions, has lead to an intensive control for water to supply the different water demands, especially those coming from the agricultural sector, through hydraulic infrastructures, such as dams or irrigation channels. In fact, Spain is the fifth country in the world with the highest number of large dams, approximately 1.200, after China, the USA, India and Japan. The capacity of these reservoirs is 56.000 hm^3 (INE 2008).

Water balance issues can worsen by climate change impacts. These impacts were assessed in 2005 by the Spanish Ministry of Environment in the “Assessment report of the preliminary impacts in Spain due to Climate Change” (Ministerio de Medio Ambiente 2005). Its main aim was to review and compile the state of the art on climate change impacts and on the preparation of the basis for future climate change adaptation initiatives in Spain. The main conclusions of the report related to water resources were: a) a general decrease of water resources will occur, b) reductions until 50% in arid and semiarid regions could arise, c) seasonal patterns of rainfalls and temperatures may even have greater effect on water resources than mean values, d) there is a need to improve and extend the monitoring networks and investigate in hydrological processes and simulation models and take into consideration climate change effects in water policies and regulations.

Historically, Spain has suffered important dry periods that have caused severe impacts, and have made it difficult to satisfy basic water needs, such as public water supply and irrigation. Water scarcity and the frequent drought episodes in Spain explain, in part, the ancient building tradition of hydraulic works. The spatial and time variability of water resources has made necessary the construction of numerous hydraulic works, to supply water demands. Furthermore, these demands, mainly coming from irrigation, are mostly concentrated in water scarce areas and especially during seasons when precipitations are lower and evapotranspiration is greater (e.g. summer periods).

The Mediterranean coast and south-eastern part of the country are the most affected areas by water scarcity and droughts with consequent socio-economic and environmental impacts. These problems in turn, have created social and political conflicts, especially in areas with high population pressures. For instance, water demands in the Segura river basin district are greater than available water resources and a 300 km long water transfer from Tajo river basin district was constructed and has been operating since the 80’s of the past century.

Most of the natural water resources are already regulated with the constructed large dams and, therefore, a significant increase of conventional water resources in the future is not foreseen. In the most vulnerable areas to water scarcity, non-conventional water resources, such as the treated wastewater or desalination of sea and brackish waters, arise as supplementary or alternative sources. These resources have significantly increased in the last years, especially in the Mediterranean basins.

Wastewater reuse may provoke quality and health concerns. In consequence, in December of 2007, the use of treated wastewater in Spain was regulated through the Royal Decree RD 1620/2007. This decree determines the necessary requirements to conduct activities in relation to the use of reclaimed wastewater. It establishes the procedures to get the government licenses required by law, and includes the minimum quality criteria required for the use of reclaimed wastewater for the different water uses. The obtained reused water volumes are alleviating pressures over natural systems and increasing the guaranty in the most water stressed areas.

Regarding seawater desalination, a process whereby sea and brackish waters are converted to freshwater, is also currently helping to meet water demands along the Spanish Mediterranean coast and on the Balearic and Canary Islands. Desalination can provide additional resources for regions suffering from drought, water shortages and related impacts if energy consumption and environmental impacts are thoroughly assessed (Estrela and Vargas 2008). Similarly to wastewater reuse, the quality of the desalinated water for public purposes follows strict national regulations.

On the other side, Spain is rich in groundwater, traditionally exploited trough wells from ancient times by private owners, since groundwater was not considered public domain until the 1985 Water Act entered into force. Fortunately, major aquifers are located in regions where water shortages are greater, which allows coping, to some extent, with droughts effects by using groundwater. Unfortunately, and despite the strict abstraction control by River Basin Authorities in some aquifers, the intensive use has often produced over-exploitation and saline intrusion problems in coastal areas (Ministerio de Medio Ambiente 2000).

5 Legal Framework for Drought Management in Spain

Drought management can be carried out by two main approaches: a) as an emergency situation, a crisis situation, which can be restored with extraordinary water resources and measures and b) as a current element of the general water planning and management, which means that a risk analysis must be carried out to assess its probability of occurrence and measures to be applied must be planned ahead. As regarded by the United Nations Development Programme (1994), while drought episodes might be regarded as unusual, they are not abnormal phenomena, and should be planned for in all countries. In Spain, as in the majority of EU countries (European Commission 2007c), droughts have been traditionally managed according to the first approach, although since the entry into force of the National Hydrologic Plan Act in 2001 both approaches have been used, and furthermore, the experiences show a shift to the planning approach.

The updated Water Act (1985) in art. 58, foresees during exceptional drought circumstances, adopting the adequate measures in the public water domain for overcoming these situations through a Royal Decree issued by the Government, agreed by the Council of Ministers, and heard by the River Basin Authorities. This approach has shifted towards a planning one in recent years. To minimise environmental, economic and social impacts caused by droughts in Spain, the National Hydrologic Plan Act established the bases for planned drought management in Article 27. Drought management, which states in Section 1 that The Ministry of Environment, for River Basin Authorities will establish a national hydrologic indicator system that will allow foreseeing these situations, and will serve as general reference for river basin authorities for the formal declaration of emergency situations and eventual drought and in Section 2 that River Basin Authorities will develop Drought Management Plans (DMP) for alert situations and eventual drought, including exploitation rules and measures.

6 National Drought Indicator System in Spain

The anticipation in the application of mitigation measures becomes an essential tool for the reduction of socio-economic and environmental impacts of droughts; that is why having completed indicator systems that allow calling an early alert of these extreme events and activate in advance the programme of measures established for these emergency situation is crucial. These systems must be considered as key elements in drought events management and in the strategic planning of the actions to be taken. In recent years, regional hydro climatic indicators, which are not necessarily indicative of the impacts of droughts on individual water storage systems, are being replaced by system specific indicators in the context of supply reliability, or likelihood of system failure (Whestphal et al. 2007).

The Spanish national drought indicator system has been developed in the last years as a response to the article 27 requirements of the National Hydrological Plan Act. This system is formed by basic variables selected in different points throughout the river basins. These variables describe the basin drought status and include: reservoir storages, groundwater piezometric levels, streamflows, reservoir inflows and precipitations. Variables in selected control points are weighted in order to obtain an integrated indicator representative of the hydrological status in each river basin. This indicator is compared to historical series representative of deficits in the basins to ensure its applicability and degree of confidence in the context of supply reliability. The standardised values of the indicators (ranging from 0 to 1) define the basin drought status: normal, pre-alert, alert and emergency. The normal situation is associated with a better hydrological situation than the corresponding to mean values; the rest of levels are established to differentiate situations below the mean one, and are useful to launch the different measures detailed in the drought management plans to mitigate the effects of droughts.

All the data produced by the River Basin Authorities are sent periodically to the Directorate General for Water of the Ministry of Environment, and Rural and Marine Affairs, where a common database is kept, and monthly public reports with maps, graphs and statistics are shown in the Ministry's web page. Figure 4 has been obtained using data coming from National Indicator System of the Ministry web page (http://www.marm.es).

The evolution of the indicator representative of drought status at Júcar river basin is shown in Fig. 5 for the period 2000–2010. This Mediterranean river basin has a drainage area of 21.600 km^2 and it is located in the Eastern area of Spain where the negative effects of water scarcity and droughts are more significant. The values of the drought indicator clearly define the drought period occurred from 2004 to 2008.

7 Drought Management Plans in Spain

The National Hydrological Plan Act established in 2001 that drought management plans (DMPs) had to be elaborated by the River Basin Authorities. These plans have already been

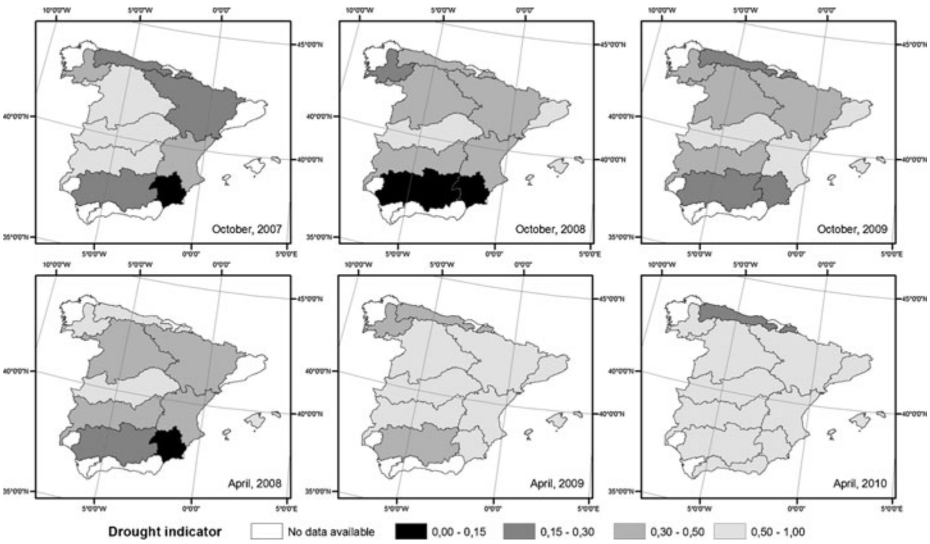

Fig. 4 Maps showing the drought status of Spanish river basin districts in October and April of 2007 to 2009. Legend status: emergency (0,00–0,15), alert (0,15–0,30), pre-alert (0,30–0,50) and normal (0,50–1,00)

developed for all the Spanish River Basin Districts managed by the State. They were approved by Ministerial Order in March 2007 and are considered, according to the Hydrological Planning Royal Decree (RD 907/2007), as a specific plan of the River Basin Management Plans (Estrela 2006).

DMPs have proved to be useful and efficient tools to manage water resources under drought episodes. The specific objectives of the DMPs are as follows: a) guarantee water availability required to sustain population life and health, b) avoid or minimize negative drought effects on the status of water bodies, especially on the environmental water flows, avoiding in any case, any permanent negative effects, c) minimize negative effects on public water supply and on economic activities, according to the prioritization of uses established by River Basin Management Plans.

To achieve these objectives, the DMPs identify the most adequate mitigation measures, adapted to the different established drought thresholds and phases. During a normal phase, the measures derive from the regular management practices. As the drought progresses and a

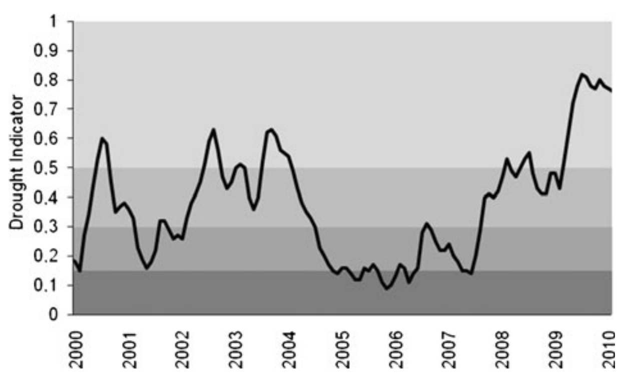

Fig. 5 Evolution of drought indicator at Júcar river basin for 2000–2010 period (elaborated with data taken from Drought Indicator System of Júcar River Basin Authority)

more critical situation takes place, measures go from control and information, to conservation and restriction types, prioritising uses.

The main contents of plans are: drought diagnosis, program of measures and management and follow-up system.

The drought diagnosis includes the identification and characterization of territorial and environmental elements. This part of the DMP analyses and characterizes historical droughts as well as learnt lessons through those episodes, taking into account local and regional acquired knowledge and technical experiences. It incorporates also one of the most relevant elements of the plans, which are the indicators, thresholds and drought phases definitions. A crucial and innovative aspect of DMP is to establish an adequate link between basin drought status and actions to be taken.

Other key part of the DMPs is the programme of measures, which defines the different types of measures that can be applied in each area of the basin, according to the drought status. This programme consists in a catalogue of actions, ranging for enforcing demand reduction strategies to establishing priority of users to allocate scarce water or approving emergency works (Garrote et al. 2007). Their action methods and established measures must be applied once the interested parties have been previously agreed them: social society, administration, scientific community, NGOs etc. The main mitigation measures included in the DMP can be grouped into different categories: structural measures (new pumping wells, new pipes, use of new desalination plants, etc.) and non-structural measures (changing the priority of the users, water savings and demand reductions, increase in the use of groundwater, etc.). In Spain, the role of conjunctive use of surface and groundwater to mitigate the deficit has been very important, by pumping, in a controlled way, the reserves of aquifers during drought periods (Ministerio de Medio Ambiente 2000).

Last, the DMPs include a management and follow-up system that allows analysing the implementation of measures, using corrective measures in case the established objectives are not met. This part of the plan describes the methodology to develop follow-up reports, and analyses each drought period as it occurs.

DMPs have provided the bases for a more planned drought management in Spain, establishing drought phases and describing the measures that should be progressively applied and the needed monitoring and follow-up processes. In the coming years, drought management plans should be an integral part of drought policy in the European Union as well as in other regions of the world such as the United States of America (Wilhite et al. 2000). Ensuring transparent public participation processes, previous agreements among the interested parties, collaboration among the water administrations at the different scales, and the use of adaptive governance, integrating local and rural knowledge as well as active participation, will be essential elements to guarantee the successful application and follow-up of public contingency and management plans (Pirie et al. 2004; Nelson et al. 2008). This participative and holistic approach will reduce vulnerability of systems, and will increase the flexibility and adaptive capacity of administrations if reference conditions change and evolve, produced, for instance by climate change effects.

8 The 2004–2008 Drought in Spain

Traditionally, Spain has faced extremely severe droughts, as those occurred at the beginning of the 1980s, during the years 1994 and 1995 or the latest drought, corresponding to the 2004–2008 period. During the occurrence of this latter drought the DMPs were approved in 2007 and they have contributed to avoid public supply restrictions.

During past droughts, emergency decrees were mainly issued to regulate performances to minimize drought impacts. They covered a group of emergency performances and measures, which included necessary works, test drillings or researches to be carried out, and addressed temporal land use (e.g. hydraulic works) or forced expropriation of goods and rights.

Since of the beginning of the last drought in 2004, several Royal Decrees (RD) have been developed every year, containing different measures and emergency works to mitigate negative effects on the irrigation sector, guarantee public water supply, or mobilize extraordinary resources (drought wells, desalination or water transfers). For example, RD Law 9/2006 included regulation fee exemptions or reduction of irrigation fares, depending on the water availability, construction of water supply points for extensive cattle farming and emergency hydraulic works for the improvement and modernization of irrigation systems.

In addition, during the 2004–2008 drought, innovative measures were also put into practice, which supposed considerable water savings in the agricultural sector, allowing to pass an extremely severe drought without applying any significant public water supply restriction (Ministerio de Medio Ambiente, Medio Rural y Marino 2008). This was possible though reductions of 50–60% for irrigation practices in the most critical areas, and water use rights exchange. In this last case, farmers renounced to irrigate their lands during drought periods, receiving an economic compensation by River Basin Authorities or exchanged their allotted water use rights among them, which ensured economic efficiency. Analysis of environmental effects during the drought period has been a priority for drought management in River Basin Districts. Among different studies taken into account by River Basin Authorities, Boix et al. (2010) analysed the relationships between the biological community structure with the ongoing and preceding hydrological patterns during the drought and recovery periods, determining the effects of water abstraction on Mediterranean river communities.

Once drought management plans came into force, a Royal Decree-Law was passed in 2008, which contained emergency measures regarding mainly fees' payment exemptions and extraordinary measures of land occupation. In addition, water use rights management was approved. The declaration of drought situation in the river basins affected was established in this decree—law taking as a general reference the basin status of the National Drought Indicator System. Furthermore, the evolution of the drought's indicator was useful to put the necessary measures into practice when needed in accordance with the criteria established in the DMPs. In the development of the DMPs, public participation and the involvement of all interested parties (users, NGOs, administration, private sector, universities etc.) and the consideration of environmental requirements have been essential to minimize social conflicts caused by the lack of sufficient water resources.

9 Conclusions

The European Union (EU) has been historically impacted by water scarcity and droughts. In recent years, important efforts, both in the scientific and technical field, have been carried out at the EU to address risk evaluation, characterization of drought episodes, development of risk indicators, identification, selection and prioritising of measures to alleviate effects and establishments of links between basin drought status and actions to be taken. In 2006, political and technical approaches were launched to assess impacts, make recommendations to Member States and apply the most effective tools. One of the major results include a Communication issued in 2007 from the European Commission to the European Parliament and Council entitled "Addressing the challenge of water scarcity and droughts in the

European Union" on how to address water scarcity and drought issues, which has triggered different technical and political initiatives to mitigate their impacts.

Since 2007 until the third Follow up Report to the Communication of the European Commission in 2011, actions to integrate water scarcity and droughts into sector policies have been undertaken by several Member States, in particular efforts to reduce water consumption and adaptation to climate change. The European Drought Observatory has been developed providing inputs for the continuous monitoring of drought indicators across Europe being the first tests for meteorological drought forecasting performed in 2010.

Within the European Union, Spain is a country characterised by presenting a high variability and uneven water resource distribution, being the Mediterranean coast and southeast region the most affected areas by water scarcity and droughts with consequent socio-economic and environmental impacts. In the past, this situation led to high investments in hydraulic works and infrastructures.

Emergency actions have been traditionally applied in Spain in past drought situations, with a series of actions heading towards increasing water resources by developing hydraulic works, especially for groundwater abstractions. In the last years, Spanish policies, in accordance to the European legislation, have evolved from emergency actions against drought situations with a focus on crisis situation to a planning approach. This translated into designing a national drought indicator system to foresee these situations and elaborating drought management plans for the Spanish river basin districts.

An indicator system that allows foreseeing extreme situations, establishing levels or thresholds depending upon the degree of the drought, and consequently developing actions aiming to delay or impede critical situations has been developed. Drought management plans approved in March 2007 have contributed to alleviate the negative effects of the last drought occurred in Spain during the years 2004–2008, resulting in water savings, avoiding public water supply restrictions and improving aquatic ecosystem protection. These plans are considered as supplementary plans to the River Basin Management Plans and have proven to be valuable management tools.

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References

Alvarez J, Estrela T (2003) Regionalisation and identification of droughts in Mediterranean countries of Europe. In: Rossi G, Cancelliere A, Pereira LS, Oweis T, Shatanawi M and Zairi A (Eds) Tools for Drought Mitigation in Mediterranean Regions, Water Science and Technology Library Volume 44. ISBN 1-4020-1140-7. Kluwer Academic Publishers, pp 123–146

Andreu, J, Solera, A (2006) Methodology for the analysis of drought mitigation measures. In: Rossi G, Vagliasindi F, Vela A (Eds) Water Resource Systems in Drought Management and Planning for Water Resources. CRC Press. Taylor and Francis, pp 133–168

Boix D, García-Berthou E, Gascón S, Benejam LL, Tornés E, Sala J, Benito J, Munné A, Solà C, Sabater S (2010) Response of community structure to sustained drought in Mediterranean rivers. J Hydrol 383:135–146

Bordi I, Fraedrich K, Sutera A (2009) Observed drought and wetness trends in Europe: an update. Hydrol Earth Syst Sci 13:1519–1530

Cancelliere A, Di Mauro G, Bonaccorso B, Rossi G (2007) Drought forecasting using the standardized precipitation index. Water Resour Manage 21:801–819

Estrela T (2006) La gestión de las sequías en España. Ingeniería y Territorio. Catástrofes naturales 74: pp 52–57, Barcelona

Estrela T, Vargas E (2008) Los Problemas del Agua, Una visión global sobre los recursos hídricos disponibles. In: La Desalación en España, Aguas de las Cuencas Mediterráneas, S.A.: Madrid pp 13–42
Estrela T, Fidalgo A and Pérez MA (2006) Droughts and the European Water Framework Directive: Implications on Spanish river basin districts. In: Rossi G, Vagliasindi F, Vela A (Eds) Water Resource Systems in Drought Management and Planning for Water Resources. CRC Press. Taylor and Francis, pp 169–192
European Commission (2007a) Addressing the challenge of water scarcity and droughts in the European Union. Communication from the Commission to the European Parliament and the Council, COM (2007) 414 final
European Commission (2007b) Water scarcity and droughts in-depth assessment, second interim report
European Commission (2007c) Drought management plan report. Including Agricultural, Drought Indicators and Climate Change Aspects. Water Scarcity and Droughts Expert Network of Common Implementation Strategy for the Water Framework Directive (2000/60/EC)
European Commission (2011) Report from the commission to the European parliament and the Counci.l Third Follow up Report to the Communication on water scarcity and droughts in the European Union COM (2007) 414 final COM(2011) 133 final
European Environment Agency (2001) Sustainable water use in Europe—Part 3: Extreme hydrological events: floods and droughts. Environmental Assessment report No 21. European Environment Agency. Copenhagen
European Environment Agency (2005) The European environment—state and outlook 2005. European Environment Agency, Copenhagen
European Parliament and Council of the European Union (2000) Directive 2000/60/EEC of the European Union and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities, 2000, L327/1
Garrote L, Martín-Carrasco F, Flores-Montoya F, Iglesias A (2007) Linking drought indicators to policy actions in the Tagus River drought management plan. Water Resour Manage 21(5):873–882. doi:10.1007/s11269-006-9086-3
Hisdal H, Tallaksen LM (2003) Estimation of regional meteorological and hydrological drought characteristics: a case study for Denmark. J Hydrol 281:230–247
Iglesias A, Garrote L, Cancelliere A, Cubillo F, Wilhite DA (Eds.) (2009) Coping with Drought Risk in Agriculture and Water Supply Systems. Drought Management and Policy Development in the Mediterranean. Series: Advances in Natural and Technological Hazards Research, Vol. 26. XVIII, 322 p
INE (2008) Cifras INE, Estadísticas e Indicadores del Agua. Boletín Informativo del Instituto Nacional de Estadística, 2008
IPCC (2007) Climate change 2007. Synthesis report. Contribution of Working Groups I, II y III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team: Pachauri, R K and Reisinger A (Eds). IPCC, Geneve, Switzerland, p 104
Lloyd-Hughes B, Saunders MA (2002) A drought climatology for Europe. Int J Climatol 22:1571–1592
Martin QW (1991) Drought management plan for lower Colorado river in Texas. J Water Resour Plan Manage 117(6):645–661
MEDROPLAN (2007) Drought Management Guidelines and Examples of Application (2 volumes in 6 languages). Iglesias, A., Cancelliere, S., Gabiña, D., López-Francos, A., Moneo, A. and Rossi, G. (eds). European Commission. MEDA-Water programme, Zaragoza. Available at www.iamz.ciheam.org/medroplan
Ministerio de Medio Ambiente (2000) Libro Blanco del Agua en España, Madrid
Ministerio de Medio Ambiente (2005) Assessment report of the preliminary impacts in Spain due to Climate Change, Madrid
Ministerio de Medio Ambiente, Medio Rural y Marino (2008) Gestión de la sequia de los años 2004 a 2007. Estrela T y Rodriguez Fontal A (coord.) Madrid
Nelson R, Howden M, Stafford Smith M (2008) Using adaptive governance to rethink the way science supports Australian drought policy. Environ Sci Pol 11(7):588–601
O'Meagher B, du Pisani LG, Wilhite DH (1998) Evolution of drought policy and related science in Australia and South Africa. Agricul Sys 57(3):231–258
Pirie L, de Loë RC, Kreutzwiser R (2004) Drought planning and water allocation: an assessment of local capacity in Minnesota. J Environ Manage 73:25–38
Quevauviller P (2011) Adapting to climate change: reducing water-related risks in Europe—EU policy and research considerations. Environ Sci Pol 14(7):722–729
Rossi G, Cancelliere A, Giuliano G (2005) Case study: multicriteria assessment of drought mitigation measures. J Water Resour Plan Manage 131(6):449–457
Tallaksen LM, Hisdal H, Van Lanen HAJ (2009) Space–time modelling of catchment scale drought characteristics. J Hydrol 375:363–372

Tsakiris G, Pangalou D, Vangelis H (2007) Regional drought assessment based on the reconnaissance drought index. Water Resour Manage 21:821–833

United Nations Development Programme (1994) Drought and famine, second edition. Disaster Management Training Programme

Vangelis H, Spiliotis M, Tsakiris G (2011). Drought Severity Assessment Based on Bivariate Probability Analysis. Water Resour Manage 25 (1): 357–371(15)

Vasiliades L, Loukas A, Liberis N (2011) A water balance derived drought index for Pinios River Basin, Greece. Water Resour Manage 25:1087–1101

Whestphal KS, Laramie RL, Borgatti D, Stoops R (2007) Drought management planning with economic and risk factors. J Water Resour Plan Manage 133(4):351–362

Wilhite DA, Buchanan-Smith M (2005) Drought as Hazard: Understanding the Natural and Social Context. In: Wilhite DA (Ed) Drought and Water Crisis. Science, Technology, and Management Issues. CRC Press Taylor and Francis. pp 3–29

Wilhite DA, Hayes MJ, Knutson C, Smith KH (2000) Planning for drought: moving from Crisis to risk Management. J Am Water Resour Assoc 36:697–710

3.3 Estrela, T., Pérez-Martin, M.A., Vargas, E., 2012. **Impacts of climate change on water resources in Spain**. Hydrological Sciences Journal. 57, 1154–1167.

This article assesses the expected impacts of climate change on water resources at the national level. It highlights availability and national specificities, hydrological variabilities and trends. The article covers studies on modelling hydrological effects of climate change, and addresses implications for policy actions. The text highlights natural variability, and the effects of using long and short data series, to show the existing degree of uncertainty in predictions and expected trends.

Impacts of climate change on water resources in Spain

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Abstract Impacts on water resources produced by climate change can be exacerbated when occurring in regions already presenting low water resources levels and frequent droughts, and subject to imbalances between water demands and available resources. Within Europe, according to existing climate change scenarios, water resources will be severely affected in Spain. However, the detection of those effects is not simple, because the natural variability of the water cycle and the effects of water abstractions on flow discharges complicate the establishment of clear trends. Therefore, there is a need to improve the assessment of climate change impacts by using hydrological simulation models. This paper reviews water resources and their variability in Spain, the recent modelling studies on hydrological effects of climate change, expected impacts on water resources, the implications in river basins and the current policy actions.

Key words climate change impact; water resources; hydrological modelling; climate change adaptation; Spain

Impacts du changement climatique sur les ressources en eau en Espagne

Résumé Les impacts du changement climatique sur les ressources en eau peuvent être exacerbés lorsque ils se produisent dans des régions aux ressources en eau déjà faibles et présentant des sécheresses fréquentes, et où existe un déséquilibre entre la demande en eau et les ressources disponibles. En Europe, d'après les scénarios de changement climatique existants, les ressources en eau seront sévèrement touchées en Espagne. Cependant, la détection de ces effets n'est pas simple du fait que la variabilité naturelle du cycle de l'eau et les effets des captages sur les débits complique la mise en évidence de tendances claires. Par conséquent, il est nécessaire d'améliorer l'évaluation des impacts du changement climatique en utilisant des modèles de simulation hydrologique. Cet article examine la question des ressources en eau et de leur variabilité en Espagne, les récentes études de modélisation sur les effets hydrologiques du changement climatique, les impacts attendus sur les ressources en eau, les implications dans les bassins versants et les actions politiques actuelles.

Mots clefs impact du changement climatique; ressources en eau; modélisation hydrologique; adaptation au changement climatique; Espagne

1 INTRODUCTION

Water is a strategic resource for socio-economic development and environmental protection, but water scarcity, water quality, floods and droughts are current challenges that could get worse due to climate change. Changes in precipitation and temperature lead to changes in water resources (IPCC 2007), thus affecting all sectors involved.

Climate change will increase water stress in some regions of the world, decreasing runoff (mainly in the Mediterranean area, some parts of Europe, Central and Southern America, and Southern Africa). In other water-stressed areas, particularly in South and East

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Asia, climate change will increase runoff, though these increases may not be very beneficial because they tend to occur during the wet season and so the excess water may not be available during the dry season when it is most needed (Arnell 2004). The European Environment Agency (2010) states that the Mediterranean basin has experienced decreased precipitation and increased temperature over past decades, a trend projected to worsen, and that there is a need to assess uncertainty in climate change assessments due to the incomplete knowledge of, and insufficient data to identify, trends in the past.

A great number of studies and investigations on climate change effects for water resources have been published in different international reports and scientific journals. These studies tend to be mainly focused on Europe, North America and Australia. Most apply hydrological models driven by scenarios based on climate model simulations. Methodological advances in climate change impact studies have focused on exploring the effects of different ways of downscaling from the climate model scale to the catchment scale, the use of regional climate models to create scenarios, the ways of applying scenarios to observed climate data and the effect of hydrological model uncertainty on estimated climate change impacts. In general terms, these studies have shown that different methods of creating scenarios from the same source (a global-scale climate model) can lead to substantial differences in the estimated effect of climate change. Regions with decreasing runoff (by 10 to 30%), and a rather strong agreement between models, include the Mediterranean, Southern Africa and western USA/northern Mexico (IPCC 2007).

Climate and water systems are interconnected in very complex ways. For instance, climate change affects water quantity and quality, but water use is also affected by climate change. Water use, in particular irrigation, generally increases with temperature rise and decreases with precipitation rise. However, there is no clear evidence for a climate-related trend in water use in the past. This is due to the fact that water use is mainly driven by non-climatic factors and to the limited availability of water-use data and time series (IPCC 2007).

The impacts produced by climate change can be exacerbated when occurring in regions thart already present low water resources levels and frequent droughts, and, hence, imbalances between water demands and available resources. Within these regions in Europe, Spain is very vulnerable to possible climate changes due to the high spatial and temporal irregularity of water resources, the elevated degree of water use and linked socio-economic impacts, in addition to its location in an area projected to have temperature increases and precipitation decreases (European Commission 2009). A large number of regional climate models highlight increases in temperature and decreases in rainfall that will lead to marked decreases in water resources. Studies on impact assessment have been developed in Spain since the mid-1990s and modelling tools are available to assess the effects of different climate change scenarios on water resources with a sufficient level of confidence. Additionally, climate change impact issues are being incorporated into the Spanish water legislation by making compulsory their consideration in River Basin Management Plans (RBMPs). This fact presents an opportunity to take into account climate change effects in water decision-making policies.

2 WATER RESOURCES IN SPAIN

Water scarcity, which means there is an imbalance between available water demand and existing demands, currently affects many European countries. At least 11% of the population and 17% of the European territories are affected by water scarcity (European Commission 2007). The number of people living in river basins characterized by water shortages will increase, especially in the Iberian Peninsula, Italy and in relatively large parts of Central Europe (EEA 2010).

Spain, with a territory of 506 000 km^2, has a clear imbalance of water availability between the northern, central and southeastern areas. The mean annual precipitation is approximately 670 mm/year, varying from 2200 mm in the north of the country to 120 mm in the southeast (Fig. 1). The map in Fig 1 has been derived using 1 km $\times$ 1 km-resolution data estimated in Ministerio de Medio Ambiente (2000) using the inverse squared-distance method with data from the nearly 9200 historical meteorological stations in Spain.

Similarly, mean annual runoff is approx. 220 mm/year and ranges from 0–100 mm in the southeastern and central areas, to approx. 1000 mm/year in the northern areas (Fig. 2). Runoff data were obtained from Ministerio de Medio Ambiente (2000) by means of the SIMPA hydrological model described later.

Spain has a population of 47 million (INE 2010), which is mainly concentrated in urban (the major

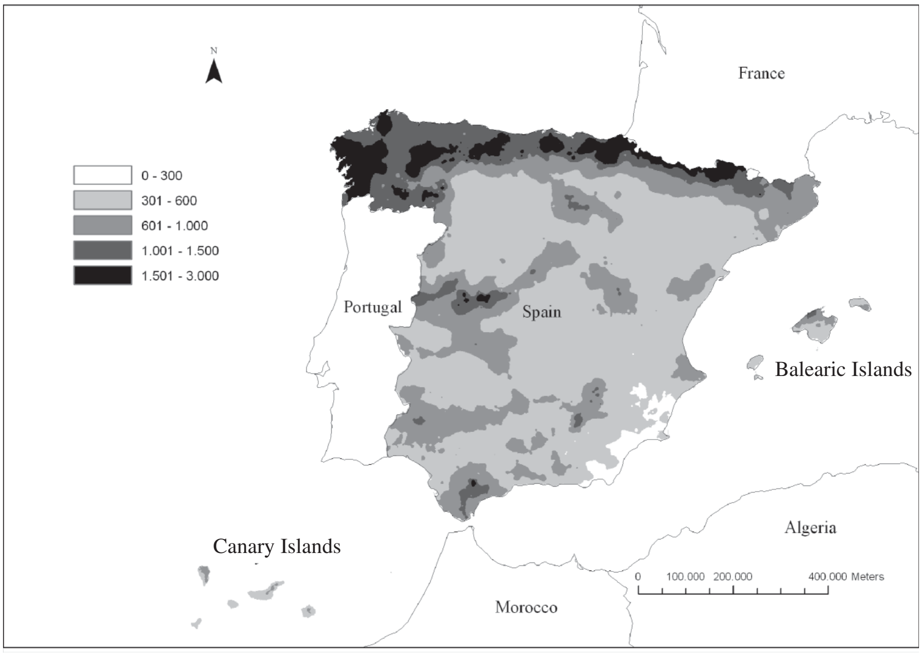

Fig. 1 Mean annual precipitation in Spain (mm). Prepared with data taken from Spanish Water Information System (http://www.mma.es).
Note: Canary Islands are represented out of the real location.

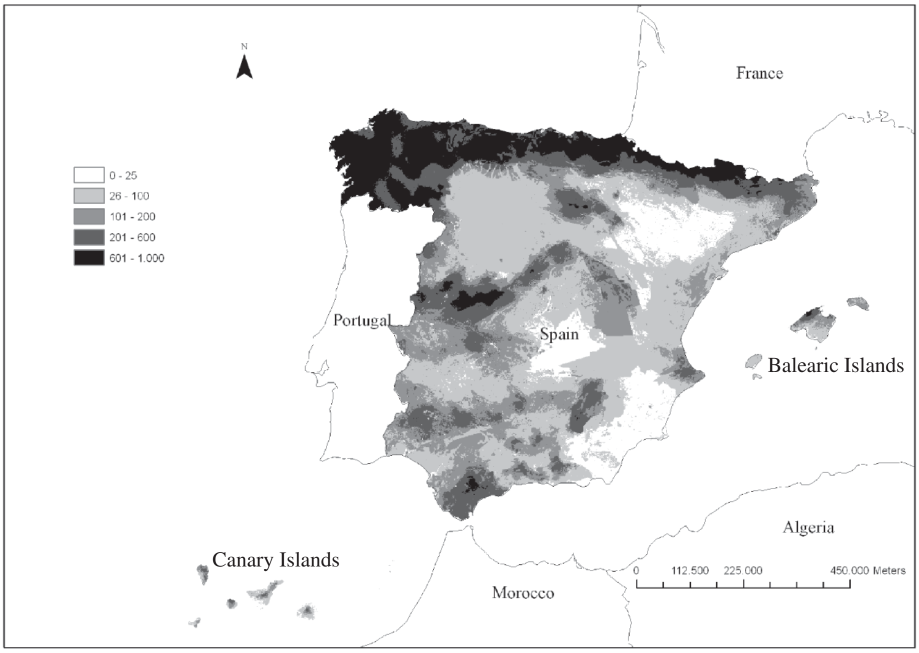

Fig. 2 Mean annual runoff in Spain (mm). Elaborated with data taken from Spanish Water Information System (http://www.mma.es).
Note: Canary Islands are represented out of the real location.

cities Madrid, Barcelona, Valencia and Seville) and coastal areas. The economic and tourist development (mainly in the Mediterranean area), coupled with highly productive agricultural areas, translate into a higher demand of water in areas where this resource is scarce. The approximate distribution of water demand per sector is 68% for irrigation, 13% for urban uses, 14% for refrigeration and 5% for industrial purposes (Ministerio de Medio Ambiente 2000). Spanish agriculture, which has the highest water demand, occupies approximately 50% of the land area, reflecting its territorial importance and its relevance to management of the environment (European Commission 2010). Climate change represents one of the main current challenges for agriculture. Impacts are expected to be diverse and heterogeneous where impacts on the quality and quantity of water are foreseen.

The previously mentioned high spatial variability and uneven distribution of water and its scarcity throughout Spain, but especially in the Mediterranean regions, have traditionally produced numerous conflicts related to water use and have led to the intensive control of water to supply the different water demands (Estrela and Vargas 2010). Different measures have traditionally been applied at the national level to decrease water scarcity impacts. For instance, numerous water supply infrastructures have been constructed, or existing ones modernized, to ensure adequate public water supply and meet irrigation demands. In fact, Spain is the fifth country in the world in terms of its number of large dams, 1200, after China, the USA, India and Japan (INE 2008). Monitoring and metering programmes for both surface and groundwater are being used to control water abstraction. Water savings and water-efficient technologies have been promoted, as well as modernization of infrastructure in the agricultural sector. These measures include public awareness campaigns led by municipalities and supply entities, and investment to implement drip irrigation systems and modern channelization of water in rural areas. In addition, joint management of surface and groundwater is carried out by the River Basin Authorities in charge of water management. Last, there has been an important increase in recent years in use of non-conventional water resources, such as wastewater re-use and desalination. If the climate change scenario projections foreseen for Spain occur in the next years, this set of measures should be applied more strongly to counteract the negative effects on water resources.

3 VARIABILITY AND TRENDS IN SPAIN

The detection of climate change effects from streamflow data is not easy; natural hydrological variability and the effects of water abstractions on flow discharges complicate the task of establishing clear trends. Precipitation and streamflows are concentrated over a few months and variations year-to-year are large in semi-arid and arid countries. Annual precipitation data recorded in Spain from 1940 (after the Spanish Civil War) show a high temporal variability, including long runs of dry years followed by humid ones. The dry run that started at the beginning of the 1980s seems to continue, as shown in Fig. 3. The mean annual precipitation for the period 1980–2009 (634 mm) is significantly lower than that for the period 1940–2009 (665 mm).

Although, there is a rainfall record of more than 200 years for the meteorological San Fernando Observatory in Cádiz, from 1805, and there are more than 50 rainfall records of approx. 150 years length, the oldest recorded river flow data in Spain dates back to only the beginning of the 20th century, approx. 100 years. The uncertainty corresponding to the river flow data is greater than that of the rainfall data given that, in the past, it was usual to record only one observation per day, which in rivers with high daily variations could result in an elevated uncertainty.

In spite of the aforementioned data uncertainty issues, study of some of the longest river flow data series in Spain can reveal valuable results. The main characteristics (location, drainage area, mean annual discharge and degree of hydrological regime alteration) of river gauging stations with some of the longest flow records in Spain are shown in Table 1; their locations are shown in Fig. 4.

The temporal evolution of the annual flow data recorded at these stations is represented in Fig. 5. Although, at first glance, they seem to show a clear

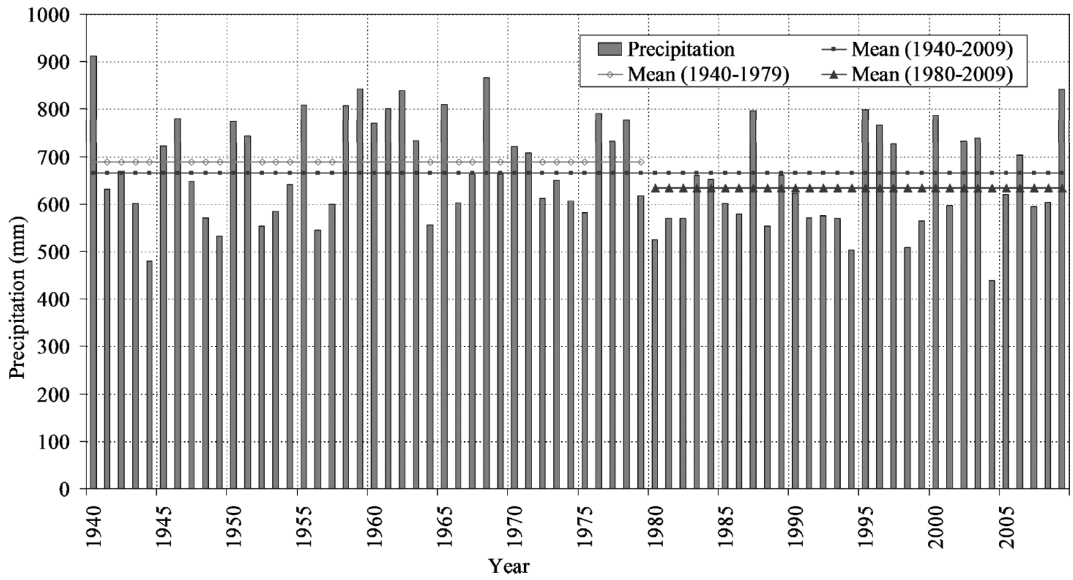

Fig. 3 Annual rainfall data in Spain. Source of data: Spanish Water Information System (http://www.mma.es).

Table 1 Main characteristics of gauging stations with longest river flow records in Spain. Source of data: Anuarios de aforo 2007–2008 (Ministerio de Medio Ambiente y Medio Rural y Marino de España 2010).

River	Location	Gauging Station	X UTM	Y UTM	Drainage area (km^2)	Mean annual discharge (hm^3/year)	Degree of alteration
Duero	Garray	2002	545390	4627600	1500	330.1	Low
Tajuña	Orusco	3082	483590	4461810	2029	162.8	Low
Segura	Fuensanta	7001	569160	4250280	1218	278.3	Low
Mijares	Villarreal	8005	745933	4427457	2504	238.0	High
Alfambra	Teruel	8027	659634	4469301	1396	38.7	Low
Júcar	Los Frailes	8036	608192	4333000	5403	647.5	High
Cabriel	Cofrentes	8112	664480	4347800	4694	609.6	Medium
Aragón	Yesa	9101	646828	4719928	2191	994.8	Low
Ebro	Zaragoza	9011	676533	4614247	40434	7359.4	High

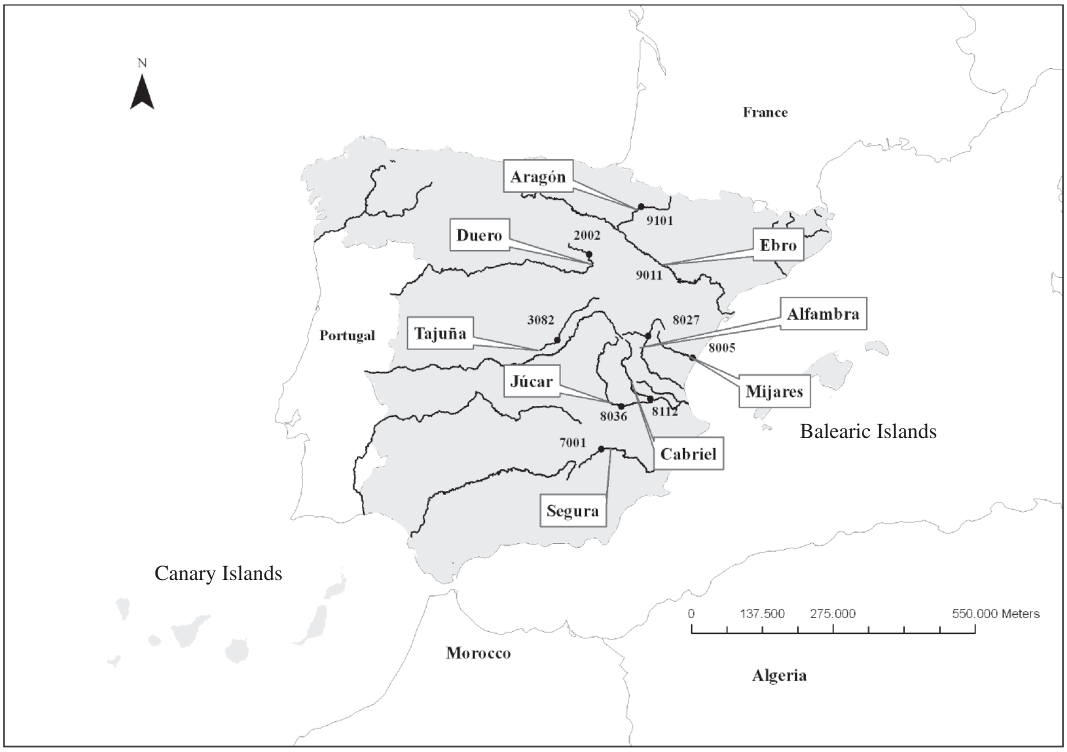

Fig. 4 Location of the gauging stations with some of the longest river flow records in Spain. Source of data: Anuarios de aforo 2007–2008. Ministerio de Medio Ambiente y Medio Rural y Marino de España (2010).
Note: Canary Islands are represented out of the real location.

decreasing trend during the 20th century, this appearance is deceptive, as illustrated later.

One of the longest data series in Spain corresponds to the Ebro River at Zaragoza. It has the largest mean annual flow, 16 500 hm^3/year, of all Spanish rivers, supplies a water demand of almost 7000 hm^3/year and has been a candidate to make a significant water transfer, 1000 hm^3/year, to several Mediterranean river basins. Its drainage area in Zaragoza (40 434 km^2) is much larger than for any other river gauges in Table 1, and for that reason, the data are not included in Fig. 5, but represented separately in Fig. 6. The Ebro flow data at Zaragoza seem to show a clear decreasing trend, if the analysis, based on linear regression, is extended back over the last 50 years (Fig. 6). However, if attention is drawn to the complete data flow series, starting in 1912, the trend is much less clear. Dry and humid periods alternate in this case, and it could be concluded that the data seem to follow a stationary pattern. Therefore, caution should be used with this type of analysis, not to establish trends using periods, even with many years, if they do not adequately represent the hydrological variability of flow discharges.

Since 1980, the dry period recorded in the Spanish Mediterranean area has been accompanied by a trend of increasing temperature (Pérez-Martin 2009), as apparent in Figs 7, 8 and 9, where precipitation, temperature and runoff annual data are shown, respectively, for 1940–2009. These data correspond

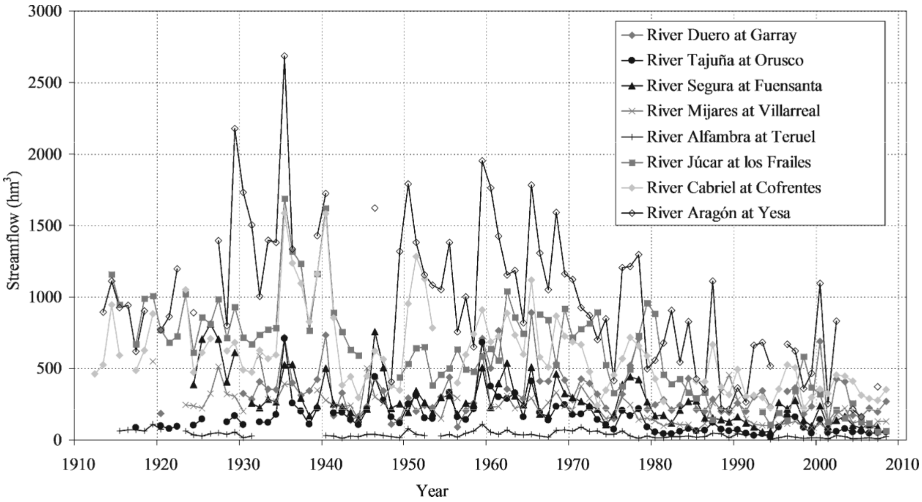

Fig. 5 Some of the longest river flow data series in Spain. Source of data: Spanish Water Information System (http://www.mma.es).

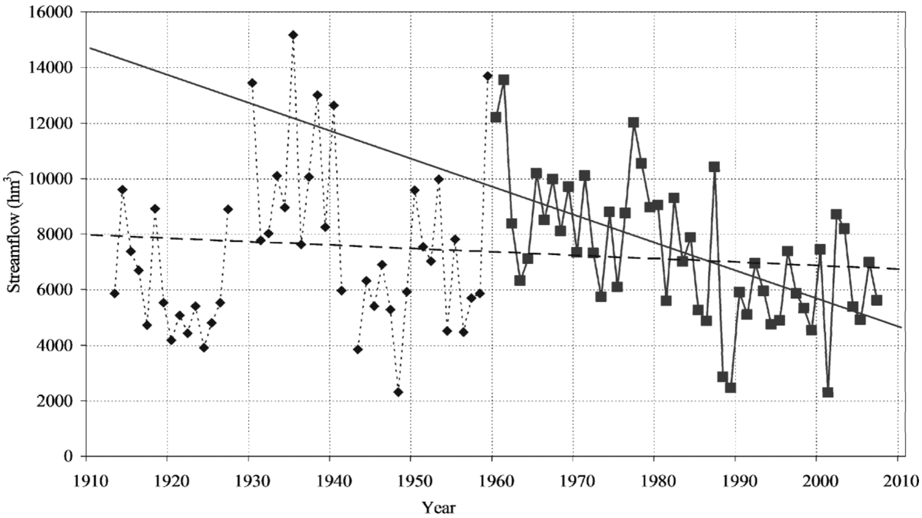

Fig. 6 Streamflows of the River Ebro at Zaragoza. Source of data: Spanish Water Information System (http://www.mma.es).

to the upper basins of the Júcar and Cabriel rivers (8600 km^2) in the east of Spain, draining, respectively, to the Alarcón and Contreras reservoirs, and natural flow regimes can be assumed. This temporal coincidence, together with the short flow series, make it difficult to discern if the cause is due to the occurrence of a dry cycle corresponding to the climate's natural variability, if the runoff reduction is related to the increase of temperature, or if both phenomena occur.

Additionally, some data series shown in Fig. 5 may also incorporate effects due to human water use. An example is the case of the Júcar River in Los Frailes, where river flow discharges reflect the effect of water abstractions from the Mancha Oriental aquifer (Estrela *et al.* 2004), which dramatically increased between the 1980s and early 2000s (Fig. 10). Regrettably, information on water abstractions it is not always available, or, if available, is not in the appropriate form to reconstruct the natural regime.

The lack of river flow data for longer periods, the effects of river regulation and water abstractions, and the high natural variability of rivers can account for the apparent reduction of river flows. Furthermore, it is not always easy to obtain data series of water uses. Therefore, it can be concluded that it is not an easy task to study climate change effects on water resources through statistical analyses of observed river flow data, which explains the convenience of using hydrological simulation models.

4 STUDIES ON MODELLING HYDROLOGICAL EFFECTS OF CLIMATE CHANGE IN SPAIN

One of the first research projects in Spain to study the effects of climate change on water resources was by Ayala-Carcedo and Iglesias López (1996) and applied a regional lumped hydrological model for each of the main Spanish river basins. They used a scenario produced by the former National Meteorological

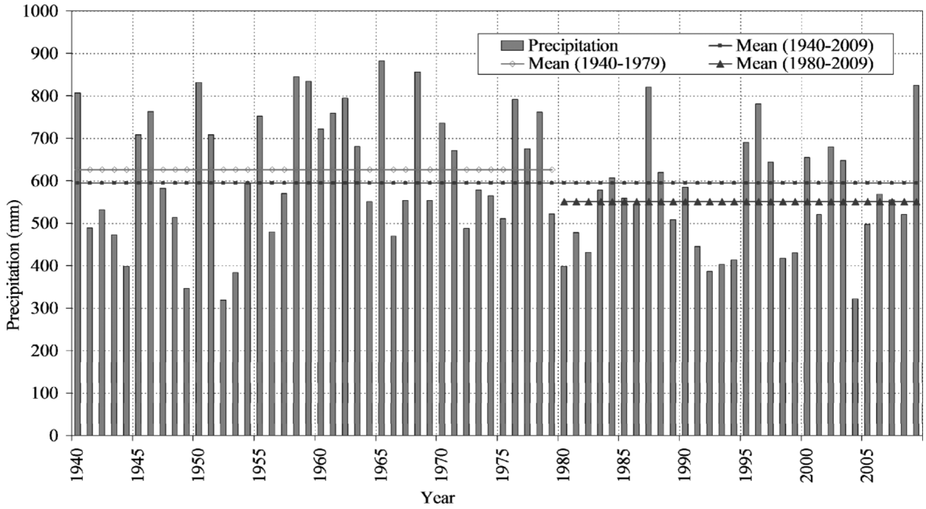

Fig. 7 Annual rainfall data for the Upper Jucar and Cabriel river basins. Source of data: Júcar River Basin Authority.

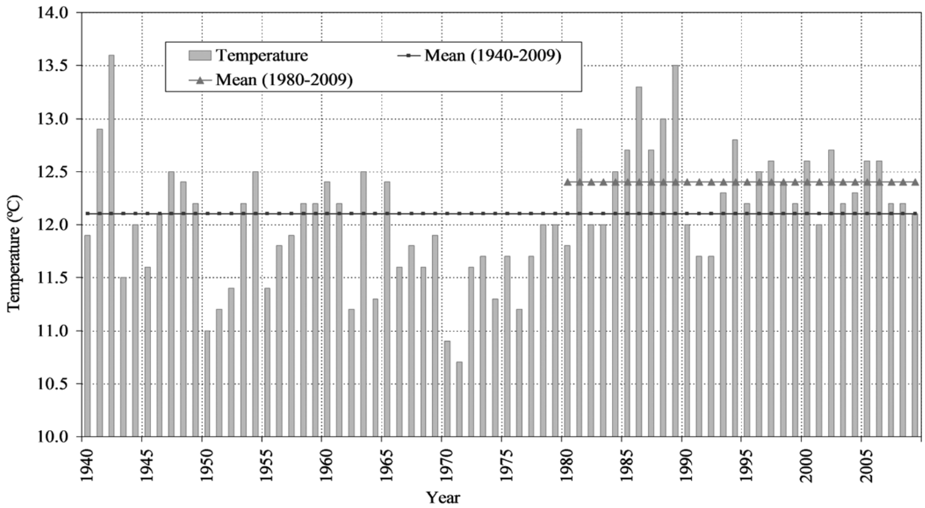

Fig. 8 Annual temperature data for the Upper Jucar and Cabriel river basins. Source of data: Júcar River Basin Authority.

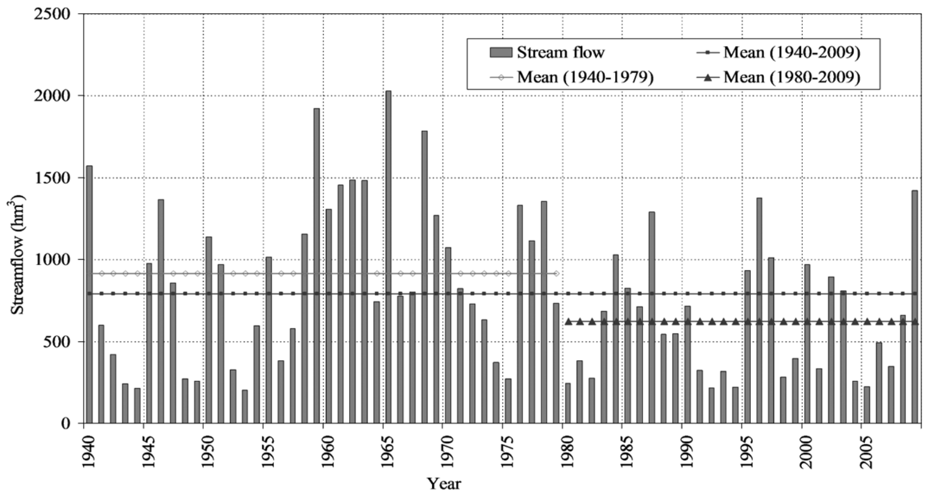

Fig. 9 Annual streamflow data for the Upper Jucar and Cabriel river basins. Source of data: Júcar River Basin Authority.

Institute of Spain applying the Hadley Centre model for horizon 2060 (2.5°C increase in mean annual temperature and a decrease of 8% in mean annual precipitation). The mean global reduction of water resources in Spain obtained was 17%, the main changes being in the southern areas of the country.

Later, the effects of climate change on water resources was systematically assessed in the White Paper on Water in Spain (Ministerio de Medio Ambiente 2000) by means of a spatially-distributed hydrological model (1 km × 1 km cells) operating on an annual basis for the whole Spanish

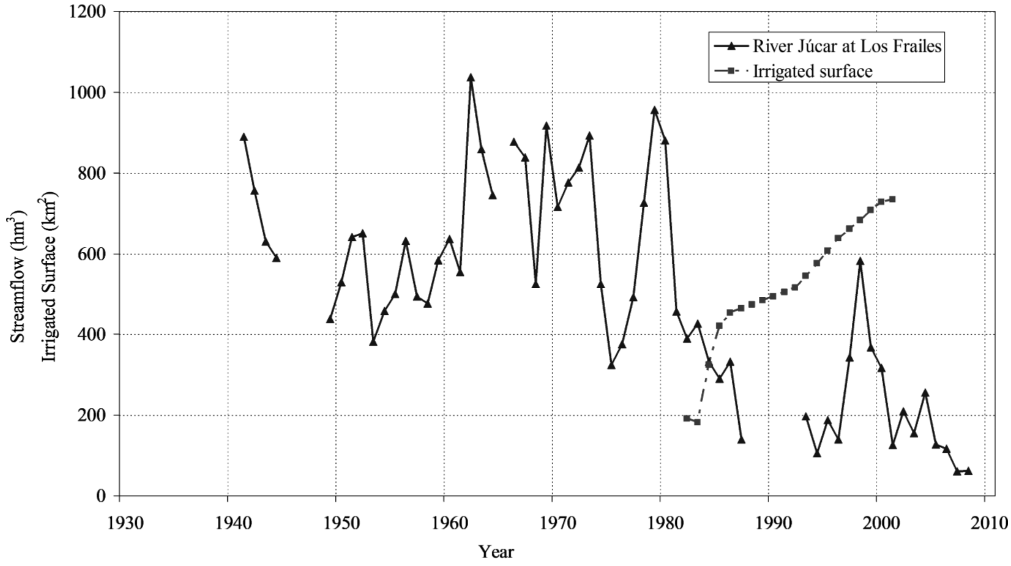

Fig. 10 Evolution of flow discharges in the Júcar River and irrigated area in the Mancha Oriental aquifer. Updated data from Estrela *et al.* (2004).

territory and based on the well-known Budyko law (Budyko and Drozdov 1953), which relates, over the long-term, the mean annual runoff with the mean annual precipitation and the mean annual potential evapotranspiration, obtained from temperature. Three scenarios derived from the National Programme on Climate (Ministerio de Obras Públicas, Transportes y Medio Ambiente 1995) were analysed for 2030. This assessment report shows a clear reduction in total water resources. For a simple scenario corresponding to a decrease of 5% in mean annual precipitation and an increase of 1°C in mean annual temperature, a decrease of 9–25% is expected in runoff for 2030, depending on the river basin district studied. The effect of climate change on water resources varies regionally, mainly following projected changes in rainfall and temperature. The most critical Spanish areas are the arid and semi-arid ones, where water scarcity and drought problems are greater, as in Guadiana, Canary Islands, the Segura, Júcar and Guadalquivir river basins, the southern part of the country and the Balearic Islands (Ministerio de Medio Ambiente 2000).

The next step in hydrological modelling of climate change impacts was the use of models simulating the main processes that constitute the hydrological cycle. These models estimate variables such as precipitation, snow, actual evapotranspiration, soil moisture, surface and groundwater runoff, aquifer recharge, volume storage in soils, etc. Models may be conceptual or physically-based in type, and different temporal operation intervals can be used.

Fernández (2002) studied climate change effects on water resources in 19 small river basins distributed throughout the Spanish territory using the SIMPA distributed conceptual model (Fig. 11), developed by Ruiz (1998) and operating on a monthly scale with a 1 km × 1 km-resolution grid. The SIMPA model applies conceptual water balance equations in each of the grid cells. It considers the subsurface as divided into two zones: the upper non-saturated or soil moisture zone; and the lower or aquifer zone, which is saturated with water and serves as a groundwater reservoir that may or may not be connected to the surface drainage network. As shown in Fig. 11, part of the rainfall is stored in the soil moisture zone, providing supplies for the evapotranspiration process. The rest can be regarded as a surplus, and it is divided into a part that flows on the surface, and the remainder that infiltrates into the aquifer. The surface runoff flows out through the basin in the present time, whereas water that has infiltrated forms part of the aquifer and is later discharged to the drainage network.

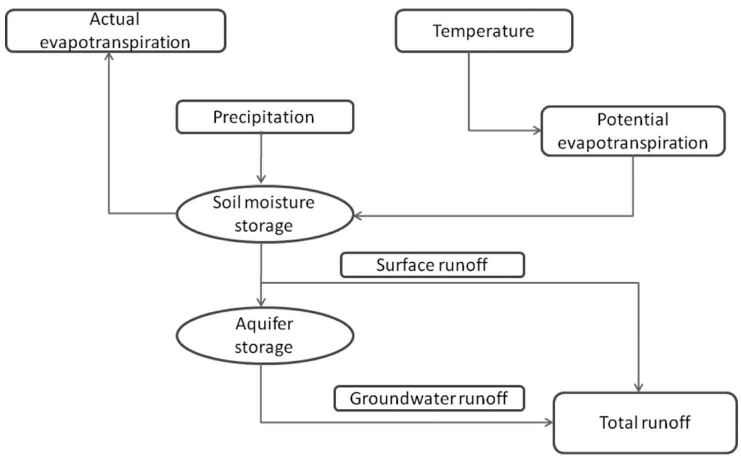

Fig. 11 The SIMPA hydrological model scheme.

The model inputs are monthly rainfall and temperature data from the meteorological stations. The model obtains the different rainfall and temperature maps for each time interval by interpolation. The hydrological model parameters are a function of the physical characteristics of the basins (terrain slopes, geology, land cover, soil types, etc.). The model outputs are the maps of the different storages (soil moisture and aquifer volume) and flows (actual evapotranspiration and total runoff, obtained as the total sum of the surface and groundwater runoff) for each time interval. The model integrates the total runoff at the defined drainage points, calculating the monthly discharges therein. The SIMPA model was used to assess Spanish water resources in the White Paper on Water in Spain (Ministerio de Medio Ambiente 2000, Estrela *et al.* 2001). Monthly maps produced by this model are published periodically in the Water Information System of the web page of the Spanish ministry of Agriculture, Food and Environment.

Different climatic scenarios, originating from the Ministerio de Medio Ambiente (2000), MCG (UKMO) models and PROMES RCM, were used by Fernandez (2002). One of the main conclusions of this work was that there was a need to allow for the seasonal distribution of climatic and hydrological variables in future assessments.

In 2005, the Spanish Ministry of Environment led the ECCE project "Assessment report of the preliminary impacts in Spain due to Climate Change" (Ministerio de Medio Ambiente 2005), in which the main focus was the review and compilation of the state of the art on climate change impacts and preparation of the basis for future climate change adaptation initiatives in Spain. Regional climate scenarios in the ECCE project were taken from the PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects) project of the European Union Fifth Framework Programme. The regional model used was PROMES, with the following characteristics: 50-km horizontal resolution; 35 layers, nested in HadAM3H with ocean surface temperature provide by HadCM3; two time periods, 1960–1990 (control) and 2070–2100; and SRES-A2 and SRES–B2 emissions scenarios. This model produced scenarios of climate changes in Spain for the 2071–2100 period compared to 1961–1990. In both scenarios and for all the seasons, a generalized warming was identified all over Spain, but greater in the A2 scenario and in the southern and eastern areas of the Spanish mainland (increases of up to 5–7°C in summer). In both scenarios, general annual reductions in rainfall occurred, but with an irregular distribution across the seasons and among the different Spanish regions.

The main conclusions of the "Assessment report of the preliminary impacts in Spain due to Climate Change" related to water resources were:

(a) a general decrease of water resources and an increase in irrigation systems;
(b) input reductions of up to 50% in arid and semi-arid regions;
(c) an increase in inter-annual variability;
(d) demand management as a palliative option;
(e) the need to improve and extend monitoring networks, increase research in hydrological process and simulation models; and
(f) climate change effects need to be taken into account in water policies and water resources management.

In general terms, this report highlights the need to develop a more in-depth assessment of the impacts of climate change on water resources.

Available climate change scenarios for the Júcar River basin (42 900 km^2 in the east of Spain) for 2070–2100 were assessed by Hernández Barrios (2007). The climate scenarios corresponded to the results obtained with the HadCM3 model for A2 and B2 SRES (Special Report on Emission Scenarios, IPCC 2000), regionalized for Spain with the PROMES model (Gallardo *et al*. 2001). Based on those climatic anomalies, impacts on natural water resources, water needs for crops and water management in hydrological systems in the Júcar River Basin District were assessed. Impact on natural water resources was estimated with the Patrical model (Pérez-Martín 2005), with a global runoff reduction of 40% for the whole Júcar River basin, but significant geographical variations. The most affected areas, with 50% reductions, are the inner zones of the basin, while the coastal areas show reductions of approximately 25%. The results obtained also showed increases in water needs of 25–30% in crops located in inland areas, and 28–38% in crops located in the coastal areas. The impact on the water resource systems derived from a reduction of natural water resources and from increases in crop water needs were also evaluated. The results show a strong impact on the system with important decreases in the irrigation guarantees and the emergence of environmental problems in river ecosystems. In addition, it was concluded that it is not possible to maintain the current water uses, especially the great water volumes used for irrigation.

Ceballos-Barbancho *et al.* (2008) analysed the temporal trend of water supplies for a network of basins in the southwestern sector of the Spanish part of the Duero River basin (78 960 km^2 in northwest Spain), and their relationship with the evolution of temperature, precipitation and the changes that have occurred in plant cover over time. The results show an important decrease in water supply associated with changes in the monthly distribution of water discharge due to alterations in the intra-annual distribution of precipitation and an increase in temperature in spring and summer.

Recently, the Center for Hydrographic Studies of CEDEX, a Spanish research and experimentation centre for water issues, has been commissioned by the Ministry of Environment and Rural and Marine Affairs to make an assessment of the climate change impact on natural regime water resources for the whole Spanish territory (CEDEX 2010). The climatic data used include climate scenarios regionalized by the Spanish State Meteorological Agency (AEMET 2008), which combine the results of global circulation models made by various international organizations with techniques of regionalization at the local level. The chosen emission scenarios (A2 and B2) are part of the set of scenarios of emission of greenhouse gases established by the IPCC in 2000. The phases of the hydrological cycle have been simulated using the SIMPA model described above.

The set of projections for scenario A2 suppose decreases of precipitation in Spain over the control period (1961–1990) of approx. 5%, 9% and 17% during 2011–2040, 2041–2070 and 2071–2100, respectively. These reductions are slightly smaller for scenario B1, especially for the period 2071–2100. The projections of the A2 scenario lead to reductions in runoff in Spain of 8% for the period 2011–2040, 16% for the period 2041–2070 and 28% for 2071–2100. The reductions for the B2 scenario are lower, 8%, 11% and 14%, respectively. Runoff reduction also varies regionally as shown in Table 2 and Fig. 12, the largest decreases occurring in river basins in southern Spain.

Chirivella (2010) characterizes future climate scenarios in the Júcar River Basin District. According to this work, scenarios collected in AEMET (2008) reproduce well the temperature of the the Júcar River Basin District in the control period (1961–1990), but generally underestimate precipitation. Outcomes obtained from the data of the global model HadCM2 best reproduce both variables. In addition, the model performs a climatic regionalization obtained with dynamic downscaling. The regional model employed is the RegCM3, with future climate data from the global model ECHAMs and considering the A1B emission scenario, corresponding to the scenarios elaborated for AR4 of IPCC. The ENSEMBLES project established the A1B scenario as the most probable for Europe. The objective of ENSEMBLES is to obtain updated and regionalized results of the probable climate scenario for the 21st century in Europe (socio-economic A1B scenario), including mid-term (2030–2050) and long-term (2080–2100) projections. The results of this project have been recently incorporated into the regionalized climate scenarios for Spain in the web page of the Spanish State Meteorological Agency (www.aemet.es). The process of downscaling is performed (Chirivella 2010) in two stages: first for all the Iberian Peninsula (nested scope), and second, with the results of the above as boundary conditions for the Júcar River Basin District (coarse scope), and a clear improvement in the characterization of the climate is observed on making this double downscaling. The impact foreseen on the water resources of the Júcar River Basin District for 2010–2040 is a reduction of 19% over the control period of 1990–2000. This reduction is significantly greater than that obtained in CEDEX (2010) for the same territorial scope for scenarios A2 (5%) and B2 (12%), which may be explained by the use of a dynamic downscaling to represent the climate variable, precipitation.

Climate change impacts on natural water resources will affect their use through the water resource system, which contributes to the regulation, transport and distribution of resources to the areas of consumption. The water resource system can absorb or amplify the climate change effects depending on the water management carried out. Therefore, the impact of climate change on water resources also depends on the system's characteristics (reservoirs, channels, etc.) and how the system's management is handled. Unmanaged systems are likely to be the most vulnerable to climate change (IPPC 2007). Garrote *et al.* (1999) estimated the effects on available water resources for the scenarios considered in the White Paper on Water in Spain (Ministerio de Medio Ambiente 2000). They conclude that a global reduction of 5% in natural water resources becomes a reduction of 4% in available

Table 2 Variation of runoff (%) for Spanish river basin districts in the periods 2011–2040, 2041–2070 and 2071–2100 with regard to the control period of 1961–1990. Source of data: CEDEX (2010).

River basin district	Period	Change in mean annual runoff (%)	
		Scenario A2	Scenario B2
Cantábrico Occidental	2011–2040	−13	−10
	2041–2070	−16	−16
	2071–2100	−29	−17
Galicia Costa	2011–2040	−6	−3
	2041–2070	−12	−8
	2071–2100	−19	−5
Cantábrico Oriental	2011–2040	−12	−10
	2041–2070	−16	−16
	2071–2100	−30	−20
Miño – Sil	2011–2040	−6	−3
	2041–2070	−12	−7
	2071–2100	−21	−6
Duero	2011–2040	−8	−7
	2041–2070	−17	−9
	2071–2100	−31	−13
Tajo	2011–2040	−8	−8
	2041–2070	−19	−9
	2071–2100	−35	−15
Guadiana	2011–2040	−12	−9
	2041–2070	−27	−11
	2071–2100	−42	−20
Guadalquivir	2011–2040	−22	−13
	2041–2070	−28	−12
	2071–2100	−43	−24
Cuencas Internas de Andalucia	2011–2040	−12	−16
	2041–2070	−30	−15
	2071–2100	−41	−27
Segura	2011–2040	−10	−13
	2041–2070	−21	−14
	2071–2100	−33	−21
Júcar	2011–2040	−5	−12
	2041–2070	−18	−13
	2071–2100	−32	−24
Ebro	2011–2040	−9	−9
	2041–2070	−14	−13
	2071–2100	−28	−16
Cuencas Internas de Cataluña	2011–2040	0	−7
	2041–2070	−4	−9
	2071–2100	−21	−16
Islas Baleares	2011–2040	−4	−15
	2041–2070	−15	−20
	2071–2100	−31	−23
Islas Canarias	2011–2040	−18	−25
	2041–2070	−32	−28
	2071–2100	−41	−34
Spain	2011–2040	−8	−8
	2041–2070	−16	−11
	2071–2100	−28	−14

water resources. Rodríguez Medina (2004) investigated water resources system sensitivity to water reductions due to climate change, observing the greatest decreases in those systems with less regulation capacity, or with an excess of it. It is clear that the impact of climate change on hydrological design and water resources management could be one of the most important challenges faced by hydrologists and water resources managers, as indicated by Teegavarapu (2010).

5 IMPLICATIONS OF CLIMATE CHANGE AND POLICY ACTIONS

The impacts of climate change on water resources may be exacerbated it occurs in regions already

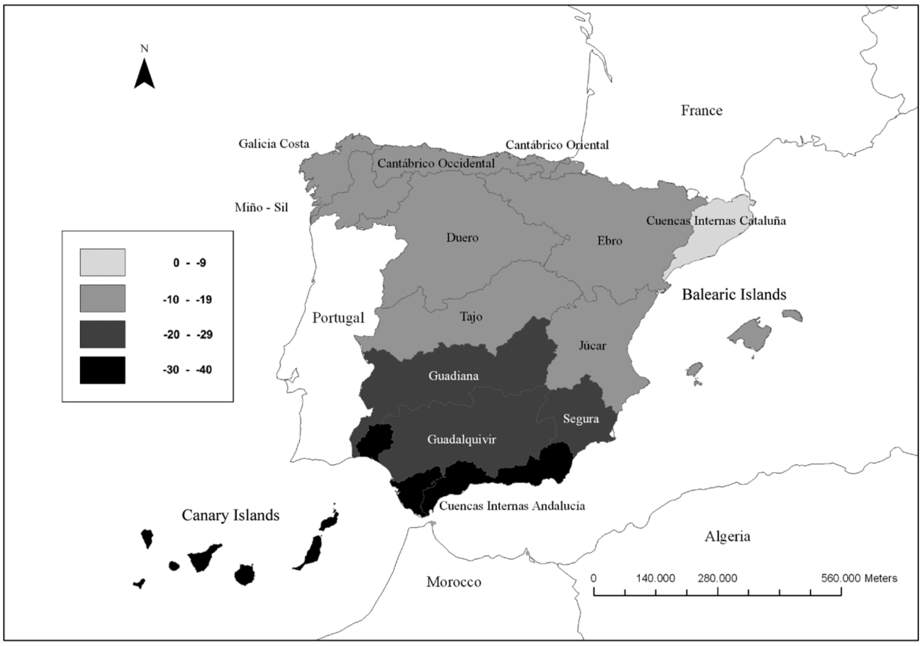

Fig. 12 Variation of runoff (%) for Spanish river basin districts corresponding to the A2 scenario in the period 2041–2070 compared to the control period, 1961–1990. Source of data: CEDEX (2010).
Note: Canary Islands are represented out of the real location.

Table 3 Comparison between reduction in runoff by climate change and water exploitation index in the Spanish River basin districts.

River basin district	Mean annual runoff (hm^3)	Δ mean annual runoff 2041–2070. Scenario A2*	Mean annual total water demand (hm^3)	Water exploitation index (%)
Cantábrico Occidental	16 142.90	−16	717.23	4.4%
Galicia Costa	12 077.40	−12	782.85	6.5%
Cantábrico Oriental	1 637.59	−16	309.85	18.9%
Miño – Sil	11 918.50	−12	581.50	4.9%
Duero	13 179.20	−17	3 829.77	29.1%
Tajo	10 075.20	−19	2 667.04	26.5%
Guadiana	4 473.50	−27	2 333.44	52.2%
Guadalquivir	7 087.40	−28	3 368.28	47.5%
Cuencas Internas de Andalucia	4 499.35	−30	1 908.48	42.4%
Segura	762.00	−21	1 807.55	237.2%
Júcar	3 357.91	−18	2 949.16	87.8%
Ebro	16 202.50	−14	7 033.62	43.4%
Cuencas Internas de Cataluña	2 603.28	−4	1 346.16	51.7%
Islas Baleares	639.41	−15	285.56	44.7%
Islas Canarias	420.17	−32	413.88	98.5%
Spain	*109 575.66*	*−16*	*32 242.84*	*29.4%*

Note: *Source: CEDEX (2010).

presenting low water resources levels. Table 3 shows, for Spanish river basin districts, the mean annual runoff, the runoff reduction for the period 2041–2070, the mean annual total water demand and an indicator of the vulnerability of a territory to water stress, the water exploitation index, obtained as the quotient between the mean annual water demand and the mean annual runoff. It is observed that the higher reductions in mean annual runoff take place in the river basin districts more vulnerable to water stress, i.e. where the value of the water exploitation index is higher.

If the climate change scenarios foreseen for Spain occur in future years, the measures traditionally used in Spain to fight water scarcity will need to be applied more strongly and in a manner consistent with regional effects on water resources. The challenges for Spanish policy makers include understanding climate change impacts and developing and implementing policies to ensure optimal levels of adaptation to the projected water resources reduction in the most affected territories, especially in those with water scarcity.

During the first cycle of river basin planning of the Water Framework Directive, a Climate-Check for the Programme of Measures has been carried out in Spanish river basin districts, similarly to that which takes place in other EU Member States. Measures that may arise in the river basin management plans should take into account the different effects of climate change in different river basins. The Spanish Royal Decree, RD 907/2007 regarding Water Planning Regulation was approved in July 2007, and mandates the consideration of the effects of climate change on water resources in the current River Basin Management Plans. According to this decree, these plans will assess the effect of climate change on water resources in each Spanish river basin district, estimating the resources corresponding to the climatic scenarios considered by the Spanish Ministry of Agriculture, Food and Environment (AEMET 2008). With the aim of assessing trends and establishing a programme of measures, each plan will estimate the balance between available water resources for those climate scenarios and the projected water demands for different uses.

A National Adaptation Plan (Ministerio de Medio Ambiente 2006) has been under development since 2006 to cope with climate change effects in Spain. Its aim is to integrate adaptation to climate change into the planning strategies of the different socio-economic sectors in the country by establishing a continuous and accumulative process of knowledge generation and strengthening of capacities. For each sector and system, the Plan identifies predicted impacts in accordance with the publication "A preliminary assessment of the impacts in Spain due to the effects of Climate Change" (Ministerio de Medio Ambiente 2005) and establishes measures, activities and lines of work to be developed for impacts assessment, vulnerability and adaptation. A key objective of this Plan for the water resources sector is to develop quantitative scenarios of water resources for the 21st century in Spanish river basins. The Plan includes an assessment of the management and capacity of the Spanish hydrological systems under different water resources scenarios, a second assessment of potential climate change effects on irrigation, and a third one of climate change impacts on the ecological status of water bodies.

6 CONCLUSIONS

Hydrological stress is expected to increase as a consequence of climate change in some regions of the world, including southern Europe, and Spain in particular, increasing the populations affected by living under water-stress conditions.

The detection of climate change effects is not simple because the natural variability of the water cycle and the effects of water abstractions on flow discharges complicate the task of establishing clear trends from river flow data. To assess these effects, major progress in hydrological modelling has occurred in Spain in recent years. Several models have been applied and gradually improved for Spanish territory. It can be stated that currently there are enough modelling tools to assess impacts on water resources in natural regimes with sufficient detail from climate change scenarios. Results obtained to date show that the negative effects of climate change will mainly affect the semi-arid zones with water shortages and a fragile balance between water resources and demands. Overall, runoff reductions will be between 10 and 30% for the whole country through the 21st century, which has important implications for water management in Spain.

Relevant recommendations to policy makers and water managers, which are reflected in recent regulations, have been produced as a result of the scientific work carried out. If the intense use of water resources continues, the environmental requirements increase and the margin to increase available water resources is reduced, then it is most likely that current water uses will not be maintained in the future. In conclusion, it becomes essential to improve assessment of the effects and to adapt water management to the already identified impacts and to the anticipated ones by using future scenarios.

A Climate Change National Adaptation Plan is being developed in Spain, which establishes a general reference framework to evaluate climate change impacts, vulnerability and adaptation. In addition, climate change impacts are being taken into account in the water balances of the upcoming River Basin Management Plans in Spain, which represents an opportunity for taking into account climate change effects in water decision-making policies. According to existing climate change scenarios, reduction of available water resources will gradually occur through the 21st century, and, therefore, the available water resource assessment carried out in the river basin planning framework will play a relevant role.

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REFERENCES

AEMET, 2008. Generación de escenarios regionalizados de cambio climático para España. Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid, Spain.

Arnell, N.W., 2004. Climate change and global water resources: SRES scenarios and socio-economic scenarios. *Global Environmental Change*, 14, 31–52.

Ayala-Carcedo, F.J. and Iglesias López, A., 1996. Impactos del cambio climático sobre los recursos hídricos, el diseño y la planificación hidrológica en la España peninsular. *Tecnoambiente*, 64, 43–48.

Budyko, M.I. and Drozdov, O.A., 1953. The laws of water cycle in the atmosphere. *Bulletin of the Academy of Science USRR Scr Geography*, 4, 167–170.

Ceballos-Barbancho, A., *et al*., 2008. Water resources and environmental change in a Mediterranean environment: the south-west sector of the Duero River basin (Spain). *Journal of Hydrology*, 351 (1–2), 126–138.

CEDEX, 2010. Estudio de los impactos del cambio climático en los recursos hídricos y las masas de agua. Ficha 1. Evaluación del impacto del cambio climático en los recursos hídricos en régimen natural. Clave CEDEX 42-407-1-001. Informe técnico para ministerio de Medio Ambiente y Medio Rural y Marino, Madrid, Spain.

Chirivella, V., 2010. *Caracterización de los futuros escenarios climáticos en la Comunidad Valenciana: propuestas de mejora para la evaluación de la oferta y demanda de recursos hídricos*. Tesis Doctoral, Universidad Politécnica de Valencia. Valencia, Spain.

Estrela, T., Cabezas, F., and Estrada, F., 2001. The water resources assessment in the White Paper on Water in Spain. Country Paper of Spain. Seventh Scientific and Technical Review. *In*: *Water modelling as a tool in river basin management within the Framework Directive*. Proceedings, Madrid. ISBN 84-7790-370-0, 113–136.

Estrela, T., *et al*., 2004. Modelo hidrogeológico del acuífero de la Mancha Oriental para el análisis de los efectos de las diferentes alternativas de sustitución de extracciones por aguas superficiales. *VIII Simposio de Hidrogeología. Asociación Española de Hidrogeólogos*, Zaragoza. ISBN 657-04-028-5.

Estrela, T. and Vargas, E., 2010. Effects of climate change on hydrological resources in Europe: the case of Spain. *In*: A. Marquina, ed. *Global warming and climate change, prospects and policies in Asia and Europe*. Houndmills, Basingstoke, Hampshire, New York: Palgrave Macmillan, ISBN 978-0-230-23771-1.

European Commission, 2007. Communication from the Commission to the European Parliament and the Council, Addressing the challenge of water scarcity and droughts in the European Union. COM(2007) 414 final.

European Commission, 2009. White Paper. Adapting to climate change: towards a European framework for action. Brussels, COM, 2009. 147 final.

European Commission, 2010. Agriculture in the EU, Statistical and economic information 2009. Directorate-General for Agriculture and Rural Development.

European Environment Agency, 2010. The European Environment – state and outlook 2010. Adapting to climate change. Copenhagen, Denmark.

Fernández, P., 2002. *Estudio del impacto del cambio climático sobre los recursos hídricos. Aplicación en diecinueve cuencas en España*. Tesis Doctoral, ETS Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Spain.

Gallardo, C., *et al*., 2001. Multi-year simulations with a high resolution regional climate model over the Iberian Peninsula. Current climate and 2xCO2 scenario. *Quarterly Journal of the Royal Meteorological Society*, 127, 1659–1682.

Garrote, L., Rodríguez, I., and Estrada, F., 1999. Una evaluación de la capacidad de regulación de las cuencas de la España Peninsular. *VI Jornadas Españolas de Presas*, 2, 645–656.

Hernández Barrios, L., 2007. *Efectos del cambio climático en los sistemas complejos de recursos hídricos. Aplicación a la cuenca del Júcar*. Tesis Doctoral, Universidad Politécnica de Valencia, Spain.

INE (Instituto Nacional de Estadística), 2008. Cifras INE, Estadísticas e Indicadores del Agua. Boletín Informativo del Instituto Nacional de Estadística.

INE (Instituto Nacional de Estadística), 2010. Available from: http://www.ine.es [Accessed 16 January 2011].

IPCC (Intergovernmental Panel on Climate Change), 2000. Special report on emission scenarios. Intergovernmental Panel on Climate Change.

IPCC (Intergovernmental Panel on Climate Change), 2007. Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Ministerio de Medio Ambiente, 2000. *Water in Spain*. Centro de publicaciones del Ministerio de Medio Ambiente, Madrid, Spain.

Ministerio de Medio Ambiente, 2005. Assessment report of the preliminary impacts in Spain due to Climate Change. Centro de publicaciones del Ministerio de Medio Ambiente, Madrid.

Ministerio de Medio Ambiente, 2006. Plan nacional de adaptación al cambio climático. Centro de publicaciones del Ministerio de Medio Ambiente, Madrid, Spain.

Ministerio de Medio Ambiente y Medio Rural y Marino, 2010. Anuarios de aforo 2007–2008. Madrid.

Ministerio de Obras Públicas, Transportes y Medio Ambiente, 1995. Programa Nacional del Clima, Madrid, Spain.

Pérez-Martín, M.A., 2005. *Modelo distribuido de simulación del ciclo hidrológico con calidad de aguas integrado en sistemas de información geográfica para grandes cuencas. Aportación al análisis de presiones e impactos de la Directiva Marco Europea del Agua*. Tesis Doctoral, Universidad Politécnica de Valencia, Spain.

Pérez-Martín, M.A., 2009. Herramientas para la evaluación de los efectos del cambio climático en los recursos hídricos. Jornada sobre repercusiones del cambio climático en la planificación y gestión de los recursos hídricos. Universidad Politécnica de Valencia, Spain.

Rodríguez Medina, I., 2004. *Sensibilidad de los sistemas de explotación de recursos hídricos frente al cambio climático en España*. Tesis Doctoral, ETS Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Spain.

Ruiz, J.M., 1998. *Desarrollo de un modelo hidrológico conceptual distribuido de simulación continua integrado con un sistema de información geográfica*. Tesis Doctoral, ETS Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Valencia, Spain.

Teegavarapu, R.S.V., 2010. Modeling climate change uncertainties in water resources management models. *Environmental Modelling and Software*, 25 (10), 1261–1265.

3.4 Vargas-Amelin, E., Pindado, P., 2014. The challenge of climate change in Spain: Water resources, agriculture and land. Journal of Hydrology. 518, 243–249.

This article addresses the impacts of climate change in sectors directly linked to water, such as agriculture or land management. It provides an assessment of expected impacts at the national level, and offers insights on both mitigation and adaptation strategies within the different sectors, mentioning specific plans and cross-sectoral structures.

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The challenge of climate change in Spain: Water resources, agriculture and land

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SUMMARY

Climate change effects are becoming evident worldwide, but some water scarce regions present higher vulnerability. Spain, located in the Mediterranean region, is expected for instance to be highly vulnerable given its unbalanced distribution between water resources availability and existing demands. This article presents an introduction to the main threats of climate change mainly on water resources, but it also assesses effects in interlinked areas such as agriculture, soil and land management. Contents focus on measures and initiatives promoted by the central government and address efforts to establish multi-sectoral coordinating bodies, specific adaptation plans and measures for the different sectors. The article highlights some political aspects, such as the complexity of involved competent authorities in water and land management, the need to strengthen public participation and the conflicts arising from the defence of regional interests. It also makes a link to current EU policies; summarises foreseeable problems derived from climate change effects, and provides some recommendations in the different areas covered.

1. Introduction to climate change in Spain

The warming of the global climatic system is a reality, and the human influence has been a dominant cause (Intergovernmental Panel on Climate Change, 2013). It is global, with the most significant local impacts occurring in certain regions, among which the Mediterranean stands out. The Report from the European Environment Agency (2008), Impacts of Climate Change in Europe, noted the high vulnerability of mountain and coastal areas as well as the Arctic and the Mediterranean. This reality was introduced already at the fourth report of the Intergovernmental Panel on Climate Change (2007), considering that there is a high probability that many semi-arid regions such as the Mediterranean basin, will suffer a significant decline in water availability due to climate change.

Spain is considered one of the most vulnerable countries to climate change within the European Union, due to its geographic and socio-economic characteristics. Forecasts obtained from models place it as a region where a further increase in temperature and decrease in precipitation is expected (European Commission, 2009a,b; Agencia Estatal de Meteorología, 2009; Garrote, 2009; Somot et al., 2008; Estrela et al., 2012) (Fig. 1 shows average precipitation in the country).

Climate change, on the other hand, is a problem closely related to human development, growth and consumption patterns. One of the difficulties in addressing climate change lies precisely in its overarching and cross-sectoral characteristics. Territorial disconnection between emissions and impacts, systems vulnerability, the difficulty of achieving proper coordination among the various administrations, and the involvement of stakeholders in decision-making processes, are additional problems for the adaptive capacity to cope with its effects. Spain experienced, since 1995, an important economic development, higher than the European average, which the current economic recession is now seriously threatening (Pérez García et al., 2011). In addition, the country witnessed a social growth, with a significant increase in population, all of which translated into a growing contribution of greenhouse gases (GHGs) and climate change consequences. For instance, emissions of CO_2-equivalent increased steadily between years 1996 and 2005 (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013a).

Another important element when addressing climate change in Spain is its political and jurisdiction organisation, since competences related to climate change (transport, industry, agriculture and environment, among others) are often shared between the Central Administration and the Regional Governments (Autonomous Regions) and, to a lesser extent, the municipalities.

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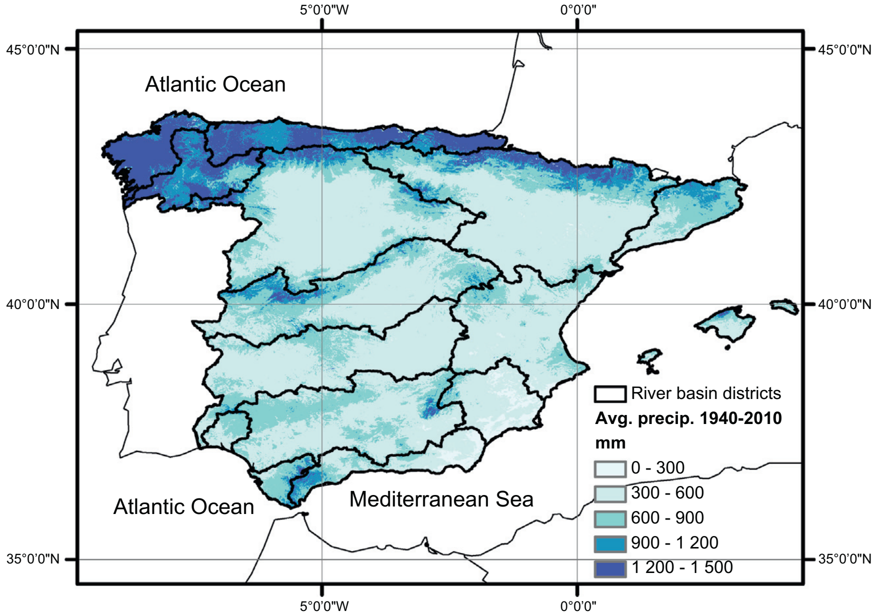

Fig. 1. Map of average precipitation for the period 1940–2010. River Basin Districts are shown inside of the boundaries of Spain. Northern Basins Districts (*Cantábrico Oriental y Occidental*, *Miño-Sil* and *Galicia-Costa*) have significantly more precipitation than the rest of Basin Districts. *Source*: Prepared with data from the *Sistema Integrado de Información del Agua* (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013c). Precipitation data originated to be used by the SIMPA model of the Centro de Estudios Hidrográficos (Centro de Estudios y Experimentación de Obras Públicas).

Therefore, entities that promote coordination, collaboration and participative approaches are essential. Some current examples include the Climate Change Policy Coordination Commission, which includes the three administrative levels (national, regional and local), and the National Weather Council, adding to the former representatives, experts and the civil society. However, these structures and other advisory bodies do not always have the ability to promote the necessary consensus for complex project implementation. That would be the case for some urban[2] projects promoted by local interests, and dependent, among others, on water and energy resources availability. These often lack a regional approach or even national interest, and expected climate change impacts can strongly affect their viability.

It is important to remember that most problems and impacts linked to climate change are not new. In fact, Mediterranean societies, and in particular the Spanish one, have always faced floods, water scarcity, heat waves, prolonged droughts, flows variability, temperature rises, and decreased rainfall with related impacts on crops. Although it is difficult to attribute to global warming the occurrence of a particular phenomenon, there are different studies that suggest that climate change will cause a higher frequency and amplification of these problems (Bates et al., 2008), and their displacement to areas that do not always have sufficient experience to incorporate uncertainty into water planning (Arnell and Liu, 2001).

2. Climate change impacts

Given the uncertainty of climate change, the Spanish Administration launched the project *Climate change effects in Spain*, from which, in 2005, the report *General Preliminary Assessment in Spain of the Impacts by Climate Change Effects* (Ministerio de Medio Ambiente, 2005) was published. This report represented a solid basis for reviewing and gathering information on the state of the art of climate change impacts and possible initiatives for adaptation. It indicated that climate change impacts could have particularly serious consequences such as water resources decreases, coastal regression, loss of biodiversity and natural ecosystems, increased soil erosion processes and loss of lives and goods resulting from the intensification of extreme weather events like floods, wild fires and heat waves.

3. Water resources

The findings of the formerly mentioned *Preliminary Assessment* related to water resources highlighted that a general reduction of water resources and increased demand for irrigation systems was expected in Spain. The report also predicted a reduction in inputs

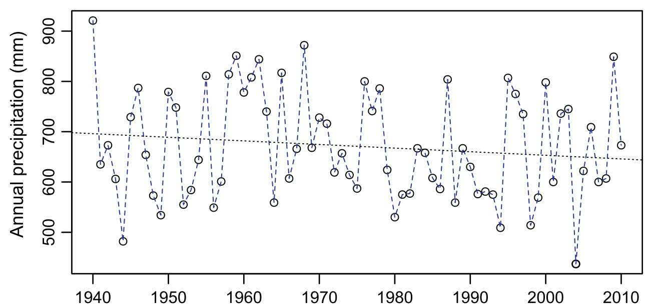

Fig. 2. Time evolution of annual precipitation (hydrological years 1940–1941 to 2010–2011). The hydrological year starts on October of year *i* ending on September of year *i*+1. The time axis shows the natural year when the hydrological year starts. The trend line shows a linear fit to the data. There has been a decrease of the average annual precipitation of approximately 1 mm per year (roughly 10%). The average annual precipitation over the time period for continental Spain and Mediterranean islands was 670 mm (standard deviation 110 mm). *Source*: Prepared with data from the *Sistema Integrado de Información del Agua* (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013c). Precipitation data originated to be used by the SIMPA model of the Centro de Estudios Hidrográficos (Centro de Estudios y Experimentación de Obras Públicas).

[2] With regard to spatial planning there is certain degree of legal gap, and competences assigned to different administrations are complex and interlinked. Some urban plans promoted by municipalities, despite having completed the formalities required by law, may be approved and developed even though unfavorable opinions are emitted by consulted bodies, which express the lack of water supply guarantee or main road access (these responsibilities are assigned in some parts of the territory to the General Administration).

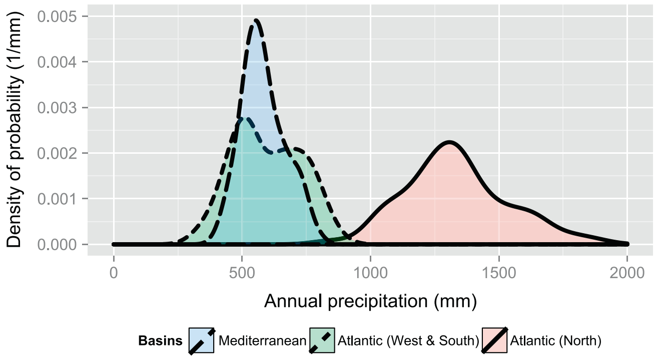

Fig. 3. Frequency of occurrence of annual precipitation over the period 1940–2010 for the three main areas. Over the period, the Northern Basins have an average annual precipitation of 1320 mm (standard deviation 200 mm), Western and Southern Atlantic Basins of 600 mm (standard deviation 130 mm), and Eastern Basins of 580 mm (standard deviation 85 mm). *Source*: Prepared with data from the *Sistema Integrado de Información del Agua* (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013c). Precipitation data originated to be used by the SIMPA model of the Centro de Estudios Hidrográficos (Centro de Estudios y Experimentación de Obras Públicas).

of up to 50% in semi-arid regions and an increase in inter-annual variability. It highlighted demand management as a palliative option, the need to improve and expand monitoring networks, the priority of further research and the importance of considering the impacts of these changes on policy and water resources management.

Fig. 2 shows the slight decrease of precipitation over a long series, which climate change impacts could exacerbate. Fig. 3 reflects the frequency of occurrence of annual precipitation for the different river basins divided in three main areas.

A more recent study published in 2011 by the Centro de Estudios y Experimentación de Obras Públicas (CEDEX), has fine-tuned impacts at the national level and predicts a generalised reduction of precipitation and water availability (near −5%, −9% and −17% during the periods 2011–2040, 2041–2070 and 2071–2100 respectively), with the greatest variability occurring in the Mediterranean coast and in the southeast. In addition, the study predicts increases in temperature, evaporation and evapotranspiration, and decreases in groundwater recharge and runoff.

It is likely that climate change will increase conflicts among the different economic sectors, since it will result in situations with higher demands and reduced availability of water resources.

These conflicts have been present in recent years in Spain (Lopez-Gunn, 2009), although not directly derived from climate change, and not only between sectors, activities or environmental needs, but also among regions, which quite often masked political motives (Estrela and Vargas, 2008). Experienced conflicts related to water transfers, the role of water in the reforms of the Autonomous Regions' Statutes, the revision of river basin districts delimitation and the transfer of powers to Regional Governments are all aspects that have contributed to the delay in approving the new River Basin Management Plans (RBMPs)[3] according to the Water Framework Directive (WFD).[4] These examples highlight the politicization of water in Spain (Lopez-Gunn, 2009). In fact, in the last decade, two trends clearly attached to counter political choices have been consolidated: an uncompromising defence of water transfers from the 'surplus' basins to the 'deficit' ones, and an opposite trend that rejected transfers and focused instead on desalination and other measures that promoted the use of non-conventional resources. Although, lately these positions have softened, they often have been intermingled with the growing decentralization of power and defence of regional interests. In any case, at present, either option cannot be applied easily or arbitrarily, in Spain, a country so culturally and geo-climatically diverse, where climate change impacts may seriously compromise water resources availability. It is necessary to conduct a case-by-case study, at least both on a large scale and also on projects' impact, ensuring their economic viability, environmental sustainability and social acceptance, accompanied by consultation and public participation processes.

Water is a key element in addressing climate change adaptation in Spain. If in addition, the country presents major water scarcity problems and recurrent droughts, especially in the south, southeast and the Mediterranean coast, the increased scarcity due to climate change will most likely cause higher tensions over water use, interfering even more with the political agenda.

The relationships between users have created conflicts, but they may also translate into greater cooperation. For instance during the last severe drought episode (2006–2008) large volumes of irrigation water were reallocated for human consumption, under the Administration's cost control and supervision.[5] It is important to highlight the strong presence of the irrigation sector in Spain, which presents the largest water consumption (75%) (Instituto Nacional de Estadística, 2008a), and includes a broad infrastructural network to store and redirect this resource, providing security and also cushioning during long periods of drought. Furthermore, policies to reallocate water rights in Spain will be an important adaptation tool in the near future.

4. Agriculture, land and desertification

Climate change poses a major current challenge for agriculture in addition to price volatility, increased global food demand and the introduction of biofuels (High Level Panel of Experts on Food Security and Nutrition, 2011). Impacts are expected to be diverse and heterogeneous affecting both water quality and quantity, including significant increase in water demand for irrigation, shortening of vegetative cycles, increase in plagues and exotic species, increased risk of heat waves or floods, direct repercussions on the agricultural production[6], or impacts on products quality (European Environment Agency, 2012; Masters and Norgrove, 2010). In addition, environmental and territorial services derived from agriculture and the landscape value of agro-systems could be affected also if significant agricultural land abandonment occurs.

On the other hand, agriculture as an economic sector contributes to an extent to climate change. In 2008, in Spain, this sector was responsible for about 10% of GHGs, of which livestock (especially pig manure management) was responsible for just over half of the emissions, compared to crop systems, which accounted for the other half (Ministerio de Medio Ambiente y Medio Rural y Marino, 2009b). The progression of the agricultural sector in Spain has been the usual for developed economies[7], having shifted from

[3] Part of this competence complexity, as well as its possible responsibility for the delays in the current water planning, has been formally reflected in the preamble to the *Royal Decree 1161/2010 of 17 September*, *amending the Royal Decree 907/2007, of 6 July, which approves the Regulation of Water Planning.*

[4] Directive 2000/60/EC of the Parliament and European Council, 23 October 2000, which establishes a framework for the Community action in the field of water policy.

[5] The Spanish government approved the *Royal Decree-Law 15/2005, of 16 September, on urgent measures to regulate transactions of water use rights*. It was launched as an urgent temporary policy to address drought impacts, facilitating the voluntary reallocation of water rights. Given the persistence of the drought episode, this measure was later extended through *Royal Decree Law 9/2006, of 15 September*.

[6] A strong decrease of crop performance is expected, between 10% and 30%, in the vast majority of the Spanish surface, which will translate into production decreases (European Environment Agency, 2007).

[7] The Spanish agriculture accounted in 2011 for 2.0% of the GDP at market prices, and employed 4.1% of the civilian working population, values close to the European averages (1.2% and 5.3% respectively in EU-27) (European Commission, 2012).

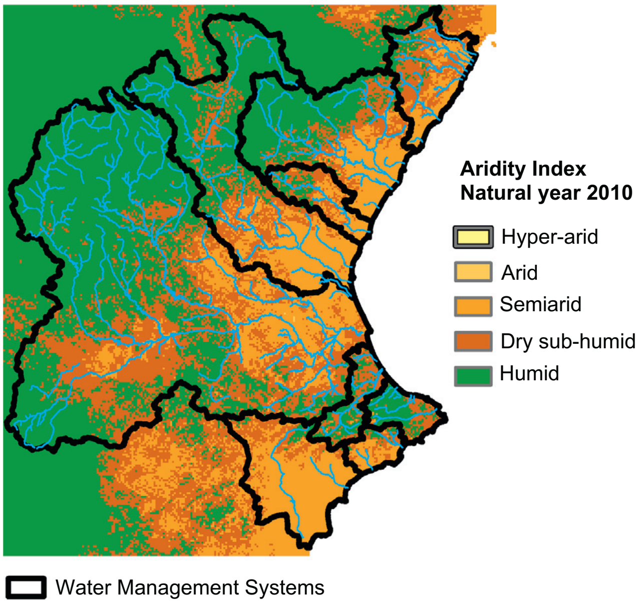

Fig. 4. Aridity Index (precipitation over potential evapotranspiration) of year 2010 in the Jucar River Basin District. Roughly 47% of the terrain inside of the Jucar River Basin District is classified as *humid*, 29% as *dry sub-humid* and 24% as *semiarid*. *Source*: Prepared with data from the *Sistema Integrado de Información del Agua* (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013c). Precipitation and evapotranspiration data originated to be used by the SIMPA model of the Centro de Estudios Hidrográficos (Centro de Estudios y Experimentación de Obras Públicas).

traditional productive systems to a greater integration with the rest of the economy, especially through the food industry. It is currently showing more modern and intensive characteristics, which in turn have direct effects on the contribution to climate change.

Spanish agriculture occupies approximately 50% of the national area (Instituto Nacional de Estadística, 2008b), reflecting its importance for territorial and environmental management. On one hand, there has been a decrease of cultivated land in the last twenty years (Ministerio de Medio Ambiente y Medio Rural y Marino, 2008a), with opposite effects occurring in relation to climate change. Part of the land has been afforested based on the common agricultural policy (CAP) aids[8], while other areas have been abandoned due to the decline of vulnerable rural areas, increasing erosion and desertification risks. On the other hand, there has been a slight increase of irrigated surfaces (e.g. from 2004 to 2012) (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013b), linked to major irrigation infrastructures of modernisation plans, which were meant to provide important water savings at a time when water scarcity increased.

Moreover, regarding soil resources, the process of desertification might represent one of the greatest impacts related to climate change in Spain, threatening an important part of its territory. According to the *National Action Program to Combat Desertification* (Ministerio de Medio Ambiente y Medio Rural y Marino, 2008b), over 30% of the area is already severely affected by desertification processes, exacerbated by human activity in areas with arid conditions. Desertification causes are diverse and complex, but usually include forest fires, loss of vegetative cover, erosion, the consequent loss of fertile agricultural land and salinization processes (Millenium Ecosystem Assessment, 2005). The projections of climate change would exacerbate these problems, especially in areas with a dry and semi-arid Mediterranean climate. Proper handling of cultivation techniques, tillage, irrigation and fertilisation should allow good adaptation to climate change impacts, and their mitigation, for which in Spain the European Strategy for Soil Conservation, the CAP and the Spanish Forest Plan are the main tools.

Recent projects, such as 'Halting Desertification in the Júcar River Basin' (HALT-JÚCAR-DES) co-financed by the European Commission, have focused on the use of water accounts based on the UN System of Environmental Economic Accounts for Water (SEEA-Water) (United Nations, 2012) to determine the link between water resources management and desertification processes in Spain (see Fig. 4 for an example). The project has concluded that water accounts can be useful tools. The European Commission is currently promoting this concept at the EU level, to determine the impact of economic uses of water, and to study future impacts of climate change in different elements subject to store water (such as reservoirs, rivers or lakes) (Evaluación de Recursos Naturales, 2013).

5. Economic aspects

Climate change involves a significant financial effort for Mediterranean countries, which should prioritize investments. However, in the short term the current global economic recession is going to affect this prioritization.

There are many examples of economic costs caused by climate change and related to water resources and agriculture. For instance, in the energy sector, and due to declining flows, a lower hydroelectric production is expected, which in 2009, it accounted for 7.3% of the Spanish power generation, (Ministerio de Medio Ambiente y Medio Rural y Marino, 2009a). In the agricultural sector, the likely increase in the cost of water, due to the full implementation of water tarification, as the WFD advocates, will probably influence the abandonment of farming in some areas, mainly the marginal ones, coupled with the loss of agricultural landscape and the associated opportunity cost. In terms of sanitation and wastewater treatment aspects, lower flows will result in less dilution capacity for spills, which authorities will need to address through more intensive treatment techniques or efforts to reduce discharges and pollution. In addition, increased investments for adaptation and development of flood protection infrastructure are expected, as well as those needed to minimise water scarcity and droughts impacts or to improve and expand monitoring networks and early warning systems. In relation to environmental issues, declining biodiversity and environmental services of ecosystems will represent a real loss although it might be difficult to assign them a market value. Increased saltwater intrusion into coastal aquifers, loss of wetlands and associated species, in addition to necessary measures for ecosystems restoration, will involve also significant costs.

Investments in non-structural measures should be promoted, such as those related to multidisciplinary education, social awareness, better use of available resources (water savings and efficiency campaigns, use of adapted crops), control, collection and data analysis, research and development of models, capacity building, or coordinated regional planning.

6. Measures and initiatives

Spain counts on solid administrative and sectoral coordination structures created as climate change policies became important: the National Climate Council (2001), the Inter-ministerial Group on Climate Change (2004), the Policy Coordination Committee on Climate Change (2005), the Secretariat of State for Climate Change (2008) and the Government Commission on Climate Change (2008). Moreover, the Spanish Strategy on Climate Change and

[8] Over 600.000 ha of agricultural land were afforested between 1994 and 2006 in Spain with EU funds (Flores and de Miguel, 2007).

Clean Energy, approved by the Government in 2007, is the framework that holds together the different climate change policies at the national level and defines basic guidelines for action at the short and medium term (2007–2012–2020) together with the Plan. It also includes measures aimed at reducing GHGs emissions or at adapting to their effects, and promotes various instruments such as the 2005–2010 Renewable Energy Plan or the Plan of Urgent Measures for 2007, among others.

Since 2008, major strategic priorities have been defined with performance targets for reducing emissions that have led to specific actions such as the Integrated National Waste Plan, the Savings and Energy Efficiency Plan in government buildings, or directly linked to agriculture, the Slurry Anaerobic Digestion Plan ("Plan de Biodigestión de Purines").

6.1. Climate Change Adaptation National Plan

The Climate Change Adaptation National Plan (Ministerio de Medio Ambiente, 2006) reflects the general reference framework in Spain for impact assessment, vulnerability and adaptation activities. It represents a relevant tool in the planning of different sectors or activities that develops work programs and assists the Administration and other interested organisations, whether public or private. The first Work Programme of the National Adaptation Plan envisaged only three sectors: coasts, water and biodiversity. The second Programme, with a timeframe of four years, incorporated new elements and activities with a holistic approach by considering health, agriculture, tourism, forests, soil and the combat against desertification, and its last follow-up report was published in 2011.

6.2. Water resources

The measures adopted in recent years, in contrast to earlier stages of large hydraulic infrastructures (dams and water transfers), have been directed mainly towards demand management (Estrela et al., 2012). Available and easily accessible water resources are limited. In addition, a growing population and development pressures, especially in coastal areas, as well as high agricultural needs, among other reasons, have resulted in difficulties to supply all demands with sufficient guarantee or to establish priorities. Therefore, authorities increasingly focus on improving the security of water availability to address main uses, while assessing the sustainability of other growing demands. Since water is a limited and precious resource, it is essential to apply the correct prioritization of uses, establishing river basin district needs, taking into account environmental requirements.

In Spain, water administrations have progressively achieved greater control and regulation of water resources, improving monitoring networks, abstractions control, processing and sanitation techniques. It is expected that the next steps will focus on a better management to control different sectors demands, reduce system losses, raise awareness, continue the modernisation of infrastructures and irrigation techniques, prioritise uses and establish socio-economic activities in the areas best suited for each case.

It is also true that other measures could focus on supply, even if such policies, at the expense of those related to demand management, in some cases can provide greater vulnerability to climate change and aggravate pressures and dependence on water resources.

In Spain, where water resources are heavily regulated (it is the fifth country with the highest number of large dams in the world; Instituto Nacional de Estadística, 2008a), an increase in supply is expected mainly from non-conventional resources such as desalination or wastewater reuse. Thus, in 2004, the AGUA Programme (Actions for the Management and Use of Water) was approved in order to redirect water policy, which comprised different performances including new desalination plants, mainly in the Mediterranean coast. A production of 1.9 million m^3/day (about 700 million m^3 per year) for 2009, located Spain as the fourth largest producer of desalinated water after Saudi Arabia, the United States and the United Arab Emirates (Ministerio de Medio Ambiente y Medio Rural y Marino, 2009a). Recent more humid hydrological years, have decreased however the use of this expensive resource. Regarding wastewater reuse, several works have been undertaken in recent years, many of them related to irrigation in southern and eastern parts of the country, with the current annual volume close to 430 million m^3 (Ministerio de Medio Ambiente y Medio Rural y Marino, 2011). In both cases (desalination and reuse), the energy and infrastructure development costs are considerable, and the potential environmental impacts should be evaluated. However, these additional resources, readily available in places with the greatest water needs, can become a guarantee for supply as well as significant release of pressure on heavily exploited river flows and aquifers. For the case of desalination, studies have been developed on the effects of increasing water salinity, the effects in the Posidonia oceanica meadows and optimisation of the dissemination and dumping devices of brine into the sea. In addition, a major research effort is being developed also to minimise the energy cost of this practice and encourage the use of desalination technologies based on renewable energies.[9]

Furthermore, Drought Management Plans in Spain and the new River Basin Management Plans have progressively introduced flexible approaches to adapt to changes in water availability and review measures or proposed infrastructures management (Vargas et al., in press).

A progressive improvement in water demand management in Spain will be essential to achieve a lower vulnerability to the impacts of climate change, as the forecasts predict an overall decrease in the availability of water resources.

6.3. Agriculture

Historically, agriculture has shown a great ability to adapt in the long term to changing conditions, whether economic, technological or related to resource availability. Nevertheless, the magnitude of the changes ahead will probably exceed the adaptive capacity of many European farmers. Climate change must be integrated within the overall objective of achieving a sustainable agriculture. In this sector, synergies between adaptation and mitigation are particularly important, with no clear separation between them.

Spanish agriculture has taken various measures aimed at reducing emissions and improving knowledge on them. The Government launched a Slurry Anaerobic Digestion Plan, as well as different measures to reduce nitrogen fertilizer use, introduce energy efficiency criteria in the Spanish Modernisation Plan of tractors and farm machinery and to modernise irrigation[10] systems.

On the other hand, the agricultural sector should also count as a temporary carbon sink, mainly in soils with annual crops. Additionally, this feature as carbon sink could be increased by implementing conservation tillage systems (no-till farming, strip-till or

[9] Las Palmas de Gran Canaria University and the Canary Technological Institute (ITC) started in 2009 the project SODAMEE, which has designed and is testing a seawater desalination system with wind energy, for producing 18m^3/day of water in isolated areas with limited technological support.

[10] In 2012, drip irrigation techniques (high hydraulic efficiency) covered 47% of the national irrigated area, when a decade before then, they did not reach 17% of the surface. Gravity irrigation techniques (low hydraulic efficiency) have experienced a reverse trend (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013b).

others), or by promoting integrated and organic[11] production and lying fallow, among others.

Another eminently territorial policy in Spain is forestry, and the Spanish Forest Plan (2002–2032) is its main tool (Ministerio de Medio Ambiente, 2002). This Plan aims at increasing the sustainability of forest systems with direct effects in the fight against climate change. For instance, it promotes increased CO_2 uptake by reforestation, afforestation of unused agricultural and marginal land or forest-hydrological restorations, which in turn reduce soil erosion and desertification processes.

Regarding adaptation, although there is evidence of spontaneous practices among farmers such as the modification of planting and harvesting dates or the introduction of different crops, it is necessary to implement tools within agricultural policies, especially framed under the CAP, to strengthen the sector's adaptation capacity to climate change.

The CAP is progressing towards strengthening synergies between agriculture, land management, water, food security and climate change. Latest reforms of this policy included in 2003, the decoupling of direct payments or cross-compliance and the 2008 Health Check, reinforced earlier reforms and introduced water management and climate change as new challenges. These reforms seem to facilitate adaptation to climate change, by decoupling subsidies from production, and allowing a more flexible and market-oriented agriculture. Within the recently approved CAP reform 2014–2020, climate change is a particularly important element on account of the high margin for manoeuvre that the agricultural policy presents for mitigation, adaptation and its contribution to the emission reduction commitment.

The agricultural insurance system is a particularly appropriate tool in Spain for adaptation of the agricultural sector to climate change, which has a national public–private implementation with significant aids to farmers. While subsidies on insurance premiums could imply a noticeable decrease in the ability (and interest) of the farmers towards adaptation, they show also the important contribution that the farm insurance can have for adaptation to impacts of extreme phenomena linked to climate change.

7. Conclusions

Negative impacts of climate change in Spain are increasingly seen as evident. The geographical location, its characteristics and predictions from different models and recent studies place it as one of the most vulnerable countries of Europe. If we add to this, that the country has a fragile water balance, with strong contrasts, a powerful and historical agricultural sector that demands water, and an increased decentralisation of competences to the regions, we find a winding path towards mitigation and adaptation.

Climate change poses a threat to the country's sustainable development, so significant efforts have focused on establishing multi-sectoral coordinating bodies and developing specific adaptation plans and measures for the different sectors.

In the case of water resources, studies point towards more frequent and intense droughts and floods, increases in temperature or decrease in river flows and therefore less availability for different uses among other impacts. These, in turn, will intensify existing conflicts that confront Spanish regions and will further place water in a position of a potential strong political tool. Impacts will be significant also in agriculture, ecosystems and biodiversity, will alter the territory's characteristics and accentuate the desertification problems already present in Spain. In addition to the issues of reduced water availability and increased costs for adaptation measures, pests, invasive species, or a decrease in the amount and quality of crop yields will be part of the foreseeable problems. On the other hand, agriculture is responsible at the same time for a significant contribution to GHGs emissions. A problem that is being addressed, as well as its role as carbon sink.

The Spanish Administration has launched a series of specific measures that focus on the management of water demand, the modernisation of irrigation systems or the commitment for using non-conventional resources such as desalination and wastewater reuse without excluding other solutions.

However, coordination among competent authorities, the lack of a firmer commitment to civic contribution, public participation and active learning, the strong defence of regional interests and the politicization of key resources such as water or energy, are part of the challenges faced by the country to achieve an effective adaptation to expected climate change impacts.

It is going to be essential to mobilise and secure the necessary funding for both mitigation and adaptation measures in different sectors and maintain horizontal structures to coordinate plans and strategies, which can be a difficult mission in a situation of economic recession and increasing transfer of competences.

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References

Agencia Estatal de Meteorología, 2009. Generación de escenarios regionalizados de cambio climático para España.
Arnell, N., Liu, C., 2001. Hydrology and water resources. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Springer, Cambridge.
Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (Eds.), 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, p. 10.
Centro de Estudios y Experimentación de Obras Públicas, 2011. Evaluación del Impacto del cambio climático en los recursos hídricos en régimen natural. Resumen ejecutivo.
Estrela, T., Vargas, E., 2008. Water Problems, a Global vision on availability of Water Resources and Desalination in Spain in Acuamed, La Desalación en España. Aguas de las Cuencas Mediterráneas, S.A. DL M-27347-2008 (Chapter 1).
Estrela, T., Pérez-Martin, M.A., Vargas, E., 2012. Impacts of climate change on water resources in Spain. Hydrol. Sci. J. 57 (6), 1154–1167.
European Commission, 2009a. White Paper Adapting to Climate Change: Towards a European Framework for Action, Brussels, COM (2009), 147 final.
European Commission, 2009b. Commission Staff Working Document, accompanying the White Paper. Adapting to Climate Change: Towards a European Framework for Action. Brussels. SEC (2009), p. 387 (01.04.09).
European Commission, 2012. Agriculture in the EU, Statistical and Economic Information. Report 2012 Directorate-General for Agriculture and Rural Development.
European Environment Agency, 2007. Climate Change: The Cost of Inaction and the Cost of Adaptation. EEA Technical, Report 13/2007.
European Environment Agency, 2008. Impacts of Europe's Changing Climate, 2008, Indicator-based Assessment. EEA, Report No 4/2008.
European Environment Agency, 2012. Climate Change, Impacts and Vulnerability in Europe 2012, an Indicator-based Report. EEA, Report No 12/2012.
Evaluación de Recursos Naturales, 2013. Halting Desertification in the Júcar River Basin. Final Report. <http://ec.europa.eu/environment/water/blueprint/pdf/HJD_Final%20Technical%20Report.pdf> (accessed 30.09.13).
Flores, V., de Miguel, M.J., 2007. La Medida de Forestación de Tierras Agrícolas. Foresta, vol. 39, pp. 12–15.
Garrote, L., 2009. Cambio climático: Impactos sobre los recursos hídricos y disponibilidad de agua. Jornadas sobre las Repercusiones del Cambio Climático en la Planificación y Gestión de los Recursos Hídricos, Polytechnic University of Valencia, 2009.
High Level Panel of Experts on Food Security and Nutrition, 2011. Price volatility and food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome, 2011.

[11] Approximately 800,000 ha of integrated production and 1,800,000 ha of organic production are grown in Spain, in the latter case being the largest area of the EU (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2012).

Instituto Nacional de Estadística, 2008a. Cifras INE, Estadísticas e Indicadores del Agua. Boletín Informativo del Instituto Nacional de Estadística, 2008.

Instituto Nacional de Estadística, 2008b. Encuesta sobre la estructura de las explotaciones agrícolas, 2007.

Intergovernmental Panel on Climate Change, 2007. Climate Change 2007: Synthesis Report. In: Core Writing Team, Pachauri, R.K., Reisinger, A. (Eds.), Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland, 104pp.

Intergovernmental Panel on Climate Change, 2013. Working Group I Contribution to the IPCC Fifth Assessment Report, Climate Change 2013: The Physical Science Basis Summary for Policymakers.

Lopez-Gunn, E., 2009. "Agua para todos": the new 'regionalist' hydraulic paradigm in Spain. Water Altern. 2 (3), 416–439.

Masters, G., Norgrove, L., 2010. Climate Change and Invasive Alien Species. CABI Working Paper 1, 30pp.

Millenium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC.

Ministerio de Agricultura, Alimentación y Medio Ambiente, 2012. Agricultura, Alimentación y Medio Ambiente en España, 2126pp.

Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013a. Inventario de gases de efecto invernadero de España, Edición 2013 (serie 1990–2011), Sumario de Resultados.

Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013b. Encuesta sobre Superficies y Rendimientos de Cultivo, ESYRCE, 2012.

Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013c. Sistema Integrado de Información del Agua. <http://www.magrama.gob.es/es/agua/temas/planificacion-hidrologica/sia-/> (accessed 12.11.13).

Ministerio de Medio Ambiente, 2002. Plan Forestal Español, 139pp.

Ministerio de Medio Ambiente, 2005. Informe Evaluación Preliminar General de los Impactos en España por Efecto del Cambio Climático.

Ministerio de Medio Ambiente, 2006. Plan Nacional de Adaptación al Cambio Climático (PNACC).

Ministerio de Medio Ambiente y Medio Rural y Marino, 2008a. Programa de Acción Nacional de Lucha contra la Desertificación en cumplimiento de la Convención de Naciones Unidas de Lucha contra la Desertificación ORDEN ARM/2444/2008, de 12 de agosto.

Ministerio de Medio Ambiente y Medio Rural y Marino, 2008b. Anuario de Estadística, 1150pp.

Ministerio de Medio Ambiente y Medio Rural y Marino, 2009a. Perfil Ambiental de España. Informe basado en indicadores (NIPO 770-09-185-7).

Ministerio de Medio Ambiente y Medio Rural y Marino, 2009b. Quinta Comunicación Nacional de España. Convención Marco de las Naciones Unidas sobre el Cambio Climático.

Ministerio de Medio Ambiente y Medio Rural y Marino, 2011. El medio ambiente y el medio rural y marino en España 2010, 2080pp.

Pérez García Dir. F., Mas Ivars, M., Maudos Villarroya, J., Quesada Ibáñez, J., Serrano Martínez, L., Chorén Rodríguez, P., Cucarella Torno, V., Hernández Lahiguera, L., Robledo Domínguez, J.C., Solaz Alamá, M., Soler Guillén, A., 2011. Crecimiento y competitividad, trayectoria y perspectivas de la economía española. Informe Fundación BBVA-Ivie 2011, 261pp.

Somot, S., Sevault, F., Déqué, M., Crépon, M., 2008. 21st century climate change scenario for the Mediterranean using a coupled atmosphere-ocean regional climate model. Glob. Planet. Change 63 (2–3), 112–126.

United Nations, 2012. SEEA-W, System of Environmental-Economic Accounting for Water, Department of Economic and Social Affairs Statistics Division. ST/ESA/STAT/SER.F/100, 216pp.

Vargas, E., Lopez-Gunn, E., Huelva, G., Estrela, T., in press. Adopting river basin planning as a framework for climate change adaptation in Spain in Stucker, D. and López-Gunn, E. (2014) Adaptation to Climate Change through Water Resources Management: Capacity, Equity, and Sustainability. Earthscan Publishers, London.

3.5 Vargas, E., López-Gunn, E., Huelva, G., Estrela, T., 2014. **Adopting river basin planning as a framework for climate change adaptation in Spain**, in: Dominic, S., López-Gunn, E. (Eds.), Adaptation to Climate Change Through Water Resources Management. Capacity, Equity and Sustainability. Earthscan/Routledge, p. 446.

This chapter provides an assessment of river basin planning, its status and development, and addresses the issue of whether it is suitable and flexible enough to adapt to climate change. It links adaptive capacity, local actions and participative processes with adaptation and mitigation. The chapter highlights the incorporation of climate change aspects in national policy tools, and the assessment of sectoral tools (specific management plans, such as RBMPs and DMPs).

17 Adopting the framework of river basin planning for climate change adaptation in Spain

Elisa Vargas, Elena Lopez-Gunn, Gema Huelva and Teodoro Estrela

Introduction

Adaptation was, until recently, neglected in climate change research, with the focus centred instead on the global collective action problem of mitigating emissions (Cerdá and Labandeira, 2010; Cerdá, 2011). In Spain, this is highly relevant because it is expected to be one of the most vulnerable countries to climate change due to its location in the Mediterranean area. The Mediterranean region, given its natural climate variability, has had a long history of coping and adapting to extreme events such as floods and droughts. However, the main differentiating factors arising from climate change are related to the uncertainty, range and magnitude of potential impacts (Grove and Lopez-Gunn, 2010).

Water resources in Spain are of relevance for all economic sectors, but especially for agriculture and tourism, public water supply and ecosystems. The irregular distribution of water resources combined with natural scarcity in some regions, have resulted in a long history of water resources management at the basin scale. In addition, the country has taken the lead at the European Union (EU) level in incorporating drought planning into river basin management (Garrote *et al.*, 2009; Estrela and Vargas, 2011). Furthermore, the prevention of flood events have recently been integrated into the river basin planning process to comply with the EU Floods Directive (2007/60/EC). This chapter, after introducing the context and the high vulnerability of the Mediterranean region and Spain, frames the discussion on a multilevel planning framework, looking at the EU and national levels. Then, we discuss initiatives taken at the basin level to prepare for climate change and analyse these using a leverage points framework (Meadows, 1999).

The Mediterranean hotspot: climate change impacts and vulnerability

The responsibility for climate change is not equal among countries and neither is the burden of climate change impacts, which is unevenly distributed. The potential impacts of climate change are going to be geographically distributed and particularly concentrated in so-called 'hotspots' (i.e. areas of land and population where the impacts are highly condensed, making them particularly vulnerable to climate change).

The Mediterranean region, where Spain is located, is one of these hotspots (Lopez-Gunn, 2009), with a relatively high degree of agreement between the different predictions from global climate models (García-Ruiz *et al.*, 2011; Estrela *et al.*, 2012; Milano *et al.*, 2012). Taking into account the analytical framework used in this book (see Ch. 1, Figure 1.1), global climate changes are reflected in changes on key variables such as temperature, river flows and rainfall and is likely to produce marked impacts on the state of a range of Mediterranean environments. It will also have differentiated distribution of burdens in relation to those water users and sectors most exposed to climate change impacts such as agriculture, with the most productive areas heavily reliant on irrigation. Equally, higher summer temperatures and more frequent and/or longer heatwaves would impact other sectors like tourism.

The Mediterranean region is an area already marked by climate variability, extreme events and water scarcity. Resources are used intensively, in some cases faster than their rate of regeneration. A high percentage of the population is living along the coast and is thus more vulnerable to sea level rise. The region is characterized by a strong rainfall deficit during the growing season and a cool or cold winter that prevents vegetation from benefiting from or making full use of winter rains. The whole geopolitical region is identified as one of the most prominent global climate 'vulnerability hotspots' in global circulation models (Giorgi, 2006). For example, in an area with relatively scarce water resources, run-off in southern European rivers is projected to decrease due to increasing temperatures and a decrease in precipitation (EEA, 2007). A study by Diffenbaugh *et al.* (2007) has estimated that elevated greenhouse gas concentrations dramatically increase heat-stress risk in the Mediterranean region, with the occurrence of hot extremes increasing by 200–500 per cent. Extreme events, such as the heatwave experienced in 2003, could become more common in the future, coupled with public health implications if CO_2 emissions continue (Costello, 2009). The greatest increase in extreme temperatures was predicted to occur in France and the Iberian Peninsula. These predictions coincide with a coupled regional circulation model (RCM) produced by Somot *et al.* (2008), which predicts an intensification of the hydrological cycle and a drier climate over Europe and the Mediterranean Basin.

Some river basins in the Mediterranean region are already facing water stress and may see marked decreases in water availability. Recent studies based on RCMs aim to downscale the output from large-scale global climate models, produce finer scale regional climate change simulations and determine with greater certainty expected impacts such as sea-level rise; decreases in precipitation, water quantity and quality, agricultural yields (and food security); and effects on ecosystems.

Box 17.1 Hotspot: climate change in the Mediterranean region and energy aspects

In terms of existing demand, the Mediterranean region has limited water resources and they are variable in nature and unevenly distributed. North African States have 13 per cent of the total water resources in the Mediterranean and most countries of the Middle East and North Africa (MENA) are experiencing water scarcity. By 2025, water demand may rise by 25 per cent in the south and east Mediterranean. Today, 20 million people in the Mediterranean region have no access to safe drinking water and the situation is becoming worse in rural areas, especially in MENA countries (Plan Bleu, 2008). Increased climate variability and change will add further pressure on the need to improve water resource governance and to maximize water efficiency and productivity from irrigated agriculture. In this context, for example, shared groundwater aquifers offer huge potential.

The Mediterranean region generates 8 per cent of global CO_2 emissions and is likely to be at the forefront of adaptation to climate change. Together with the Arab world, the region is in the epicentre of the water/energy nexus. First, in terms of water resources, the Mediterranean has 60 per cent of the population of the world's 'water-poor' countries, yet it is an economically important region precisely because of its Mediterranean climate with 30 per cent of the world's tourism. Second, in terms of energy and emissions, the disparity between the northern and southern Mediterranean is wide: Spain, France, Italy and Greece are responsible for 70 per cent of the total emissions of CO_2 in the region. Yet the southern Mediterranean has 5 per cent of the global oil and natural gas reserves between Algeria, Egypt and Libya, with the EU receiving 18 per cent of its natural gas imports from these same countries. The importance of these imports (not only for the EU but worldwide) was reflected in the 30 per cent price increase of oil in the markets due to the stop in Libyan production during the 2011 civil war (Escribano and San Martín, 2011) and the Syrian war is likely to have similar effects. Meanwhile, renewable energies (especially wind and solar energy) are under-exploited, representing only 3 per cent of Mediterranean energy consumption.

In addition, lost energy due to a number of factors like poor infrastructure is estimated to range from 30 to 50 per cent, depending on the country (Adamo and Garonna, 2009). In addition, according to Plan Bleu estimations (2008), energy demand in the Mediterranean region may increase by 65 per cent before 2025, due to population growth and higher demand linked to economic development. It is very likely that global warming and increased climate variability could amplify the effects of environmental degradation and energy needs with potential social, economic and humanitarian repercussions.

Adaptation in multilevel governance planning frames

Spain has started to take steps towards adaptation planning in a multilevel framework: initiatives taken at the EU level, which provide a continental level framework for Spain as part of a wider geopolitical region and initiatives taken at the national level.

EU, climate change adaptation and water resources

There is a marked interest in the EU in identifying and downscaling potential impacts of climate change at the regional and local catchment level. One of the 'untapped' opportunities is to incorporate adaptation as part of the comprehensive and sophisticated process of river basin planning under the EU Water Framework Directive (WFD) (Directive 2000/60/EC). River basin planning includes all the elements, ready-made structures and potential financing channels for adopting the basic aspects of the EU White Paper on Adaptation (EC, 2009) and the EU adaptation strategy (EC, 2013). The Blueprint to Safeguard Europe's Water Resources (EC, 2012) identified as one of its three key pillars the assessment of water resources vulnerability to climate change and anthropogenic pressures in specific catchments, as well as information on how to integrate climate change in the assessment and review of River Basin Management Plans (RBMPs) under the WFD (Box 17.2 and Figure 17.1).

Box 17.2 The EU Blueprint on Water

Catchment Adaptation and the Blueprint to Safeguard Europe's Water Resources (COM(2012)673)

A decade after the adoption of the Water Framework Directive (WFD), the European Community (EC) made a retrospective assessment and reviewed achievements to ensure the protection and availability of EU waters. The Blueprint was approved in November 2012 in the form of a Communication called 'A Blueprint to Safeguard Europe's Water Resources', with the objective to look into the future by evaluating water resources vulnerability, taking into account climate change impacts and pressures. The Communication aims at determining the sufficiency of existing measures and tools and to consider potential new instruments. The potential to increase water availability will be assessed, as well as savings and systems resilience. In addition, the Blueprint synthesizes policy options from an assessment exercise, accompanied by reports and new initiatives, including legislative options when necessary.

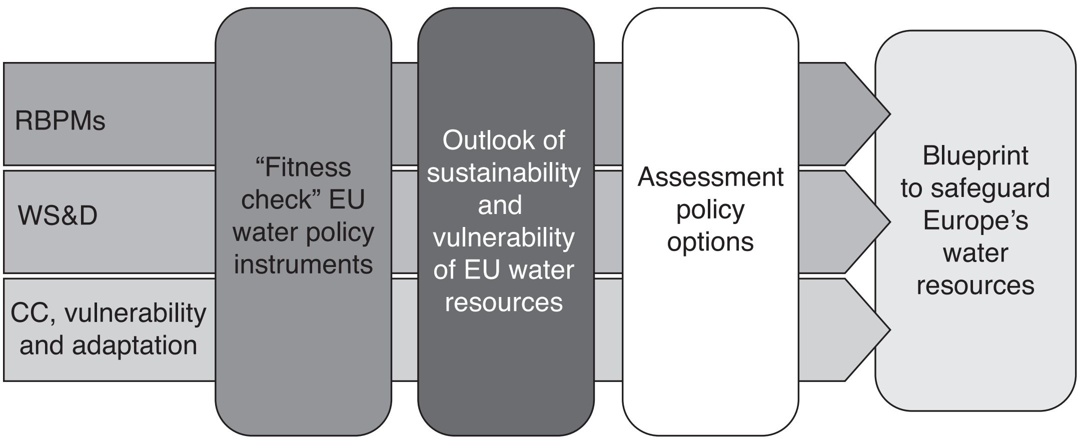

Figure 17.1 General scheme of the Blueprint (source: own elaboration based on EC (2011)).

The three main pillars of the Blueprint are:

1 Assessment of RBMPs (WFD)
2 Review of the policy on Water Scarcity and Droughts
3 Assessment of water resources vulnerability to climate change and anthropogenic pressures

Against this background, the water policy Fitness Check will be a building block of the Blueprint.

In terms of climate change adaptation, some of the proposed actions include improving water efficiency (especially for irrigation practices), decreasing leakage from water distribution networks or promoting green infrastructure and natural retention measures to minimize floods and droughts impacts. In addition, the Communication promotes better integrating drought risk management and climate change aspects into River Basin Management Plans and improving resilience of aquatic ecosystems (e.g. towards invasive alien species). The support of these water measures is proposed through different funds or policies: the Commission's Multiannual Financial Framework 2014–2020, the Common Agricultural Policy pillar I, Cohesion and Structural Funds or loans from the European Investment Bank.

National water and climate change adaptation planning

In terms of adaptation to climate change and impact on water resources, it is necessary to look at the intersection of national adaptation planning and national water resources planning. In relation to the former, Spain presented its National Plan on Adaptation to Climate Change (PNACC) in 2006 (MMA, 2006). The Plan provided a framework stating the objectives as well as future climatic scenarios and identified impacts and actions for 15 key sectors, including water. Objectives include:

- Development of coupled climate-hydrology models to obtain reliable scenarios of all aspects of the hydrological cycle, including extreme events.
- Assessment of water management options in terms of the hydrological scenarios generated for the twenty-first century.
- Application of the foreseen hydrological scenarios to other sectors highly dependent on water (energy, agriculture, tourism, etc.).
- Identification of climate change indicators under the implementation scheme of the Water Framework Directive.
- Development of guidelines and regulations to incorporate the foreseen impacts of climate change into the processes of environmental impact assessment and strategic environmental assessment of plans and programmes within the hydrological sector (MMA, 2006).

In relation to adaptation in the water sector, the National Adaptation Plan commissioned a study from the Ministry of Environment, Rural and Marine Affairs to assess climate change impacts with four objectives (CEDEX, 2011): (1) water resources under a natural regime (i.e. considering no infrastructure or flow modifications; (2) water demands (irrigation, public and industrial supply), including adaptation strategy proposals; (3) water resources available by management units (sub-basin division); and (4) to look at the ecological status of water bodies. The first objective was undertaken for the whole of Spain, with results that include updated reports with the latest models and hydrological data (CEDEX, 2010). The climatic data used include climatic scenarios regionalized by the Spanish State Meteorological Agency (AEMET, 2008), combining the results of global circulation models made by various international organizations, with techniques of regionalization at the local level.

In relation to national water planning that develops adaptive capacity, measures taken to cope with extreme events are important. In what could be considered spontaneous adaptation and part of the National Water Plan, the Directorate General for Water (Ministry of Agriculture, Food and the Environment) took the lead in coordinating drought management plans (DMPs) (CHG, 2007). Section 2 of Law 10/2001 of the National Water Plan considers these plans as an essential tool to reduce the socio-economic and environmental impacts of droughts. DMPs included the development of a national drought indicator system, a strategic environmental assessment, a consultation process and submission to the river basin water councils. The latter approved DMPs in 2007 for all river basins (Box 17.3).

Box 17.3 Drought management plans and climate change considerations

The specific objectives of the DMPs are to guarantee water availability required for the population and avoid or minimize any negative drought effects (for example on the status of water bodies, environmental flows or economic activities). The DMPs identify the most adequate mitigation measures, adapted to the different established drought thresholds and phases. During a normal phase, the measures derive from regular management practices. As the drought progresses and a more critical situation arises, measures go from control and information, to conservation, restriction and prioritization of uses.

Precipitation regimes of Spanish basins are highly variable, which has fostered the use of non-conventional resources and numerous retention and storing infrastructures (dams, weirs, channels, etc.). These characteristics and infrastructure are considered in the DMPs. The first supply priority established in the DMP is for the population, the second for the environment. Environmental minimum flows are decreased during a drought episode only under the circumstances that urban supply is compromised. Irrigation and other uses under a water scarce situation come in third and fourth places respectively.

Surface and groundwater resources are characterized and described in the plan, as well as additional inputs, e.g. from water transfers, wastewater reuse and desalinated water. Climate change could alter this characterization, but the plan already considers estimation revisions according to the PNACC and research study results.

The DMPs are not reviewed according to a specific schedule, but any of the following circumstances can trigger a revision:

- modification of minimum environmental water levels established by the RBMP;
- substantial alteration of the information related to aquifer abstractions;
- relevant improvement of the knowledge on water resources dependence mechanisms of habitats and species;
- relevant improvement of the knowledge of the hydrological relation between areas of environmental protection, surface water or groundwater bodies;
- high magnitude variances, which require introducing important changes to indicators, forecasts or the programme of measures of the DMP.

To ensure that there is a continuous follow-up of the DMP's implementation, river basin authorities have to set up Technical Drought Offices since the beginning of the water scarce period (pre-alert status according to the plan). There is also a Permanent Commission for Drought Follow-up made up of representatives from the River Basin Authority, users and interested parties or stakeholders. The plan takes into account possible increases in urban and industrial consumptions (percentages per month) due to extreme climate conditions. For example, in the case of the Segura Basin (CHS, 2007) these increases vary between 10 and 15 per cent for urban areas, 7.5 per cent for industry and 18 per cent for irrigation. The plan presents elasticity towards actions: each consumption type can be reduced to some point depending on the involved factors (for instance economic impacts or drought duration). Measures are presented assessing average reductions in each case and per demand activity (indicating the time horizon in which reductions are expected and their duration).

The indicator system used in these plans is based on drought risk (Table 17.1 and Figure 17.2), from very low to very high, which is then translated into water planning assigned to sub-basins depending on different status levels (normal, pre-alert, alert and emergency). With the gathered information and indicator status, drought risk maps are generated on a monthly basis and made publically available.

Droughts were considered a crisis until the development of DMPs. The approval of these new Plans meant that these were fully integrated into the general planning framework, through a risk analysis and development of a strategy (Antolín, 2008). One of the main reasons for the emergence of DMPs as a proactive planning approach was in response to the severe drought of 1993–1995. The drought affected more than 11 million people in eastern

Table 17.1 Typology of drought risk for water planning

Drought risk indicator	*1.0–0.5*	*0.5–0.3*	*0.3–0.15*	*0.15–0*
Status	Normal (green)	Pre-alert (yellow)	Alert (orange)	Emergency (red)
Objective	Planning	Information-control	Conservation	Restrictions
Type of measure	Strategic	Tactical	Tactical	Emergency

Source: CHJ (2007).

and southern Spain, which suffered water restrictions and associated water-quality problems in their public water supply. Estimates of agricultural losses ranged between US$4.7 billion and US$10 billion at 1995 value. Since the 1990s, drought has been the natural hazard that has affected the most people in Spain (Iglesias *et al.*, 2009). These drought plans are a positive example of proactive policy-making related to climate variability and they represent strategic tools with concrete results in terms of drought warning, impact mitigation and aquatic ecosystem protection (Estrela and Vargas, 2010, 2011). The DMPs define the different actions to be taken, which include enforcing water demand reduction strategies, establishing priority between uses and developing specific water infrastructure works.

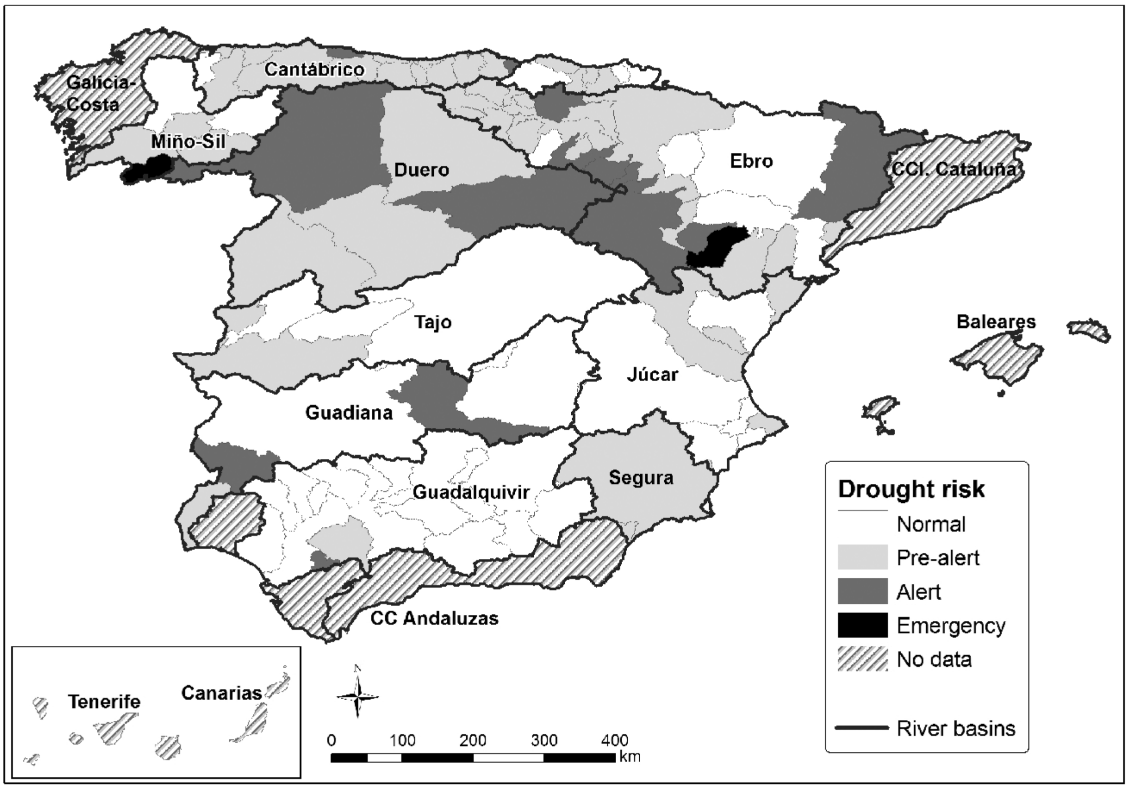

Figure 17.2 Map of drought status in Spain, December 2012 (source: adapted from MAGRAMA (2012) by Pedro Zorrilla-Miras, Terrativa Sociedad Cooperativa Madrileña).

Table 17.2 Integration of climate change impacts into water planning

Level	*Year*	*Initiative*	*Details*
EU Water Framework Directive and its implementation in Spain	2000	EU Water Framework Directive	RBMPs should include information on whether planned measures are climate change proofed according to the agreements made under the WFD Common Implementation Strategy.
	2007 and 2008	Royal Decree on Hydrological Planning and Ministerial Order, approving the Hydrological Planning Regulation (*Instrucción Técnica de Planificación Hidrológica)*	Art 11.4: Inventory of Natural Water Resources, establishing the balance between available resources and foreseeable demand for different uses and their allocation. Concept of available resources to include a reserve for environmental demand requested under the WFD in terms of water resources. Due consideration should be given in water planning to climate change.
National	Various, from 2005	National and DMPs (foreseen in Law 10/2001 of the National Water Plan under section 2)	e.g. CHG (2007)
Regional	Various	Regional strategies addressing climate change	e.g. Castilla La Mancha, Extremadura and Andalusia
Local	Various	e.g. Cities (*Ciudades contra el clima*) e.g. Public water supply companies	e.g. Canal de Isabel II (public water supply company of Madrid)

Source: own elaboration.

Downscaling adaptation to the river basin

It is at the level of the river basin that the intersection between EU and national planning is grounded. For the case of Spain, the development of adaptation in relation to water resources had two clear phases. The initial phase, from 2000 to 2010, was marked by initiatives taken at the national level through the incorporation of adaptation into river basin planning as a result of the national adaptation plan and the development of DMPs. The second phase, from 2010 onward, is incorporating EU regulation in the form of the WFD, the Floods Directive and voluntary adaptation measures for river basin planning, which in Spain coincides with the adaptation developed under national adaptation and water planning policies.

First phase: spontaneous adaptation of river basin planning at national level

Climate change impacts were considered for the first time in the preparation of the White Paper on Water in Spain, as part of the Technical Documents prepared for the 2001 National Water Plan. This White Paper (MMA, 2000) undertook a study on how two scenarios (1 and 2) would impact river flows up to 2030. This in turn helped to generate water scarcity risk maps showing temporary scarcity and structural scarcity as well as percentages per river basin of the drop in rainfall for these scenarios (Table 17.3 and Figure 17.3).

Each RBMP is expected to estimate the balance between available water resources and projected water demands for different uses, taking into account climate scenarios, like those produced by the AEMET study (2008). The Royal Decree of Hydrological Planning determines that this balance should be done for the 2027 time horizon taking into account climate change impacts on water resources. RBMPs and their Program of Measures should check that medium- and long-term planned measures are coherent with foreseeable climate change impacts. The latest cycle of Spanish hydrological planning indicates some evidence of a drop in rainfall when using the 'short series' (i.e. from 1980/1981–2005/2006), compared to the 'long series' (1940/1941–2005/2006). Precipitation from 1961 to 1990 often reached a 30 per cent decrease in the summers (CEDEX, 2011; Estrela *et al.*, 2012). It is predicted that there will be an average drop in river flows (for example, 19 per cent in the Guadiana basin),

Table 17.3 Climate scenarios from different authors

Scenario 1 by 2030	*Scenario 2 by 2030*	*Scenario 3 by 2030*	*Scenario 4 by 2060*
1°C increase no change in rainfall	1°C increase 5% decrease in rainfall	PROMES Model no change in rainfall	2.5°C increase 8% decrease in rainfall

Sources from left to right: CEDEX (1998), MMA (2000), Fernández Carrasco (2002), Ayala-Carcedo (1996).

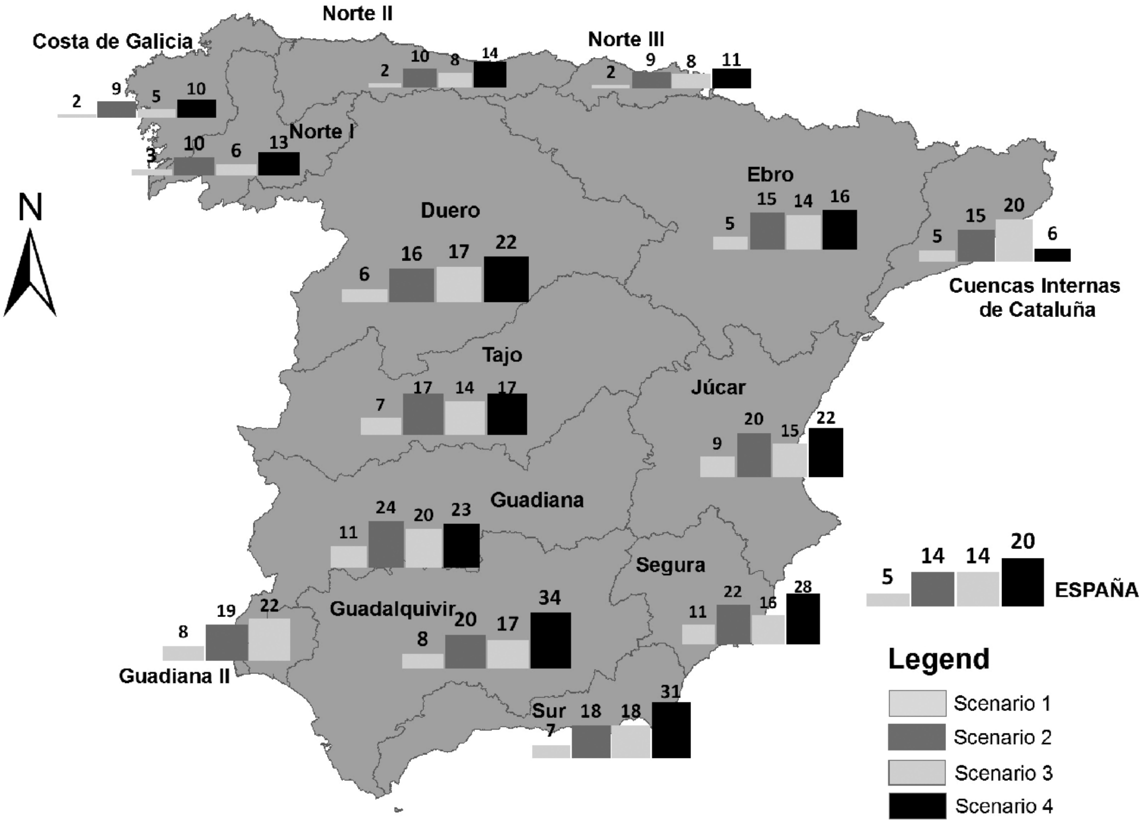

Figure 17.3 Scenarios of potential reduction in water resources by river basin (source: own elaboration based on data from PNACC (MMA, 2006)).

a shift towards more rain in autumn and a higher frequency and intensity of droughts periods. This corresponds with estimates in Iglesias *et al.* (2005) of an average reduction in precipitation of 35 per cent for the horizon 2070–2100 (up to 48 per cent for the city of Madrid) and increases in temperature.

However, there could be other important factors that affect river flow data, for instance water abstractions (not always fully controlled), river regulation, natural variability, land use changes (Garcia-Ruiz *et al.*, 2011; Willaarts, 2012) and water use volumes. It is not always easy to clearly differentiate or establish the effects of climate change on water resources through statistical data analyses. Thus, river basin authorities are increasingly using hydrological simulation models to improve the understanding of potential impacts and causes (Estrela *et al.*, 2012).

As discussed earlier, DMPs were developed in 2007 for all Spanish River Basin Districts and have been implemented and used since then. From the point of view of developing adaptive capacity for climate change and extreme events, these provide a very important stepping-stone in reducing vulnerability to droughts. DMPs already consider climatic variations and flexibility in adaptation planning and implementation of measures according to water availability reduction scenarios. The experience in producing and applying DMPs could provide a 'template' or precursor, paving the way to elaborate climate change adaptation plans by incorporating a range of additional risks (like, e.g. floods and heatwaves).

Second phase: adaptation planning at basin scale under the EU

In the first cycle of river basin planning there was no obligation to consider or include planning for climate change. However, as established by the WFD Common Implementation Strategy, RBMPs must include a Climate Check on their Programme of Measures. Undertaking this in a coordinated way for the different river basins is still to be worked out. Nevertheless, most plans in Spain – in an example of spontaneous adaptation – have included a section that considers climate change. By September 2013, most of the updated RBMPs in accordance to the WFD were approved, with the exception of Júcar, Tagus, Segura and Ebro (Figure 17.4). These plans were developed for watersheds within the corresponding autonomous regions (Galicia and Andalusia).

Flood management plans are being developed according to the EU Floods Directive and should be approved by 2015. These also mean, in effect, an increased capacity for planning for extreme events at the basin level. However, as discussed below, it is the coming phase that will provide the real test, since the 'philosophy' underpinning EU river basin adaptation planning and the adaptation frame for Spain have some important differences. Box 17.4 captures the experience in the Júcar basin.

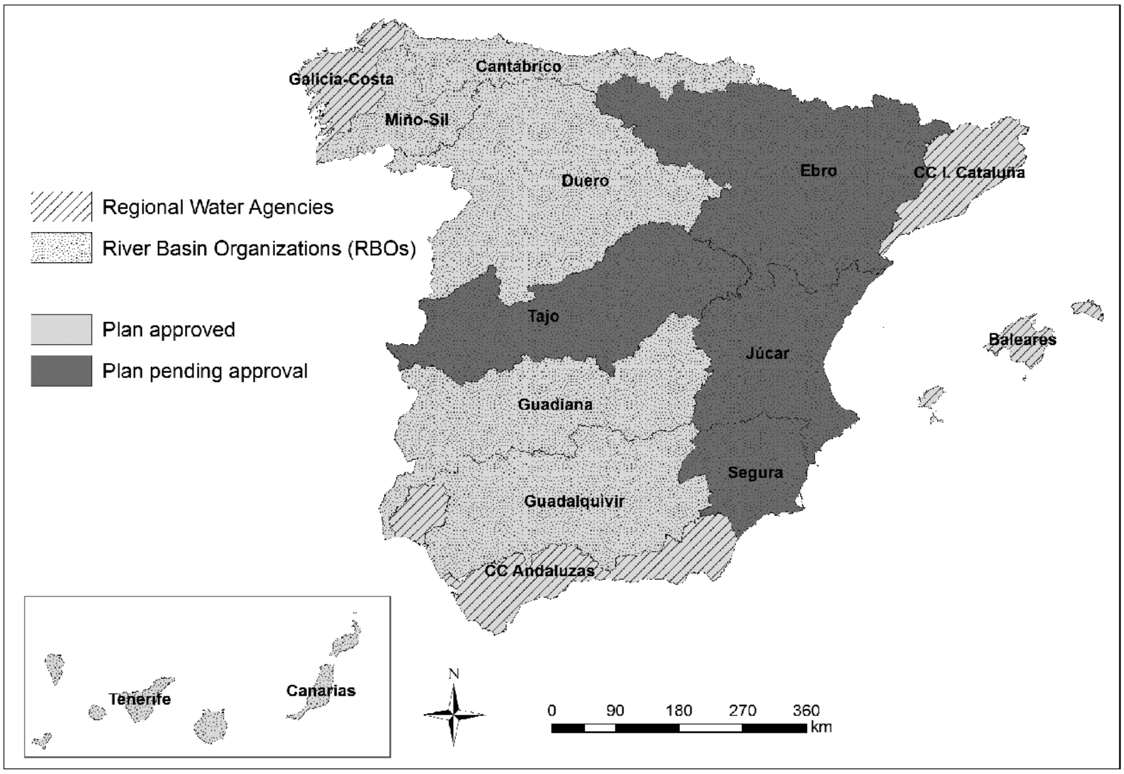

Figure 17.4 Status of Spain's RBMPs in accordance to WFD requirements, February 2013 (source: own elaboration; map by Pedro Zorrilla-Miras, Terrativa Sociedad Cooperativa Madrileña).

Box 17.4 Júcar River Basin Management Plan: Predicted impacts and adaptation

For the case of the Júcar RBMP, a reduction in water resources of 12 per cent is being considered (which is higher than the 9 per cent indicated in the Royal Decree on Hydrological Planning) and takes into account recent studies and those developed by Chirivella Osama *et al.* (2011) for the Júcar Basin. The draft RBMP for the Júcar Basin (CHJ, 2009) considered the official predictions of the Spanish White Paper on Water (2000) and two possible scenarios under the prospect of a doubling of CO_2 emissions: Scenario 1 with a potential increase of 1°C in annual mean temperature and Scenario 2 with the same temperature increase, but a decrease of 5 per cent in annual mean precipitation. For the Júcar River Basin District, the reduction of total renewable water resources have been calculated for the time horizon 2027 obtaining the following: for Scenario 1 a mean 9 per cent reduction and under Scenario 2 a 20 per cent reduction. What is most important for basin planning and adaptive capacity is that, according to the Hydrological Planning Regulation (2008), these reductions have to be reflected in the water balance between available resources and demands, in the progressive updates of the plan and in the implementation of the river basin plan measures.

The draft RBMP considers that climate change effects will more likely translate into an increase of floods and droughts and sea level rise with coupled coastal erosion. To cope with these impacts, a range of different measures is included in the Program of Measures in order to: reduce flood risk in the most vulnerable areas, plan and manage drought episodes, minimize extreme climatic phenomena and sea level rise impacts on the environment, assess beach erosion impacts and costs of regeneration measures (which is linked to the National Strategy for Sustainable Coastal Areas) and promote aquifer protection to avoid saline intrusion.

The managing authority envisions applying measures consistent with foreseen climate change impacts to increase the resilience of the system, for example recovering riverine woodlands. The Júcar draft RBMP considers measures that are linked directly to the protection of aquatic ecosystems, taking into account a possible decrease in water inputs. These measures include, for instance, ensuring ecological flows in rivers and decreasing urban and industrial wastewater discharges.

One step forward two steps back: opportunities for adaptation through river basin planning

In terms of barriers and bridges to adaptation in water resources management at the basin level, this section discusses the 2015 planning cycle, when revised RBMPs should be ready.

One step forward . . .

One of the main bridges in Spain is the well-established tradition in river basin planning which has made it possible to spontaneously integrate adaptation into the existing national frames, even ahead of the EU. According to the book's theoretical framework, this indicates a level of robustness in terms of local adaptive capacity. Compliance with the national Hydrological Planning Regulation (2008) goes one step ahead on the WFD, since updated plans already incorporate climate change aspects. This Regulation requires the calculation of balances between demand and available resources to 2015 using available series (1940–2005 and 1980–2005). More specifically, with regard to the evaluation of the effect of climate change on water resources, the Regulation states that

> for the 2027 time horizon the plan should estimate water balances between predictably available resources and the foreseeable demands expected for the different uses. To achieve these balances, the potential impact of climate change on natural water resources should be taken into account.
>
> (Ibid.)

The Regulation establishes that 'these estimates should be done using hydrological simulation models that would determine resources corresponding to climatic scenarios provided by the Ministry of Environment and Rural and Marine Affairs'. Furthermore, it indicates that – if the scenario assessments are not available – reference reduction percentages should be applied. In many basins, the results from the recent CEDEX study (2011) have been incorporated. Most of the updated RBMPs have used these reference reductions, ranging from 2 per cent in the Cantabrico to 11 per cent in the Segura, one of the basins most at risk for the year 2027 (Table 17.4). This leaves the simulations suggested in the Regulation for the next planning cycle, set for 2015. In a strict sense, now that more updated studies are available these reduction coefficients should be updated.

The pre-established reference reductions in the Decree have been used in other cases, such as in the recently approved RBMP for Galicia Coast. In the Cantabrico basin it is interesting to note that, while it expects the lowest reduction of water resources (2 per cent), it has allocated the greatest

Table 17.4 Estimated reduction due to climate change in natural water resources availability by river basin

River basin	*Percentage reduction*
Guadiana	11
Segura	11
Júcar	9
Guadalquivir	8
Tajo	7
Duero	6
Ebro	5
Miño-Sil	3
Cantabrico	2

Source: Spanish Hydrological Planning Regulation (2008).

percentage of its budget for adaptation measures (Figure 17.5). For the nine basins (out of 27), that cover most of Spain and span over more than one region, there are only four plans that define climate change adaptation measures as such, such as for the Cantabrico or the Ebro. In basins managed by regional governments, there are two plans: Galician Coast and the Basque Basins. However, estimated investments for these measures peak at only 0.15 per cent of the respective River Basin Management Plan budget. It could seem paradoxical that the basins that are expecting to experience the lowest level impacts (e.g. Cantabrico) are the ones dedicating most financing efforts to adaptation measures. On the other hand, these basins are located in more humid climates with attendant limitations in river regulation capacity, making them more vulnerable, for instance, to short drought events.

However, this analysis on adaptation measures is preliminary. In many cases it is difficult to clearly distinguish climate change adaptation measures from those focused on demand management (e.g. to improve efficiency) or supply increase (e.g. wastewater reuse). These types of measures are in many cases triggered by climate change effects as resources decrease and water scarcity increases. Figure 17.5 shows measures embedded in RBMPs that

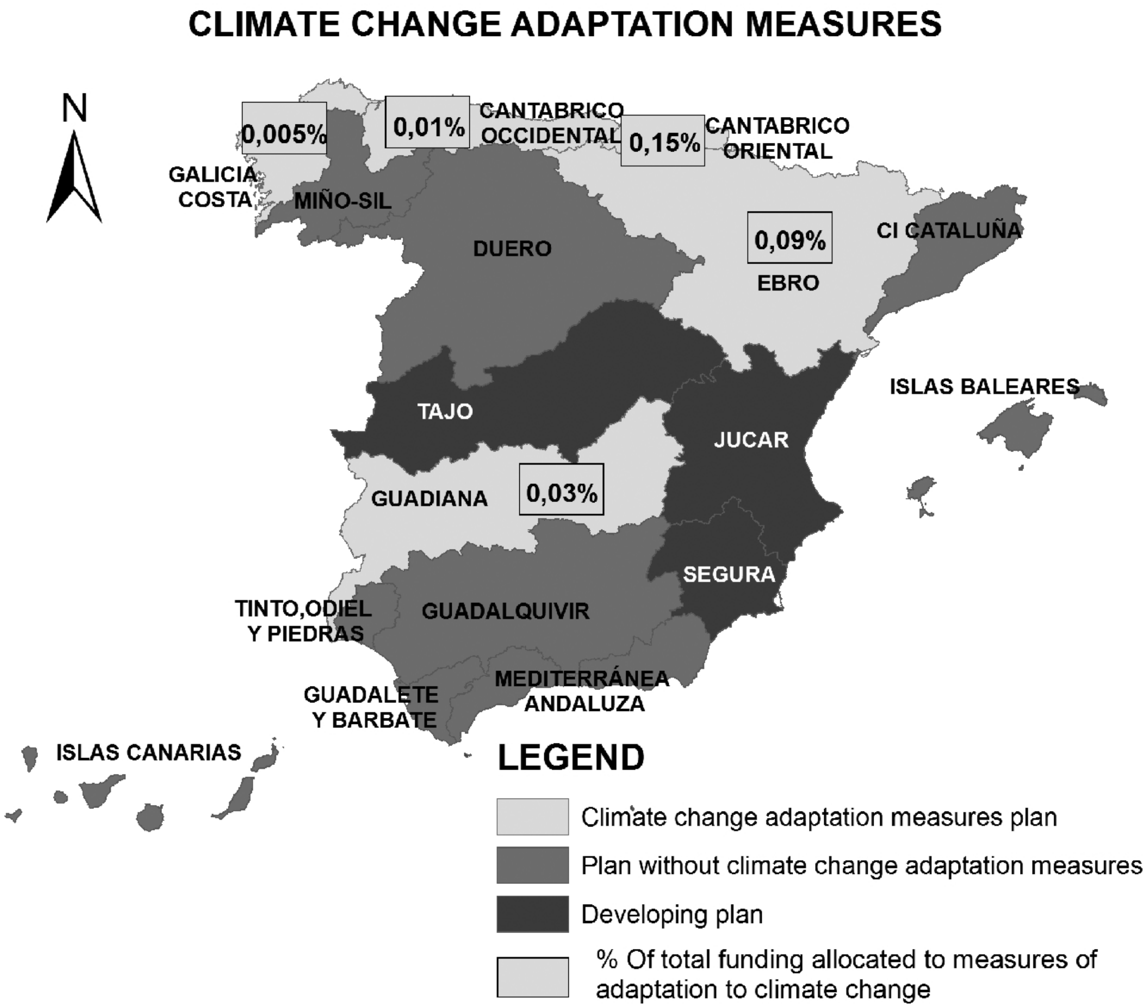

Figure 17.5 Inclusion of climate change adaptation measures in RBMPs and percentage of budget, February 2013 (source: own elaboration).

explicitly refer to climate change adaptation. The per cent of the total budget allocated to the plans' programmes of measures is also indicated, although these figures could be low for the reasons just explained. Horizontal adaptation measures should also be considered, as well as other measures that, while related to climate change adaptation, are classified under other categories within the plan. An important issue in the current Spanish economic context is that, under the first cycle of WFD water planning (2009–2015), it is not compulsory to consider climate change. Therefore, it is difficult to justify new investments to compensate for potential climate change impacts. The second best option has been to ensure that measures adopted are coherent or aligned with the foreseen climate change scenarios.

. . . and two steps back

One of the main barriers when addressing adaptation is a heavily technocentric and top-down approach to river basin planning. Adaptation will require a more networked approach to governance where there is less familiarity in Spanish water planning cycles. In this sense, it is clear that the supply aspects in adaptation are much more developed than the demand side ones. Thus, it is desirable to incorporate climate change expected impacts on demands. The current law does not address this issue and technical and scientific studies are more limited in this area where effects present higher uncertainty. Additionally, an area not fully explored so far due to the disconnection between land use and water planning is the potential offered by green infrastructures. This could be due to a number of reasons ranging from the fact that water agencies have no competences on land use planning to a traditional preference for 'hard' infrastructures.

Overall, water management and planning practices are the river basin authorities' competence, while land planning and agricultural aspects lie under the regional governments' responsibilities. Public water supply and local transport facilities are managed by municipalities. This pool of different management levels and maze of organizational responsibilities has made it more difficult to approach the *horizontality* of climate change impacts on water in a coordinated way. Particularly noticeable has been the limited engagement with local stakeholders and the identification of the different roles for different players.

In fact, the role of non-governmental organizations (NGOs) and civil society organisations (CSOs) at the local, regional (i.e. Autonomous region) and river basin scale has consisted mainly in critically assessing national strategies, scientific studies and initiatives related to climate change and water. There is limited evidence of specific local actions beyond those taken by municipalities that could increase the adaptive capacity or raise public awareness on climate change impacts in the water sector. Among other reasons, this could be due to the slow-onset nature of these risks combined with a legacy of lack of funding for NGOs and CSOs to launch participative actions.

Some of the areas that still need to be assessed are the effectiveness in the application of the water reduction percentages and implementation of measures in RMBPs in terms of adaptive capacity, environment impacts, water equity and people's livelihoods. For instance, more analysis is needed on whether the administrative and technical processes will be adaptable, flexible and responsive to further adaptation measures and water infrastructures if water reductions vary considerably from the estimated percentages. It is also important in the medium and long term to assess the conditions that impede and facilitate these adaptation strategies (e.g. political will, technical and economic resources and local stakeholder involvement and engagement). In addition, there is a need to evaluate the capacity of the population and sectors most vulnerable to severe climate change related extreme events such as prolonged droughts (i.e. to increase the resilience to risks). In reference to the book's theoretical framework, the evidence indicates that certain factors increase local adaptive capacity (flexibility on updating plans) and others decrease it (limited public involvement).

Finally, RBMPs are developed for quite large geographical scales; the Júcar basin, for example, is 42,851 km^2. In many cases, technical measures apply to large problems that affect several municipalities and even regions. The latest discussions focus on applying more case-specific adaptation strategies that actively involve CSOs and even develop plans for larger cities that might have very specific characteristics and face concrete challenges like the case of Madrid (see Lazaro-Touza and Lopez-Gunn, 2011). Competent authorities in these cases vary and have different technical and political approaches (e.g. River Basin Authority and the City Hall). Thus, it will be important to determine synergies for working in parallel, ensuring strategies that make adaptation plans at different scales compatible.

Conclusions

The precision of climate change scenarios is limited and downscaling techniques to determine effects at local levels can be challenging. Thus, managers and scientists sometimes question the efficiency of measures developed at the local and/or regional levels. On the other hand, if authorities do not support these adaptation efforts, the gap between the desired and current local state could widen. Where there is an engaged civil society, however, public concern and spontaneous local adaptive capacity building and adaptation measures could emerge. The effects of climate change are increasingly being monitored and documented and the direct influence of human activities is indisputable. Changes in climate are directly impacting the water cycle and water resources availability, which are particularly noticeable in the Mediterranean region and, as shown, in Spain.

Due to its geographic location, Mediterranean climate and socio-economic factors, the use of water resources in Spain has been traditionally maximized through water infrastructures. Progressively, a shift has been incorporated from water supply to demand management by including planning and adaptation strategies. Thus, the inclusion of climate change aspects in water planning processes has become a reality. Although climate change effects have a slow onset and are hard to predict due to different factors (data robustness, natural variability, water abstractions control, etc.), the use of models for different climatic scenarios and downscaling techniques are indicating non-negligible effects: e.g. lower precipitation levels, decrease of river flows and increase of number and intensity of droughts.

All of these impacts affect water availability for different socio-economic sectors and the environment. There have been influential initiatives and studies at the EU, national and river basin levels to better understand expected impacts. For instance, the first RBMPs in accordance with the EU water policy (EU WFD) have considered water balances in the medium term being consistent with the Programmes of Measures. Meanwhile, adaptation measures and initiatives at the autonomous region or local levels are more patchy and emergent and they usually run without a common thread, due to some extent to the complex administrative context and levels of competence. Moreover, local actions that could increase adaptive capacity or raise public awareness on climate change impacts in the water sector are limited (like in the case of the Júcar basin), as well as bottom-up initiatives and participative actions.

Important barriers for strengthening adaptive capacity include adequate coordination between different economic sectors and across administrative boundaries. This could prove difficult considering, for example, the complexity of aligning water and energy policies, or agricultural and water demands, or in terms of administration coordination between regional governments and river basin authorities, which would need to strengthen integrated land and water use planning.

In spite of these barriers, there are relevant bridges for building on capacity and adapting to climate change impacts. These can be found in technical management plans that consider flexible measures to cope with water issues directly linked to climate change effects. For instance, Spanish Drought Management Plans and RBMPs include programmes of measures that already anticipate climate change effects and variability in water resources availability and set actions accordingly. These also present a basis to build upon, together with future flood plans, with clear flexibility in terms of applying changes in water availability percentages, revision of plans and consideration of newer climate change studies. The policy and technical experiences derived from these plans could eventually provide a robust base and be highly valuable to produce future climate change adaptation plans.

Spanish River Basin Management Plans will need to consider newer and more sophisticated studies that engage with uncertainty in terms of climate change effects on water resources. Moreover, these plans will need to incorporate possible updates in EU legislation, such as the Water Framework Directive, or in specific policies such as the Common Agricultural Policy, which could require further climate change considerations. Furthermore, progress is still needed in assessing specific areas such as impacts on ecosystems, on demands and on water balances that could limit water use in the future.

Some additional aspects to be considered include coordination mechanisms, including sectorial climate change adaptation plans, assessing the conditions that impede and facilitate adaptation strategies and finding methods to integrate adaptation plans that apply to different scales (e.g. river basin vs city plans) while actively involving stakeholders. Furthermore, technical experience should be transferred to society in ways that develop adaptive capacity and can be easily interpreted, fostering resilience to extreme events such as heatwaves and droughts.

Adaptive capacity in the second round of RBMPs should be strengthened with the development of best practice guidelines on e.g. eco-adaptation, catchment planning and societal involvement at the local level. Adaptation plans could then be assessed (or developed where these do not yet exist) and embedded into existing planning frameworks, in particular those related to land use, Local Agenda 21 and RBMPs in compliance with the EU Water Framework Directive. Thus, the main bridge for adaptation at the river basin scale in Spain will be the successful integration of technical planning measures with societal demands and capacities.

References

Adamo, K. and Garonna, P. (2009) *Euro-Mediterranean Integration and Cooperation: Prospects and Challenges*, UNECE Annual Report Economic Essays.

AEMET (Agencia Estatal de Meteorología) (2008) *Generación de escenarios regionalizados de cambio climático para España*, Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid, Spain.

Antolín, M. (2008) *Drought Management as Example for the Adaptiveness of Spanish Water Management*, Head of International Affairs, General Directorate for Water, MARM, NeWater Conference, Seville, Spain.

Ayala-Carcedo, F.J. (1996) *Reducción de los recursos hídricos en España por el posible cambio Climático*, Tecnoambiente, Madrid, Spain.

CEDEX (Centro de Estudios y Experimentación de Obras Públicas) (1998) *Estudio sobre el impacto potencial del cambio climático en los recursos hídricos y demandas de agua de riego en determinadas regiones de España*, Informe técnico para el Ministerio de Medio Ambiente, CEDEX: 43–496–1–089, Madrid, Spain.

CEDEX (2010) *Estudio de los impactos del cambio climático en los recursos hídricos y las masas de agua, Ficha 1, Evaluación del impacto del cambio climático en los recursos hídricos en régimen natural*, Informe técnico para Ministerio de Medio Ambiente y Medio Rural y Marino, CEDEX 42–407–1–001, Madrid, Spain.

CEDEX (2011) Evaluación del Impacto del cambio climático en los recursos hídricos en régimen natural, Resumen ejecutivo, CEDEX, Madrid, Spain.

Cerdá, E. (2011) 'Comercio internacional y cambio climático. Cambio climático: Aspectos económicos e internacionales', *ICE*, no. 862.

Cerdá, E. and Labandeira, X. (2010) *Climate Change Policies: Global Challenges and Future Prospect*, Edward Elgar, Cheltenham, UK.

CHG (Confederación Hidrográfica del Guadiana) (2007) Drought Management Plan of the Guadiana Basin (Plan especial ante situaciones de alerta y eventual sequía de la cuenca del Guadiana), CHG.

Chirivella Osama, V., Capilla Romá, J.E. and Pérez Martín, M.Á. (2011) 'Impacto del cambio climático en los recursos hídricos de la Cuenca Hidrográfica del Júcar', in I. Escuder-Bueno, E. Matheu, L. Altarejos-García and J.T. Castillo-Rodríguez (eds) *Risk Analysis, Dam Safety, Dam Security and Critical Infrastructure Management*, CRC Press, Leiden, Netherlands.

CHJ (Confederación Hidrográfica del Júcar) (2007) *Drought Management Plan of the Júcar Basin (Plan especial ante situaciones de alerta y eventual sequía de la Confederación Hidrográfica del Júcar*), CHJ.

CHJ (2009) *Interim Overview of the Significant Water Management Issues of the Júcar RBD (Esquema provisional de Temas Importantes de la Demarcación Hidrográfica del Júcar)*, CHJ.

CHS (Confederación Hidrográfica del Segura) (2007) *Drought Management Plan of the Segura Basin* (Plan especial ante situaciones de alerta y eventual sequía de la cuenca del Segura), CHS.

Costello, A. (2009) 'Managing the health effects of climate change', *The Lancet*, vol. 373, no. 9676, pp. 1693–1733.

Diffenbaugh, N.S., Pal, J.S., Giorgi, F. and Gao, X. (2007) 'Heat stress intensification in the Mediterranean climate change hotspot', *Geophysical Research Letters*, vol. 34, no. 11.

EC (European Commission) (2009) *Adapting to Climate Change: Towards a European Framework for Action*, White Paper, 147pp., COM, Brussels, Belgium.

EC (2011) *Roadmap – Fitness Check – Freshwater Policy*, Directorate General Environment, EC, Brussels, Belgium, www.ec.europa.eu/environment/water/blueprint/pdf/roadmap.pdf.

EC (2012) *Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee of the Regions, A Blueprint to Safeguard Europe's Water Resources*, 673pp., COM, Brussels, Belgium.

EC (2013) *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions, An EU Strategy on Adaptation to Climate Change*, 216pp., COM, Brussels, Belgium.

EEA (European Environment Agency) (2007). *Climate Change and Water Adaptation Issues*, EEA Technical Report, no. 2.

Escribano, G. and San Martín E. (2011) 'La energía y la "primavera" árabe', in J.M. López Bueno (ed.) *El Mediterráneo tras 2011*, FHIMADES, Melilla, Spain.

Estrela, T. and Vargas, E. (2010) 'Effects of climate change on hydrological resources in Europe: The case of Spain', in A. Marquina (ed.) *Global Warming and Climate Change, Prospects and Policies in Asia and Europe*, Palgrave Macmillan, Houndmills, UK.

Estrela, T. and Vargas, E. (2011) 'Drought management plans in the European Union. The case of Spain', *Water Resources Management*, vol. 26, no. 6, pp. 1537–1553.

Estrela, T., Pérez-Martin, M.A. and Vargas E. (2012) 'Impacts of climate change on water resources in Spain', *Hydrological Sciences Journal*, vol. 57, no. 6, pp. 1154–1167.

Fernández Carrasco, P. (2002) *Estudio del Impacto del Cambio Climático Sobre los Recursos Hídricos. Aplicación en Diecinueve Cuencas en España*, PhD thesis, Universidad Politécnica de Madrid, Spain.

Garrote, L., Iglesias A. and Flores, F. (2009) 'Development of drought management plans in Spain', in L. Iglesias Garrote, A. Cancelliere, F. Cubillo and D. Wilhite (eds) *Coping with Drought Risk in Agriculture and Water Supply Systems, Drought Management and Policy Development in the Mediterranean*, Springer Science and Business Media BV, Dordrecht, Netherlands.

García-Ruiz, J.M., López-Moreno, J.I., Vicente-Serrano, S.M., Lasanta, T. and Beguería, S. (2011) 'Mediterranean water resources in a global change scenario', *Earth-Science Reviews*, vol. 105, nos 3–4, pp. 121–139.

Giorgi, F. (2006) 'Climate change hot-spots', *Geophysical Research Letters*, vol. 33, no. 8.

Grove, A.T. and Lopez-Gunn, E. (2010) *Uncertainty in Climate Change*, Real Instituto Elcano, International Economy and Trade Working Paper Series WP 25/2010, pp. 1–49.

Iglesias A., Estrela, T. and Gallart, F. (2005) 'Impactos sobre los Recursos Hídricos', in *Evaluación Preliminar General de los Impactos en España por Efecto del Cambio Climático*, pp. 303–355, Ministerio de Medio Ambiente (MMA), Madrid, Spain.

Iglesias, A., Moneo, M., Garrote, L. and Flores, F. (2009). 'Drought and climate risks', in A. Garrido and M.R. Llamas (eds) *Water Policy in Spain*, Taylor and Francis, London, UK, pp. 175–185.

Lazaro-Touza, L. and Lopez-Gunn E. (2011) 'Climate change policies: Mitigation and adaptation at the local level: The case of the city of Madrid (Spain)', in M. Tortora (ed.) *Sustainable Systems and Energy Management at the Regional Level: Comparative Approaches*. IGI Global Publishers, Hershey, Pennsylvania, USA.

Lopez-Gunn, E. (2009) *Spain, Water and Climate Change in COP 15 and Beyond: Aligning Mitigation and Adaptation through Innovation*, Real Instituto Elcano, Working Paper 65/2009.

MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente) (2012) *Mapa de seguimiento de los indicadores de estado de la sequía*, NIPO 280–12–011–7, Informes y Mapas de Seguimiento, Observatorio Nacional de la Sequía, MAGRAMA, www.magrama.gob.es/es/agua/temas/observatorio-nacional-de-la-sequia/informes-mapas-seguimiento/default.aspx, accessed 1 January 2013.

Meadows, D. (1999) *Leverage Points: Places to Intervene in a System*, The Sustainability Institute, Hartland, Vermont, USA.

Milano, M., Ruelland, D., Fernandez, S., Dezetter, A., Fabre, J. and Servat, E. (2012) 'Facing climatic and anthropogenic changes in the Mediterranean basin: What will be the medium-term impact on water stress?' *Comptes Rendus Geoscience*, vol. 344, no. 9, pp. 432–440.

MMA (Ministerio de Medio Ambiente) (2000) White Paper on *Water in Spain*, MMA, Madrid, Spain.

MMA (2006) *Plan Nacional de Adaptación al Cambio Climático (PNACC)*, MMA, Madrid, Spain.

Plan Bleu (2008) *The Blue Plan's Sustainable Development Outlook for the Mediterranean*, Plan Bleu, Sophia Antipolis, France.

Somot, S., Sevault F., Déqué M. and Crépon M. (2008) '21st century climate change scenario for the Mediterranean using a coupled Atmosphere-Ocean Regional Climate Model', *Global and Planetary Change*, vol. 63, nos 2–3, pp. 112–126.

Willaarts, B. (2012) 'Linking land management to water planning: Estimating Spanish forest water consumption', in L. Stefano and R. Llamas (eds) *Water, Agriculture and the Environment: Can We Square the Circle?* Taylor and Francis, CRC Press, London, UK.

3.6 Escribano, G., Quevauviller, P., San Martín E., Vargas E., 2015. Climate change policy and water resources in the EU and Spain. A closer look into the Water Framework Directive. *(In review).*

This final article provides a comparison between EU and national policies on water and climate change, with a greater focus on the WFD as main overarching water protection legislative piece. It addresses policy implementation and coherence, economic tools and needs, and the interface with research programmes and projects. The article also approaches emerging issues, such as the nexus water-food-energy, the use of green infrastructures, or the usefulness of ecosystems services valuation.

Climate change policy and water resources in the EU and Spain

A closer look into the Water Framework Directive

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Abstract

Climate change effects are becoming evident worldwide, with serious regional and local impacts. The EU has launched and developed initiatives and policies that scratch the surface of water resources impacts. This article presents an introduction of the existing environmental policy and more concisely in the areas of climate change and the interactions with water resources. It also addresses main management tools, and plans linked to policies, recent updates on the science-policy interface, highlighting major results from research and development projects. The importance of establishing appropriate policies to tackle climate change impacts on water is essential given the cross-sectorial and flowing nature and the importance of water in all environmental, social and economic sectors. There are still some pending reviews and updates in the current EU policy and its implementation, as well as

at the national level in Spain. This article identifies existing gaps, and provides recommendations on how and where reforms could take place and be applied by decision makers in the water policy sector.

Keywords: climate change, EU policy, water resources, Spain, economic impacts, water framework directive.

1. Introduction to climate change and EU policy

The evidence that climate change is producing effects at the global, regional and local scales is growing, as well as the recognition that human action has had a clear impact on its development and on the worsening of natural climatic variations (European Environment Agency, 2008; IPCC, 2013). Impacts in Europe include increases in temperatures, changes in precipitation and decreases in ice and snow, with high vulnerability of mountain and coastal areas as well as the Arctic and the Mediterranean region (European Environment Agency, 2012, 2008). Decrease in precipitation and runoff in Mediterranean areas, could in addition aggravate other existing problems such as saline intrusion in aquifers, coastal subsidence, water pollution problems and agricultural high water demands[1] (European Commission, 2009a, 2009b; European Environment Agency, 2012; IPCC, 2008; Somot et al., 2008). Furthermore, these impacts could translate into modifications in habitats, reduced crop yields, impacts on human health, and increasing conflicts over water uses or have effects on security issues (Estrela and Vargas, 2008; European Commission, 2011).

Many of the problems and impacts on water resources derived from climate change are not new. In fact, EU Member States, have often faced floods, water scarcity, heat waves, prolonged droughts, flows variability, temperature rises, and decreased rainfall. However, studies suggest that climate change will cause a higher frequency and amplification of these problems (IPCC, 2008), as well as a shift to countries that may lack sufficient experience to incorporate uncertainty into water planning (Arnell and Liu, 2001). Furthermore, impacts will affect water treatment, system reliability and

[1] This article refers to concepts such as water demand (water withdrawn to be used) or water scarcity (lack of sufficient water for a specific use) according to their meanings in sectorial EU policy and their common use in international hydrological planning, which vary substantially from their economic definitions.

operating costs as many forms of pollution are expected to be exacerbated (European Commission, 2011).

In recent years, European institutions have launched numerous actions, strategies and policy instruments related to climate change in the European Union although knowledge and policy gaps exist.

While the specific impacts on water resources vary considerably among European regions, Spain is considered to be in a 'hot spot' where a greater increase in temperature and decreased precipitation, evapotranspiration and runoff are anticipated (Estrela et al., 2012; Lázaro-Touza and López-Gunn, 2014; Morata Gasca, 2014).

In addition, the variability of temperatures and the spatial and temporal distribution of water resources are very high within the country, with annual mean precipitation values ranging from 2000 mm in the northwest to less than 300 mm per year in the southeast. This variability, coped with the uncertainty of regionalised models and downscaling techniques adds difficulties to estimating the direct effects of climate change in water resources. However, one of the most recent and comprehensive studies developed at national level (Centro de Estudios y Experimentación de Obras Públicas, 2011), provides some important insights of impacts expected in the short-medium term. It predicts a generalised reduction of precipitation and water availability (near -5%, -9% and -17% during the periods 2011-2040, 2041-2070 and 2071-2100 respectively), with the greatest variability occurring in the Mediterranean coast and in the southeast. In addition, the study predicts increases in temperature, evaporation and evapotranspiration, and decreases in groundwater recharge and runoff.

Spain is in the process of complying with EU policies and respond to the recommendations made on climate change mitigation and adaptation.

2. EU climate change policies

Over the past years, one of the most important documents on climate change adaptation published by the EU was the White Paper ‘Adapting to climate change: Towards a European framework for action’ (European Commission, 2009a). This paper established a framework to reduce the EU’s vulnerability to the impacts of climate change, and marked the starting point for implementing a strategic approach to ensure that adaptation measures were consistent across different sectors and levels of management. That is, it started to strengthen the concept of policy coherence. The White Paper also recommended the integration of climate change adaptation in the implementation of EU policies on water. More recently, the EC published the Green Paper, ‘A framework for climate and energy policy in 2030’ (European Commission, 2013a). This document launched a public participation process to gather ideas that would allow establishing goals up to 2030 on energy and climate policy (carbon sequestration, reduction of greenhouse gases, fund raising and support of a competitive economy while energy security would be promoted).

Furthermore, and with greater relevance, the Commission adopted and EU strategy on adaptation to climate change on April 2013 (European Commission, 2013b). The aim of this strategy is to make Europe more climate-resilient, complement on-going efforts within Member States, promote information-sharing, coordination of efforts, and sector and policy coherence. It builds on the demand to develop conceptual and practical systems for monitoring impacts of, and adaptation to, climate change and to inform the adaptation policies. It is important to highlight that the Strategy provides funding tools to strengthen adaptation capacities, and addresses specific vulnerable areas such as water resources.

Moreover, while substantial progresses have been made on mitigation to achieve the established ‘20-20-20’ targets (20% reduction of greenhouse gas emissions, 20% share of renewable energy consumption, 20% improvement of energy efficiency), the 2030 framework for climate and energy policies goes further and establishes stronger commitments. As stated by eh EU Council conclusions of October 2014 (European Council, 2014), new targets are set to reduce greenhouse gas by 40% (compared to 1990 levels), and achieve a share of renewable energy and energy savings of at least 27%.

EU documents that have linked even more closely climate change and water are mainly the Water Framework Directive (WFD)[2], the Guidance Document No. 24 'River Basin Management in a changing climate' within the Common Implementation Strategy (CIS) of this Directive or the communication of the 'A Blueprint to Safeguard Europe's Water Resources' (European Commission, 2012, 2009c).

The WFD[3] does not explicitly address the relationship between climate change and river basin management plans (RBMPs), although all qualitative and quantitative water aspects referred in the directive may be affected by climatic changes. The Annex II of the Directive however, refers to the need to identify 'significant pressures' affecting water bodies, it provides a framework to incorporate the impacts of climate change in the water planning process. In addition, the cyclical approach of the Directive, with specific steps and envisioned periodic revisions, which allow incorporating scientific and technical progresses, and the integration of other Directives domains within the text (habitats, agricultural development) make this policy suited to adapt to and manage climate change impacts (Quevauviller, 2014). Given that climate change could aggravate future anthropogenic pressures, expected impacts should therefore be considered within the framework of the Directive (Quevauviller, 2011; Wilby et al., 2006). The Guidance document No. 24, previously mentioned, provides more direct support to river basin organisations for incorporating climate change projections into the second and third planning cycles and more specifically in the assessment of pressures and impacts, monitoring and establishment of measures. The document gives recommendations on how to manage the available scientific knowledge and high level of uncertainty in data, or to address specific challenges such as floods and water shortages. For instance, the document recommends the process for determining if measures are "climate proof" and ensures revisions for each planning cycle, so updated scientific evidence is considered and uncertainty decreased (see figure 1 on the planning cycle).

[2] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ L 327, 22.12.2000, p. 1–73.
[3] According to its article 19, 'Plans for future Community measures' a revision of the Water Framework Directive should take place in 2019.

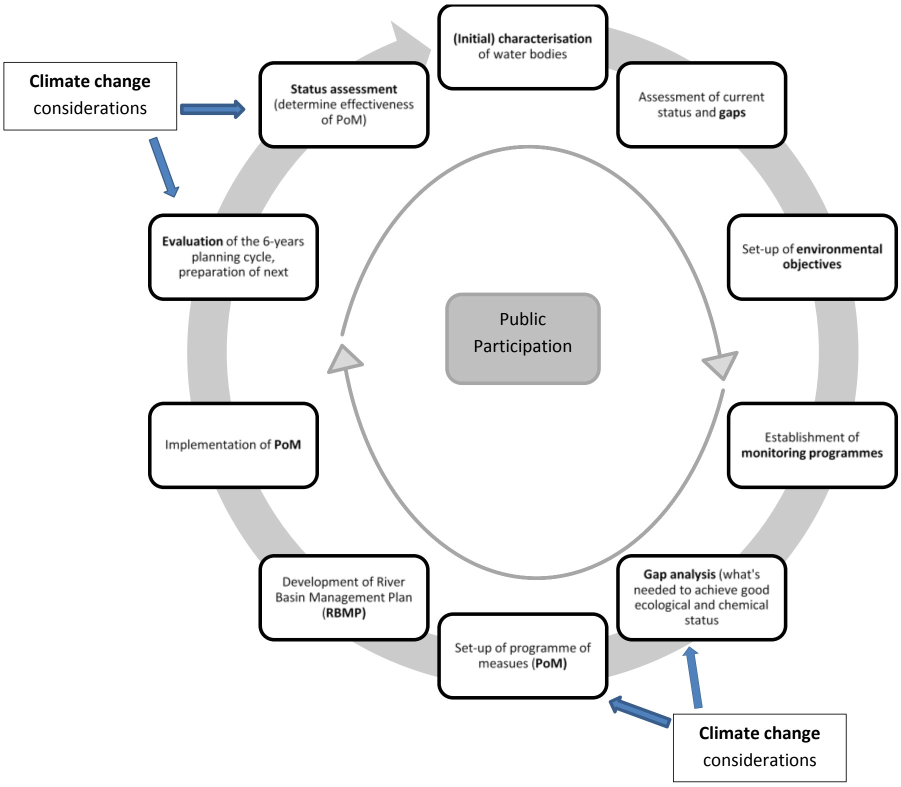


Figure 1. Planning cycle according to the Water Framework Directive to develop River Basin Management Plans, including main steps at which climate change considerations should be incorporated (own elaboration, based on European Commission, 2009).

Overall, the WFD comprises monitoring, reporting and evaluation systems that could significantly contribute to have a broader and more comprehensive view of climate change impacts in the EU and adaptation actions in the water sector.

As part of the assessment of EU water policies, and more closely on the WFD, the communication of the 'Blueprint' (European Commission, 2012) also presents a series of actions and recommendations that are directly linked to climate change aspects. These include improving water efficiency (especially in irrigated agriculture), reducing losses in distribution networks, promoting 'green infrastructure' and natural retention measures that minimise impacts of droughts and floods, better integration of risk management and drought issues in RBMPs, and improving the resilience of aquatic ecosystems (e.g. when facing the impacts of invasive species).

To support these measures, the Communication proposes the use of the 2014-2020 Multiannual Financial Framework (in this instrument, circa 20% of the funds are allocated to climate related actions), Pillar I of the Common Agricultural Policy, Structural and Cohesion Funds or loans from the European Investment Bank.

Finally, it is important to keep in mind the importance of anticipating to adverse effects of climate change and act in ways so these can be prevented or expected damages minimised. It is therefore essential to address the particularities of water-related disasters, which fall under other EU policies such as the Floods Directive[4], or the strategy on water scarcity and drought and its communication (European Commission, 2007).

3. Research and Development projects, science-policy interface

There have been different research and development lines promoted at the EU level to fund specific environmental related projects, and more specifically to water and climate change. Some of these lines were included the 6th and 7th Framework Programmes (FP6 and FP7) and more recently Horizon 2020 (2014-2020).

Within the European Commission, the Directorate General for Research and Innovation is responsible for Horizon 2020 the largest EU Research and Innovation programme that has commitment to dedicate at least 35% to climate-related research, through both specific climate research and the integration of climate into the full research and innovation agenda. Furthermore, the Commission has initiated a 'Roadmap Towards a European market for Climate Services" to be implemented through Horizon 2020. There are also ongoing projects under FP7[5] that are explicitly addressing the topics of adaptation, evaluation of impacts and vulnerability. In addition, EU institutions such as the Joint Research Centre, are also working on several projects addressing impacts, vulnerability and

[4] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance).

[5] Within the European Commission's web site http://cordis.europa.eu projects in the area of 'climate change and carbon cycle research' can be searched and selected.

adaptation. For instance, the PESETA[6] set of projects cover estimations on projected impacts and costs of climate change in the EU over the 21st century, including impacts on ecosystem services.

There are several examples of projects that have focused on climate change effects on water resources. For instance, and to name a few, the WATCH[7] (2007-2011) project examines climate change impacts on the global water cycle, evaluates uncertainties and addresses vulnerability issues of global water resources cycles. The project EURO-LIMPACS[8] (2004-2009), evaluates global climatic changes on freshwater ecosystems at the catchment scale, examining interactions with other drivers and pressures at multiple time scales. The project CIRCE[9] (2007-2011) assessed climate change impact in Mediterranean regions, assessing specific effects in the hydrological cycle, such as changing precipitation patterns. A third specific example is the AquaStress[10] project (2005-2009), which approaches water stress with the integration of management, technical, economic and institutional instruments.

To adopt effective and resilient actions in water management, it will be essential to integrate recent research projects' results within EU water and climate policy cycles; that is to ensure effective science-policy interfacing mechanisms. This type of interfacing would also facilitate connecting scientific results at different scales, the exchange of findings and the identification of required adaptation measures in river basins (Quevauviller, 2014; Quevauviller et al., 2012).

These recent projects' outputs reinforce the conclusions from the IPCC and point out towards more and more frequent extreme phenomena in Europe and more scarce water resources. On a more technical approach, many of the finished projects call for better and more robust data that can be shared through joint repositories, stronger early warning systems, or better policy implementation, among other.

[6] https://ec.europa.eu/jrc/en/peseta
[7] http://www.eu-watch.org/
[8] http://www.eurolimpacs.ucl.ac.uk/
[9] http://climate-adapt.eea.europa.eu/projects1?ace_project_id=30
[10] http://www.aquastress.net

The previously mentioned EU Adaptation Strategy of 2013 also addresses knowledge gaps through research, and aims at promoting information exchange using, for instance, the adaptation platform, Climate-ADAPT[11]. This platform provides different useful resources to support policy and decision-making related to adaption efforts, such as a toolset for adaptation planning, a database that covers projects and case studies, and information on adaptation actions at different scales (EU, national, regional, local).

While research and technological projects have translated into better cooperation among Member States, institutions, and stakeholders, several gaps have been identified between the obtained and expected results. One of the soundest problems relies on transmitting useful information on results to professionals, such as decision and policy makers. Furthermore, the public rarely knows about the existence of on-going projects except for when these tackle local issues and include participative processes. In other occasions, the media or the outreach strategy of the project itself, does not achieve the hard task of approaching the public and translating complex scientific language to a more understandable one.

In Spain a new national strategy on science, innovation and technology (2013-2020) and a new national plan on scientific technical and innovative research Plan (2013-2020) were adopted in 2013. Environmental programmes represented about 4% of the total national research and development budget in 2014. Actions within these tools correspond to a broad range of areas such as agriculture, marine, mining, energy and environmental sciences. Overall, budgets allocated to environmental research have been falling since 2008 (over 74 million euros in 2008, and just below 20 million euros in 2012) (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2014). A specific assessment on actions, publications and projects would be needed to determine those focusing on water resources and climate change.

Regarding scientific and policy linkages in Spain, projects and initiatives are often developed by academic or scientific institutions, which often lack a direct input from managing authorities on needs

[11] http://climate-adapt.eea.europa.eu/

and gaps. Thus, while research outputs can be innovative and useful for certain sectors, they are rarely tailored to specific needs and knowledge gaps of water managers. Communication and information flow problems are also common within official organisms. For instance, within a large institution such as the Ministry of Agriculture, Food and Environment, departments participating in a research project rarely share information among each other, and less often between Ministries (even when scientific topics are horizontal and clearly affect competences of several public organisms). Thus, there are still gaps in information sharing on a cross-sectorial way within entities and not just in 'top-down' approaches (from research partners to citizens). Transmitting achievements and scientific information from research to citizens is also a pending subject in Spain[12].

4. Climate change in Spain: administration, plans and measures

4.1 Administration in charge of climate change

In Spain, there are several administrative units in charge of climate change adaptation and mitigation at the national and regional level. This article focuses only on those that exist at the national level and set the general guidelines and strategies, which often follow offices or centres from regional governments or those that are related to research practices.

The pivotal structure that is currently in place is the Spanish National Office of Climate Change (OECC), dependent on the Ministry of Agriculture, Food and Environment. The OECC, created in 2001, is in charge, among other tasks, of developing the national strategies, promoting the appropriate policy and reporting according to the established international agreements (UN Framework Convention on Climate Change, IPCC etc.). There are however, sectorial coordination structures created as climate change policies became important: the National Climate Council (2001) (formerly the National Climate Commission), the Inter-ministerial Group on Climate Change (2004), the Policy Coordination Committee on Climate Change (2005), the Secretariat of State for Climate Change

[12] For instance, while the Xerochore project (2010) provided important information on drought impacts, and made relevant policy and management recommendations, results were not transmitted at the national level or outside the main participating institution http://www.feem-project.net/xerochore/partners.php.

(2008) and the Government Commission on Climate Change (2008). Their main aim is to promote administration coordination (at national and regional levels), participative approaches and exchange of views, mainly among institutional entities but also with some stakeholders. However, some argue that additional stakeholders and sectors should participate in these structures (Intermón Oxfam Editorial, 2008) and that their effectiveness on influencing sectors to take into account climate change impacts could improve. It should be noted that the assessment of these sectorial structures is out of the scope of this article.

4.2 Overall plans and overarching tools

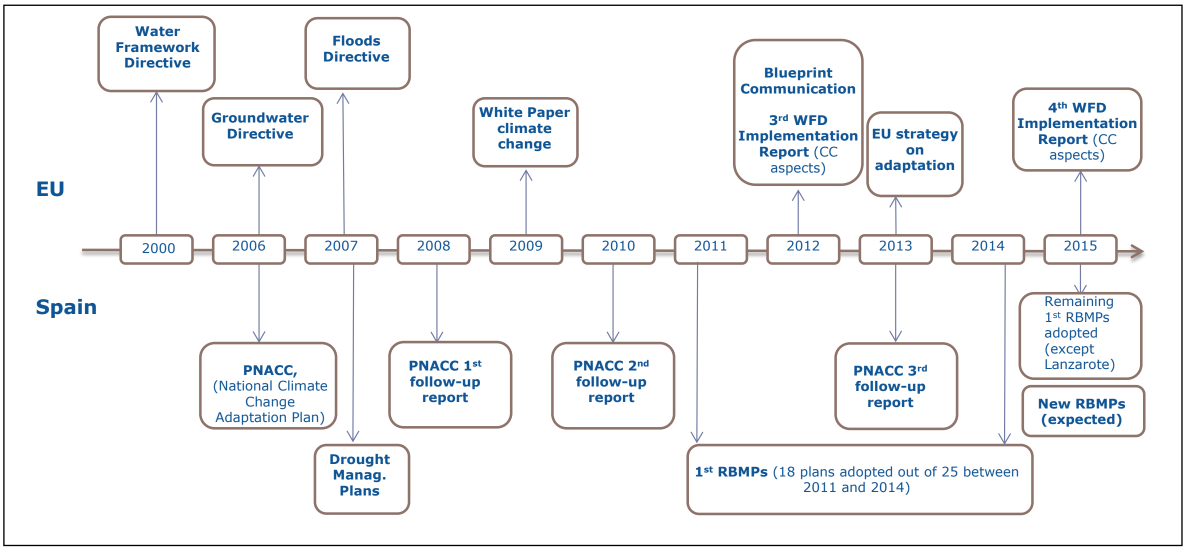
The Climate Change Adaptation National Plan or PNACC (Ministerio de Medio Ambiente, 2006) represents the general framework in Spain for impact assessment, vulnerability and adaptation activities. Moreover, the Spanish Strategy on Climate Change and Clean Energy, approved by the Government in 2007, is the framework that holds together the different climate change policies at the national level and defines basic guidelines for action at the short and medium term (2007 -2012-2020) together with the PNACC. It also includes measures aimed at reducing greenhouse gasses emissions or at adapting to their effects, and promotes various instruments such as the 2005-2010 Renewable Energy Plan or the Plan of Urgent Measures for 2007, among others.

Since 2008, major strategic priorities have been defined with performance targets for reducing emissions leading to specific actions such as the Integrated National Waste Plan, the Savings and Energy Efficiency Plan in government buildings, or more directly linked to agriculture, the Slurry Anaerobic Digestion Plan.

Regarding energy, Spain presents a high dependency compared to other EU Member States, and has traditionally imported energy from neighbouring countries. This dependency has decreased since 2008, due in part to the impulse of renewable energies (solar, wind, hydroelectric, and biomass). Hydropower represents quite a large share of renewable energy production and places Spain at the fifth position as producing country in this category in the EU (Montoya et al., 2014). However, decreasing river flows and other associated impacts from climate change could greatly decrease this production and alter dependency rates on other sources and from other countries.

4.3 Climate Change Adaptation National Plan

The Climate Change Adaptation National Plan or PNACC is the main national tool setting adaptation and mitigation strategies and main working lines for different sectors or activities, the Administration and other public or private interested organizations. The first Work Programme of the National Adaptation Plan envisaged three main sectors: coasts, water and biodiversity. The second Programme, with a timeframe of four years, incorporated new elements and activities with a holistic approach by considering health, agriculture, tourism, forests, soil and the combat against desertification, and its last follow-up report was published in 2011. (See figure 2, which shows the main milestones on climate



change and water resources policies in the EU and Spain).

Figure 2. Milestones on climate change and water resources. Main policy and management tools in the EU and Spain.

This Plan was developed with the support of the OECC, which has worked with different national and regional governments, as well as stakeholders to disseminate its contents and goals.

According to the European Environment Agency (European Environment Agency, 2014), Spain was one of the first EU Member States to have a national strategy and national authority set up to follow-up its progress and implementation (only Finland developed its national plan in 2005, France had it in 2006 and for most Member States this happened between 2007 and 2014). However, the full implementation of the PNACC is lying behind in comparison with other EU countries.

In line with the EU Climate Adapt, the OECC, has set up a reference web portal called AdapteCCa[13] that provides information on any activity, project, or line of action related to climate change. Set up on 2013, this portal also provides a document repository and a searching engine for articles, reports and relevant documents, in addition to working groups in which stakeholders and organisation can take part.

5 Upraising concerns and water resources management tools in a changing climate

5.1 In the EU and beyond

The different impacts derived from climate change are questioning whether conflicts and security issues will increase. The Mediterranean region already witnesses recurrent conflicts and social movements (Arab Spring in 2010, Syrian war 2011…) that often start with the rise of food and energy prices, and thus are somehow linked to water management, its use and effects of climate change. For instance, the revolts on Morocco during 2011 led the government to appease revolts by creating a specific fund to ensure affordable prices on local markets for fuel and basic goods (sugar, cereals, oil). Additional military conflicts over the past years have had in one way or another a link to water resources. For instance, Israel has historically targeted the control of water bodies and key infrastructures such as water treatment facilities or bridges (Isaac et al., 2009; Vargas-Amelin, 2011). Popular revolts in Algeria due to lack of ensured potable water supply, were also common in 2011.

While conflicts in EU MS might not be as violent, or might lack military actions, they also exist and are likely to increase if the availability of water resources is reduced over time, as the different economic sectors will still demand their share. Climate change might translate into security threats,

[13] http://www.adaptecca.es/

although it can provide options for better cooperation as well. The direct effects on threats are likely to depend less on the nature or intensity of climate change direct impacts, and more on the socio-economic aspects, resilience capacity of societies and institution robustness (European Commission, 2011). Water security will also deal with how societies ensure an appropriate water use, and how they cope with extreme events. As the OECD points out (The Organisation for Economic Co-operation and Development (OECD), 2013) water security refers to finding a balance between having enough water resources in terms of quantity and quality to address socio-economic and environmental needs, while addressing their destructive nature and finding an acceptable level of risk (e.g. minimizing water-related risks). This organisation calls for better water governance[14] with strong participative strategies, which play a relevant role in minimising conflicts and promoting security.

Possible conflicts and the appropriate management and prioritisation of uses, will be directly linked to the availability of water and the management of the existing demands.

5.2 In Spain

Important protests occurred in Spain on 2001-2004 due to the proposed water transfer from the Ebro basin to the south-eastern part of the country. The issue translated into numerous demonstrations, mobilising for instance up to 200.000 people in a sole protest in Madrid in 2001. Additional conflicts, protests and political tensions often arise from the existing water transfer between the Tagus river and the Segura river (from the centre of the country to the southeast), which actually exists since 1979.

While Spain has tried to shift from supply to demand management (Estrela et al., 2012), the reality shows that the true change still needs to occur. Important efforts can be spotted and they have been made to improve infrastructures efficiency, promote water savings through public awareness

[14] Water governance is the socio-economic, political and administrative systems that exist to manage, develop and use water as a resource within a society. That is the institutions and groups behind all decision making for water use. For instance, within a country, water governance covers institutions and policies that allocate water resources and regulate its use and the administrative processes involved (permits, water services management etc.).The OECD provides the following definition: *Water governance is a dynamic concept referring to who does/gets what, when and how. It encompasses political, institutional and administrative rules, practices and processes through which stakeholders articulate their interests, their concerns are considered, decisions are taken and implemented, and decision-makers are held accountable in the development and management of water resources and delivery of water services.*

campaigns, and even by the development of secondary water distribution networks (water with less quality than the one used for drinking purposes is used for instance in irrigation). However, on the other hand, within the hydrological planning sector, satisfying existing demands is still a priority and no true public dialogue has been held to determine their feasibility, compatibility with environmental requirements or economic efficiency. This can be seen in the content of the updated RBMPs, for instance in the one published for the Jucar River Basin (Confederación Hidrográfica del Júcar - Ministerio de Agriculutra Alimentación y Medio Ambiente, 2015).

Within these Plans' programmes of measures, proposed actions rely primarily on new infrastructures to mobilise new water resources or to increase exploitation guarantee of existing ones. Furthermore, the scarcity of resources, mainly in Mediterranean and other coastal areas (aggravated by climate change effects and demographic pressures) has boosted the use of non-conventional resources, mainly wastewater reuse and desalination, which are a way of increasing water supply. Their use has increased over the past years and techniques have modernised, obtaining important energy reduction inputs, where further relevant savings are not foreseeable (Institut Méditerranéen de l'Eau, 2014). These resources have actually become part of the overall 'water resources pool' making them almost 'conventional', but major scarcity problems remain unresolved.

Tailored saving campaigns or the application of subsidies for less water consumption in different sectors (public supply, agriculture or industry) are marginal. There is a still a need to promote public awareness, to truly reduce consumption in the most demanding sectors, reduce uptakes form water bodies and thus the pressure made over them. This seems progressively harder as population and economic activities keep growing, and climate change impacts predict less water availability. Furthermore, Spain as most Member States, still needs to introduce pricing policies (according to used volumes) and apply instruments to recover the environmental and the resource costs, in particular for the agriculture sector as it is described later in this article. (European Commission, 2012).

There are also important gaps in the data gathering and water use control, which if filled in, could facilitate management decisions, address those water sources with greater pressures and improve resilience of water basins.

For instance, monitoring networks and information systems have improved considerably over the past years and have had a very relevant support from water administrations. However, there is still an important gap on controlling and monitoring water abstractions (demands). This is a very relevant aspect in hydrological planning and modelling to determine future needs, trends and water availability. While many climate change scenarios show important decreases of precipitation values and water availability volumes, having a thorough control of which amount of water is abstracted and used for different economic activities will be paramount to establish the appropriate management and resiliency measures. Tools such as water accounts[15] within a systematic framework (United Nations Department of Economic and Social Affairs, 2012) could actually be very helpful in refining knowledge of water abstraction volumes, flows of water between river basin elements, and ultimately better determine which water amounts are available and facilitate decision making (e.g. allocation of water rights during a specific season).

Some pilot projects have been developed on water accounts, and specifically several projects co-financed by the European Commission, shed some light on their feasibility, application, and usefulness for water managers in several Spanish river basins (Tajo, Segura, Jucar, Guadiana, Andalusian Mediterranean basins) (European Commission, 2015a).

5.3 Water-energy-food nexus

The horizontality of water resources and their use in so many productive sectors, complicates even more its management and the integration of water protection in different policy areas. Water is needed

[15] Eurostat, the statistical office of the European Union, manages relevant sources of information and databases on environmental accounts and socioeconomic indicators. On-going works on sectorial accounts could shed light in the future on determining environmental costs, costs of climate change adaptation, vulnerability of European countries and their adaptive capacity or resilience. http://ec.europa.eu/eurostat/web/environment/overview

to produce energy and food, and thus, the relationship between these three elements is essential for socio-economic development, food security and the development of societies.

Food security is likely to be affected by climate change effects, and its impacts could interfere with access to food products, their use, or price stability in markets (IPCC, 2013). A coherent and multidisciplinary approach would be necessary to establish common goals and objectives, to manage resources according to their status and availability taking into account the existing interconnections (International Institute for Sustainable Development, 2013). Unfortunately, competences and administrations have specialised and evolved independently, and cooperation and joint policy development have rarely taken place. In addition, managing scales are often different and lie within different administrations schemes, which complicate even more the task of coordinating objectives and instruments.

For instance, while water resources general planning often lays at the national scale, the 'on the ground' management should ideally take place at the river basin level (main principle of the WFD), where interactions with regional and local authorities converge (new infrastructures development, natural sites, tourism…).

Other aspects that can contribute to reduce water demand and build bridges among water consuming sectors relay on focusing on less traditional approaches, and improving efforts on increasing resilience[16] of water ecosystems and populated areas that use or depend upon them. Several actions can increase resilience towards climate change effects. These include the identification of threats (drivers and pressures) to water ecosystems, protecting their biodiversity and avoiding for instance ecological quality deviation, halting environmental degradation that could reduce environmental services, or improve societal knowledge on ecosystems, their functioning and complex interlinks with

[16] In this context, resilience expresses the ability of a system to cope with expected changes (climate change impacts such as for instance decrease of precipitation values) adapt, and continue its fundamental functioning. An ecosystem with higher plant biodiversity will have a greater capacity to withstand fewer water inputs, and maintain its biological functions and ecosystem services (nutrient filtering capacity, fodder to birds, local products to communities).

economic activities and global trends. In addition, there is a need for improving the understanding of ecosystem connectivity, the time frame of variables, impacts and expected responses from the ecosystem (CGIAR Research Program on Water, 2014).

5.4 Green infrastructures

To build and develop resilience strategies, administrations and managers need to apply both physical and social techniques, invest in options based on natural ecosystems or processes and use hybrid approaches ('green' and 'grey' infrastructures). Furthermore, it is important to prioritise critical infrastructures that play essential roles for communities as well as conservation efforts for the most valuable and fragile ecosystems (those that will be harder to restore). These actions can take place if administrations incorporate resilience-building in relevant policies such as environmental and water management, climate change adaptation and disaster risk reduction (The Royal Society, 2014).

More prepared and resilient ecosystems and societies should in turn be less water demanding and be ready to cope with shortages and variations linked to climate change. In this context, green infrastructures and natural water retention measures have been proven to be more environmentally friendly, efficient and often less expensive than traditional 'grey infrastructures' (European Union, 2014).

6 EU policy tools

The EU environmental *acquis* addresses these conservation concepts and promotes these types of action to build in resilience (Birds and Habitats Directive, WFD, Groundwater Directive[17]…). However, the key of increasing societies resilience still depends on reducing vulnerability and exposure, and in this sense, policy implementation might be insufficient without proper administration coordination and participative mechanisms as previously mentioned.

[17] Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration, OJ L 372, 27.12.2006, p. 19–31.

Regarding existing water management tools, three main types of plans exist or are under development: droughts, floods and RBMPs.

According to Directive 2007/60/EC[18] MS are required to assess flood risk of water courses and coastal areas, develop risk maps, and coordinate measures to reduce impacts on humans, assets and the environment. The Directive also reinforces public right to access related information and participate in the planning process. MS should report flood management plans focused on prevention, protection and preparedness by 2015. The management of flood risks is a key component of climate change adaptation, and the Directive requires that countries take it into account in the preliminary flood risk assessment.

The updated RBMPs should also be ready by the end of 2015 and reported to the European Commission by March 2016 according to the Water Framework Directive.

6.1 Policy related tools in Spain

In Spain, Drought Management Plans are in place since 2007 and have been proven useful tools for prioritising water allocations and use under drought situations with previously agreed processes and mechanisms among the main water consuming sectors. These plans have as main features the use of indicator systems with established thresholds, the identification of specific measures tailored to each of the drought phases (normal status, pre-alert, alert and emergency), and the prioritisation in the use of water. The objectives are set to sustain population life and health, protect environmental requirements and minimize negative effects on public water supply and on economic activities (such as agriculture). The engagement of stakeholders and affected sectors allowed for a better acceptance of the proposed measures prioritisation and water use restrictions (Estrela and Vargas, 2008).

The revision of these plans is recommended to take place every six years, and according to different circumstances, as for instance if important changes need to be applied to indicators thresholds or measures as a consequence of models that take into account climate change. These plans vary between river basins, but in general, among the identified measures, they include the use of models that

[18] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. OJ L 288, 6.11.2007, p. 27–34.

consider climate change effects. Furthermore, these plans already allow for some flexibility and adaptation to their measures if climate effects are observed.

For the first RBMPs, there was already an important delay in Spain. In fact, plans were adopted between 2011 and 2014 and still one of the Canary Islands Plans (at the moment of writing this article) has not been approved (see figure 2). Thus, it is not very likely that all updated plans will be ready by the stated date. By taking into account the available second draft plans, demand management and types of basic and complementary measures are quite similar to the first plans. In addition, the identification of gaps to achieve good ecological status, the link of water management to protected areas and Natura 2000 sites or the establishment of planning strategies to improve aquatic ecosystems in the long-term still need large improvements. For instance, measures for better metering and controlling all abstractions have not been extended, neither has a reassessment of environmental flows to guarantee the link to good water status taken place (WRc plc, 2015).

The update of the plans is quite relevant in terms of climate change considerations, since the programme of measures should be climate-proof. What is meant by this is that different scenarios should be considered, measures should allow for some flexibility and be adjusted as information and models provide updated and more reliable information (European Commission, 2009c).

Regarding floods, Spain has carried out a preliminary assessment of river basins and coastal areas at risk of flooding and produced comprehensive flood risk maps as requested by the Floods Directives. The first Flood Risk Management Plans (FRMP) should be presented by December 2015 and reported in March 2016 to the European Commission. Climate change has not been considered in the statistics of flood flows due to linked uncertainties, and it is still to be assessed, whether the first FRMP will take its impacts into consideration (European Commission, 2015b).

7 Economic considerations

Climate change is expected to have important economic impacts in many sectors, and a broad effect on the value of financial assets through, among other, changing agriculture and commodity prices, scarcity of essential resources (i.e. water), or damage to infrastructures. It could, however bring new market opportunities, that could be taken by investors, which in turn would also allocate significant capital towards the fight against climate change (Abramskiehn et al., 2015). Extreme events, for instance, will require greater investments in defensive structures, and lesser water quantity due to drought periods will translate into higher costs for water treatment and investment needs. More frequent droughts and heatwaves have caused electricity cuts and generators overheating, and authorities had to apply emergency measures at high costs. Energy availability has also witnessed limitations affecting the delivery of water services (United Nations World Water Assessment Programme, 2015).

Under the WFD (art. 5), MS are required to carry out an economic analysis of water use, which mainly includes recovering costs of water services and determining the most cost-effective combination of measures in respect of water uses. The recovery of costs, should include environmental and resource costs associated with damage or negative impact on the aquatic environment (i.e. externalities), according to the polluter-pays principle. To carry out the economic analysis the WFD refers to the need of taking into account long-term forecasts of supply and demand for water in the river basin. In this context, climate change effects and direct impacts on water availability, which will in turn affect water supply, should be clearly considered as potential additional pressures.

As indicated in Guidance document 24, long-term assessments of water supply and demand within the river basin should consider climate change scenarios. The same applies to selecting and determining the most cost-effective measures. While a feasible and useful infrastructure might be considered necessary under the programme of measures of the RBMP (PoM), managers should consider the effects of climate change over it (e.g. reduced water flows will affect stored water in a dam and different scenarios might guide water managers in estimating reductions and impacts) (See figure 1). One of the recommendations of the guidance document stresses the importance of selecting measures that are either robust (will not be affected by climate change impacts) or are flexible enough to adjust under different climatic scenarios. Both cases should translate into economically efficient measures, to avoid wasteful investments. When identifying measures sensitive to climate change, these should be re-evaluated or reconsidered, and adjusted or alternative measures applied, in which case further economic assessment will be required.

The document also refers to water pricing and other incentives to use water resources more efficiently, which can be paramount under climate change conditions where less water availability is expected. Due to the different conditions that can occur in a changing climate, water managers need, and will need even more in the coming years, to identify water scarcity, determine its causes and apply tailored regulations to achieve sustainable balances. The European Commission and different working groups have recommended using market-based instruments to address water scarcity problems in addition to developing an economic assessment of water uses, determining water´s value and promoting efficiency and saving measures whenever possible. Some of the instruments recommended include block tariffs, metering to determine real consumptions, pricing policies that favour savings and penalise overconsumption, allocating water funding more efficiently, improving drought risk management, and applying stricter control of consumption (demand) to appropriately address management measures (i.e. through better knowledge and data collection (European Commission, 2009c, 2007). In addition, under the supplementary measures for the PoM, the Directive refers to economic or fiscal instruments.

As mentioned, climate change is expected to have important economic impacts on energy and food production. For instance, lower river flows will affect hydropower production and drought and dry periods will affect crop yields and the whole food chain. Thus, under a changing climate prioritisation of uses and establishment of socio-economic activities in the best suited places for each case (opportunity cost) will need public dialogues, political commitment and planning at different scales. The concentration of agricultural practices in sunnier areas will also mean higher needs of water infrastructures, greater pressures to the soil and environment in the form of diffuse pollution, all of which will need to consider climatic variations.

Under the current economic recession, affecting most European countries, but being especially hard in Spain, water managers will also face the dilemma of prioritising investments and approving the most urgent and useful ones. However, political pressures and interests do not always help in applying a transparent and participatory process. In this context, the use of cost-effective measures, green infrastructures and non-structural measures such as education, social awareness, and capacity building, should be considered due to their multi-benefit nature.

As the UN points out, the economic valuation of water can be very useful in different policy areas. It can serve for instance to determine how efficient water management and allocations are. Furthermore, countries should promote an efficient and equitable allocation of water, which takes into account the value of water used by different demanding sectors. This value should, according to the organization, consider the current generation, the allocation of resources between current and future generations and the degree to which anthropogenic impacts affect water quality. Water economic valuation could also serve in establishing water pricing policies and in designing economic instruments, such as taxes on water pollution, to achieve better use of water resources (United Nations Department of Economic and Social Affairs, 2012).

Ecosystem services

Water is a horizontal natural resource, used in practically all socio-economic activities, and is also essential to sustain life and ecosystems. It supplies different ecosystem services for society and several sectors such as agriculture or forestry. It provides for instance pollution dilution in rivers and habitat protection, allows recreational practices, or reduces risk impacts.

Under the Millennium Ecosystem Assessment, services have been classified as *provisioning* (e.g. food or water), *regulating* (e.g. affect climate or floods), *cultural* (recreational or aesthetics benefits) and *supporting* (e.g. nutrient cycling or soil formation)(Millennium Ecosystem Assessment, 2005).

While important efforts have been achieved in the study and assessment of services, their economic valuation still stirs important debates and faces knowledge gaps (data) and standardised agreed methodologies. As important steps, the SEEA-2003 framework combines accounts on water, land and forests, fisheries, pollution and economics, (United Nations Department of Economic and Social Affairs, 2012), and the System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting has progressed in the development of a statistical framework for ecosystem accounting. (European Commission et al., 2013).

Finally, water and climate actions should always take into consideration the cost of inaction, the loss of environmental services and the intrinsic value of water caused by not applying the appropriate measures on time. The European Commission has estimated that the cost to the EU of not adapting to climate change would be at least 100€ billion a year by 2020 and at least 250€ billion a year by 2050. These costs could dramatically reduce if small investments are applied for drought and flood prevention measures.

8 Identified policy gaps, needed reforms and recommendations

While there is some coherence and coordination among the major water management tools, as for instance between droughts, floods and RBMPs, this is not so evident for other environmental and agricultural tools, as for instance Natura 2000 sites network[19] or rural development programmes[20] under the EU Common Agricultural Policy. This problem is identified by different organisations and reflected in several reports (European Court of Auditors, 2014; European Environment Agency, 2013a; United Nations, 2015). When competences are distributed among large number of highly compartmentalised administrations, with often limited public funding and human resources, coherence and coordination efforts become complicated. In the Spanish administration all these competences are actually found within the same Ministry. The decision of joining competences as encountered as agriculture and water protection entered into force in 2011 with the creation of the Ministry of Agriculture, Food and Environment (the Ministry of Environment had existed by its own since 1996). However, in practice, competences have been subdivided and carried away independently.

To overcome obstacles and improve policy coherence, better participatory mechanisms could be incorporated among authorities (European Environment Agency, 2013a). For instance, inter-ministerial groups (at the technical level) with clear political mandates could be created and supported.

[19] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7)

[20] Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 december 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005

Integrating water policy into other policies (e.g. agriculture) is a problem at the EU wide scale (European Court of Auditors, 2014), thus not only affecting Spain, but most MS and even EU institutions.

Within the Common Implementation Strategy of the Water Framework Directive, efforts have been invested in having a better communication and exchange of information and practices on water and agriculture with limited success. The specific technical group on agriculture proved ineffective in facilitating the integration of water concerns into the implementation of national agricultural policy. In the latest reports a suggestion has been made to elevate the problem to a higher political level to try to achieve better results (European Commission, 2015c).

In addition to improving administrations and departments' coordination, a better effort to communicate the importance of water use and protection in different economic sectors should be promoted.

As discussed, a better approach to water-food-energy-ecosystem nexus could help in improving policy coherence, building in societies' resilience and transmitting the relevance of water to different economic sectors.

Cost-recovery measures within RBMPs are very limited, and water related budgets, even in public administrations, lack transparency. For instance, users, can rarely access detailed water bills that clearly establish a direct link with the actual amount of water consumed or discarded. In addition, there is not always a clear disaggregation of the costs of services (sewage and wastewater treatment) (European Environment Agency, 2013b).

In the context of science-policy-public interface, there is a need of transmitting results to the public, of contributing to awareness raising, and providing recommendations for individual and local actions to combat climate change impacts.

Furthermore, often harmful subsidies exist in the water sector (e.g. subsidised irrigation practices), and the application of ‘green taxes’ or the appropriate application of the ‘polluter-pays principle’ is unfortunately not common in EU Member States.

Additional recommendations include the possible incorporation of environmental accounting (e.g. water accounts) in national economic systems, introduce appropriate payment for ecosystem services, provide subsidies for the use of green infrastructures, apply and enforce environmental flows, and use ecosystem-based solutions (which are often more cost-effective).

Furthermore, there is a need to improve training and professional development on climate change issues and promote information exchange and knowledge transfer between administrations and departments that deal with water, energy and land management. In addition, by ensuring stakeholder involvement in measures assessment and promoting scientific input on updated climate change knowledge that could adjust projections, would translate into more precise and useful management decisions.

9 Conclusions and recommendations

Negative impacts of climate change in Spain are increasingly evident. The geographical location, its characteristics and predictions from different models and recent studies makes it a highly vulnerable country in the EU. In the case of water resources, Spain studies point towards more frequent and intense droughts and floods, increases in temperature or decrease in river flows, exacerbated water pollution problems and in essence less availability for different uses among. In addition to the issues of reduced water availability and increased costs for adaptation measures, pests, invasive species, or a decrease in the amount and quality of crop yields will be part of the foreseeable problems.

Climate change poses a threat to the country's sustainable development, and more specifically on water resources management and protection. Significant efforts have focused on establishing climate change policies, multi-sectoral coordinating bodies and specific adaptation plans and measures for the different sectors. However, there are important gaps, at the policy coherence and implementation levels, which hamper adaptive efforts and resilience building. Economic instruments, prioritisation of cost-effective and 'green' measures and the appropriate use of the cyclic nature of the WFD can all play important roles towards better adaptation and resilience building.

The following points summarise the major recommendations approached throughout the text:

- Knowledge gaps addressed by research projects should be better transmitted to professionals in need of the results. Researchers should also make a greater effort in translating scientific results in a language that can be absorbed and understood by the overall public.
- Horizontal and inter-ministerial climate change structures can be helpful in coordinating efforts to better adapt to expected impacts. The public could be better informed on the existence of these structures and their roles, and a larger number of representative stakeholders could take part of them.
- There is a need for better participatory mechanisms within and among administrations to improve policy coherence. This should include exchange of information and updates on the water policy and management sectors and climate change impacts studies and predictions.
- Participatory mechanisms and better water governance can also be quite relevant for avoiding possible conflicts linked to competing water uses, which under a changing climate are expected to increase.
- A better control of water demands and abstractions, through, for instance better metering, is essential in the shift towards demand management. It is important to remember that countries such as Spain are expected to witness a decrease of water availability, thus supply management approach is likely to be unsustainable.
- Water authorities should use market-based instruments and apply pricing policies that truly incorporate the value of water and that address the impacts economic activities can have in this valuable resource (degradation, pollution, over abstraction, loss of ecosystems services…).

- To ensure a better water management under recession conditions, authorities should prioritise measures that are cost-effective and climate proof. In this context, green infrastructures and natural water retention measures can play a relevant role.
- Better training and awareness raising for professionals on climate change and water issues are needed. This could specifically be applied in sectors that have traditionally not considered possible impacts on water resources (for instance, infrastructures departments that develop roads, railroads and infrastructures, which can directly impact water bodies).
- Since a revision of the Water Framework Directive should take place in 2019, some of the aspects that could be considered include the implicit mention of climate change as anthropogenic pressure, the inclusion of climate change impacts in the economic analysis of measures. Furthermore, technical developments and common EU guidelines and approaches for considering resource costs and environmental costs could be very useful for applying appropriate pricing policies in Member States.

To conclude, at the EU level and in Spain there is a robust environmental legislation and efforts are progressing towards a better incorporation of climate change aspects and coherence with other sectors. However, there are several gaps in policy implementation, in the uptake of societal views or in administrations coordination. Thus, there is still quite a lot of work ahead to ensure a resilient and sustainable management of water resources.

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References

Abramskiehn, D., Buchner, B., Wang, D., 2015. The Landscape of Climate Exposure for Investors. The Climate Policy Initiative.

Arnell, N., Liu, C., 2001. Hydrology and Water Resources, in: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, p. 1005.

Centro de Estudios y Experimentación de Obras Públicas, 2011. Evaluación del Impacto del cambio climático en los recursos hídricos en régimen natural. Resumen ejecutivo.

CGIAR Research Program on Water, L. and E. (WLE), 2014. Ecosystem Services and Resilience Framework Science with a human face. CGIAR Research Program on Water, Land and Ecosystems, International Water Management Institute (IWMI), Colombo, Sri Lanka. doi:10.5337/2014.229

Confederación Hidrográfica del Júcar -Ministerio de Agriculutra Alimentación y Medio Ambiente, 2015. Propuesta de proyecto de revisión del Plan Hidrológico. Memoria. Ciclo de planificación hidrológica 2015-2021; Demarcación Hidrográfica del Júcar 896.

Estrela, T., Pérez-Martin, M.A., Vargas, E., 2012. Impacts of climate change on water resources in Spain. Hydrol. Sci. J. 57, 1154–1167. doi:10.1080/02626667.2012.702213

Estrela, T., Vargas, E., 2008. Water Issues, overview of available water resources, in: Aguas de las Cuencas Mediterráneas S.A. (Acuamed) (Ed.), La Desalación En España. Sociedad Estatal Aguas de las Cuencas Mediterráneas, Madrid, p. 324.

European Commission, 2007. Communication from the Commission to the European Parliament and the Council, Addressing the challenge of water scarcity and droughts in the European Union (No. COM(2007) 414 final). Brussels.

European Commission, 2009a. White Paper, Adapting to climate change: Towards a European framework for action (No. COM(2009) 147 final). Brussels.

European Commission, 2009b. Commission Staff Working Document, accompanying the White Paper. Adapting to climate change: Towards a European framework for action (No. SEC(2009) 387). Brussels.

European Commission, 2009c. Guidance Document No. 24. River Basin Management in a Changing Climate. European Commission, Brussels.

European Commission, 2011. Climate Change Impacts on Water and Security in Southern Europe and neighbouring regions. European Union. doi:10.2777/56413

European Commission, 2012. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Blueprint to Safeguard Europe's Water Resources (No. COM(2012) 673 final). Brussels.

European Commission, 2013a. Green Paper A 2030 framework for climate and energy policies (No. COM(2013) 169 final). Brussels.

European Commission, 2013b. Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions, An EU Strategy on adaptation to climate change (No. COM (2013) 216 final). Bruss.

European Commission, 2015a. Guidance Document No.34. Guidance document on the application of water balances for supporting the implementation of the WFD. Brussels.

European Commission, 2015b. Commission Staff Working Document. Report on the progress in implementation of the Floods Directive. Accompanying the document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL, The Water Framework Directive and the Floods Direc. Brussels.

European Commission, 2015c. Discussion paper on the CIS Work Programme 2016-2018. Water Directors – Riga 26-27 May 2015. Brussels.

European Council, 2014. European Council (23 and 24 October 2014) Conclusions (No. EUCO 169/14). Brussels.

European Court of Auditors, 2014. Integration of EU water policy objectives with the CAP: a partial success. Publications Office of the European Union, Luxembourg. doi:10.2865/15216

European Environment Agency, 2008. Impacts of Europe ' s changing climate- 2008 indicator-based assessment. Office for Official Publications of the

European Communities, Copenhagen. doi:10.2800/48117

European Environment Agency, 2012. Climate change, impacts and vulnerability in Europe 2012, An indicator-based report. Publication Office of the European Union, Copenhagen. doi:10.2800/66071

European Environment Agency, 2013a. Adaptation in Europe, Addressing risks and opportunities from climate change in the context of socio-economic developments. Publication Office of the European Union, Copenhagen. doi:10.2800/50924

European Environment Agency, 2013b. Assessment of cost recovery through water pricing. Luxembourg. doi:10.2800/93669

European Environment Agency, 2014. National adaptation policy processes in European countries — 2014. Luxembourg. doi:10.2800/21394

Institut Méditerranéen de l'Eau, 2014. Synthèse générale & Conclusions, in: 2ème Forum Méditerranéen de l'Eau; Murcie, Espagne 25-27 Novembre 2014. p. 6.

Intermón Oxfam Editorial, 2008. La realidad de la ayuda 2008-2009. Una evaluación independiente de la ayuda al desarrollo española e internacional. Intermón Oxfam Editorial.

International Institute for Sustainable Development, 2013. The Water-Energy-Food Security Nexus:Towards a practical planning and decision-support framework for landscape investment and risk management. International Institute for Sustainable Development.

IPCC, 2008. Climate change and water, IPCC Technical Paper VI. IPPC Secretariat, Geneva.

IPCC, 2013. Summary for Policymakers, in: Socker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Sience Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

Isaac, J., Iskandar, M., Ayeb, H., Muhammed Khalid, K., Abdelmoumni, F., Partow, H., 2009. Consecuencias económicas y ecológicas de los conflictos en el mundo árabe. Rotosa, Madrid.

Lázaro-Touza, L., López-Gunn, E., 2014. Climate change diplomacy in Spain ’ s future foreign policy. Real Inst. Elcano Spain’s Fo, 1–21.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being; A Framework for Assessment.

Ministerio de Medio Ambiente, 2006. Plan Nacional de Adaptacion al Cambio Climatico; Marco para la coordinación entre administraciones públicas para las actividades de evaluación de impactos, vulnerabilidad y adaptación al cambio climático. Ministerio de Medio Ambiente.

Montoya, F.G., Aguilera, M.J., Manzano-Agugliaro, F., 2014. Renewable energy production in Spain: A review. Renew. Sustain. Energy Rev. 33, 509–531. doi:10.1016/j.rser.2014.01.091

Morata Gasca, A., 2014. Guía de escenarios regionalizados de cambio climático sobre España a partir de los resultados del IPCC-AR4. Ministerio de Agricultura, Alimentación y Medio Ambiente, Madrid.

Quevauviller, P., 2011. Adapting to climate change: reducing water-related risks in Europe – EU policy and research considerations. Environ. Sci. Policy 14, 722–729. doi:10.1016/j.envsci.2011.02.008

Quevauviller, P., 2014. European water policy and research on water-related topics – An overview. J. Hydrol. 518, 180–185. doi:10.1016/j.jhydrol.2014.02.007

Quevauviller, P., Barceló, D., Beniston, M., Djordjevic, S., Harding, R.J., Iglesias, A., Ludwig, R., Navarra, A., Navarro Ortega, A., Mark, O., Roson, R., Sempere, D., Stoffel, M., van Lanen, H.A.J., Werner, M., 2012. Integration of research advances in modelling and monitoring in support of WFD river basin management planning in the context of climate change. Sci. Total Environ. 440, 167–177. doi:10.1016/j.scitotenv.2012.07.055

Somot, S., Sevault, F., Déqué, M., Crépon, M., 2008. 21st century climate change scenario for the Mediterranean using a coupled atmosphere–ocean regional climate model. Glob. Planet. Change 63, 112–126. doi:10.1016/j.gloplacha.2007.10.003

The Organisation for Economic Co-operation and Development (OECD), 2013.

Water Security for Better Lives, OECD Studies on Water. OECD Publishing. doi:10.1787/9789264202405-en

The Royal Society, 2014. Resilience to extreme weather. The Royal Society Science Policy Centre report 02/14. London.

United Nations, 2015. Transforming our world: the 2030 Ageda for Sustainable Development, in: The United Nations Summit for the Adoption of the Post-2015 Development Agenda. New York, p. 29.

United Nations Department of Economic and Social Affairs, 2012. SEEA-Water; System of Environmental-Economic Accounting for Water. New York.

United Nations World Water Assessment Programme, 2015. The United Nations world water development report 2015: Water for a sustainable world. UNESCO, Spello.

Vargas-Amelin, E., 2011. El agua en la cuenca Mediterránea, in: López-Bueno, J.M. (Ed.), El Mediterráneo Tras 2011. FHIMADES, Melilla, p. 248.

Wilby, R.L., Orr, H.G., Hedger, M., Forrow, D., Blackmore, M., 2006. Risks posed by climate change to the delivery of Water Framework Directive objectives in the UK. Environ. Int. 32, 1043–1055. doi:10.1016/j.envint.2006.06.017

WRc plc, 2015. Screening Assessment of Draft Second Cycle River Basin Management Plans. Swindon.

4 Summary of Overall Results

This section summarises the main results, based on the presented publications. Under the discussion and conclusions (sections 5 and 6), an overall assessment is provided on whether these results have answered the stated research questions, and which are the most relevant findings.

4.1 Vargas-Amelin, E, 2011. **El agua en la cuenca mediterránea**, In J. M. López-Bueno (Ed.), El Mediterráneo tras 2011 (p. 200). Melilla: FHIMADES. p. 248.

This chapter presents an overall introduction to water resources in the Mediterranean region, main management policies, economic tools and sectors, international initiatives and conflicts linked to water resources. The chapter provides specific examples on agricultural practices and impacts on water resources, as well as detailed figures per country.

The main conclusions are summarised below:

- The Mediterranean region has high pressures from a growing population, urban and industrial activities, mainly occurring in coastal areas.
- While water is a catalyst for development, it is suffering from scarcity, uneven distribution, high pollution, conflicts from demanding sectors, and overexploitation of groundwater.
- These water resources problems are aggravated by droughts, floods and climate change impacts.
- Agricultural practices, while having different degrees of economic importance between northern and southern countries, create important pressures in water resources as well as environmental externalities. A better integration of policies and practices in different linked sectors should occur (agriculture, industry, water resources, land-planning…)

- There has been an important progress in water control and regulation, but pricing policies and cost-recovery principles are far from being met.

- A progress towards demand management (instead of supply management) is expected to improve in the upcoming years. Also, an increase in the use of non-conventional resources is happening, although their environmental impacts should be considered.

- Water resources also offer a framework of better cooperation, exchange of know-how and conflict resolution. In this context, the EU has launched several programs and financing opportunities.

- Implementation of environmental policies is still sometimes weak as well as participative processes in decision-making.

4.2 Estrela, T., Vargas, E., 2012. **Drought Management Plans in the European Union. The case of Spain**. Water Resources Management. 26, 1537–1553.

This article focuses on extreme phenomena that commonly occur in Mediterranean basins, i.e. drought episodes. It offers an overview of drought management and policies in the EU, analysing the specific case of Spain. In particular, it provides information on the National Drought Indicator System and DMPs.

This article's main conclusions are:

- Important efforts have been done at the EU level to address drought risk evaluation, characterisation of drought episodes and development of specific common indicators.

- The EU has also provided tools and recommendations to better approach drought impacts and minimise their impacts.

- Actions have been undertaken by several MS to better integrate water scarcity and droughts into sector policies, including better management and consideration of climate change impacts.

- Spain is a country characterised by presenting a clear uneven distribution of water resources, and large areas suffer from water scarcity and drought episodes. In the past, these have caused important economic and environmental impacts, and triggered investments in hydraulic works.

- Drought management in Spain has progressively shifted from a crisis to a more planned approach. In this context, DMPs (approved in 2007) have proven to be useful tools to determine drought phases, establish appropriate measures and prioritisation of water uses.

- DMPs have helped to better planned water availability, avoid public supply restrictions and improve aquatic ecosystem protection.

4.3 Estrela, T., Pérez-Martin, M.A., Vargas, E., 2012. **Impacts of climate change on water resources in Spain**. Hydrological Sciences Journal. 57, 1154–1167.

This article provides the main insights of climate change effects expected in Spanish water resources. It mainly addresses the complexity of determining those impacts and their degree due, in part, to the natural variability of the water cycle. The article tackles uncertainty issues, and highlights the usefulness of robust hydrological simulation models. In addition, it addresses policy implications and the challenge of implementing policies and measures that ensure optimal levels of adaptation to the projected water resources reduction.

Main conclusions include:

- Climate change is likely to increase hydrological stress, mainly in those areas already facing water scarcity.

- The identification of climate change impacts in water resources is complex, in part because of the natural variability of the water cycle and also due to the effects of water abstractions (not fully monitored).

- The progresses achieved by hydrological water models are noticeable, and have contributed to better understand and estimate expected water reductions.

- Recent assessed studies point out towards greater climate change impacts in semi-arid areas, that is, areas already facing water scarcity and over abstraction.

- Scientific outputs and results obtained from hydrological models have contributed to update water policies.

- Current water demands and their intensive water use should not be maintained. Water management should actually adapt to the identified impacts and consider future scenarios.

- Highlighted management tools to incorporate climate change predictions and adaption measures are the Climate Change National Adaptation Plan (PNACC) and the second RBMPs.

4.4 Vargas-Amelin, E., Pindado, P., 2014. The challenge of climate change in Spain: Water resources, agriculture and land. Journal of Hydrology. 518, 243–249.

This article also provides insights of climate change effects in Spain, but addresses other sectors directly linked to water resources management such as agriculture, soil and land management. It describes imbalances occurring between existing demands and water availability, as over abstraction, which is a generalised problem in water scarce areas. The article summarises the main governmental initiatives to cope with climate change impacts in the mentioned sectors, highlights the role of cross-sectoral entities, plans and measures. It also covers some political concerns such as the complexity of competences in the water field, the need to improve public participation processes, and problems arising from politicised regional interests.

The main conclusions of the article are:

- Recent climate change studies place Spain as one of the most vulnerable countries in Europe.
- Greater mitigation and adaptation efforts will be require to minimise expected impacts in water resources, agriculture and land.
- Expected impacts, such as less water availability, is likely to translate into greater conflicts among demanding sectors.
- Problems such as desertification and decreased crop yields are expected to be exacerbated by climatic variations.
- National authorities have launched several initiatives such as modernising irrigation systems, or promoting the use of non-conventional resources (e.g. wastewater reuse).
- Coordination among competent authorities is weak, as well as the integration of participative processes in decision making. The politicisation of water resources often translates into aggravated problems.
- Greater economic resources should be invested in mitigation and adaptation measures, and in cross-sectoral initiatives and administrative structures.

4.5 Vargas, E., López-Gunn, E., Huelva, G., Estrela, T., 2014. **Adopting river basin planning as a framework for climate change adaptation in Spain**, in: Dominic, S., López-Gunn, E. (Eds.), Adaptation to Climate Change Through Water Resources Management. Capacity, Equity and Sustainability. Earthscan/Routledge, p. 446.

Furthermore, within the book "Adaptation to climate change through water resources management" a specific case study in Spain is provided. The chapter highlights the high vulnerability of the country given its location in the Mediterranean region, which is considered to be a hotspot in terms of expected impacts. It provides links to energy impacts, consumption and expected increased needs, adaption planning at the national level and EU policies. However, the main focus of the chapter is the assessment of the role of river basin management plans, to determine how well they are designed to cope with climate change impacts, and to be integrated with other regional, local and national initiatives.

The chapter's main conclusions are summarised below:

- Climate change scenarios have some limitations, and downscaling techniques can be challenging and present uncertainties. However, they point out towards non-negligible effects such as lower precipitation levels, decrease o river flows and increase of drought episodes.
- Engaged public society and active social networks could facilitate spontaneous local adaptive capacity building and adaptation.
- Spain has traditionally maximised the use of water resources through infrastructure development.
- Adaptation measures at the regional and local levels have commonly run without a common thread, due to some extent to complex administrative context and levels of competence.

- Climate change aspects have been progressively incorporated in water planning processes, and are being considered to some extent in RBMPs, which measures anticipate climate change effects.

- Barriers for strengthening adaptive capacity include inadequate coordination between economic sectors and across administrations.

- Technical experiences should be transferred to society using tailored language to assist in developing adaptive capacities, and in fostering resilience towards for instance droughts and heatwaves.

- The main bridge for adaptation at the river basin scale in Spain will be the successful integration of planning measures with societal demands and capacities.

4.6 Escribano, G., Quevauviller, P., San Martín E., Vargas E., 2015. Climate change policy and water resources in the EU and Spain. A closer look into the Water Framework Directive. *(In review).*

Finally, an assessment of EU policies on climate change and water is developed, providing a parallel study on Spanish legislation and management tools. A closer look is taken for the main overarching WFD (2000/60/EC), and a gap assessment is done, which addresses, for instance, the lack of policy coherence or the effects of environmental harmful subsidies.

Main conclusions:

- Negative impacts of climate change in Spain are increasingly evident. Reduced water availability and increased costs for adaptation measures, pests, invasive species, or a decrease in the amount and crop yields will be part of the foreseeable problems.

- There are important gaps, at the policy coherence and implementation levels, which hamper adaptive efforts and resilience building. Economic instruments, prioritisation of cost-effective, 'green' measures and the appropriate use of the cyclic nature of the WFD can all play important roles towards better adaptation and resilience building.

- There is still a disconnection between management needs and research studies, and moreover, scientific results rarely reach the public with the appropriate language.
- There is a need for better participatory mechanisms within and among administrations to improve policy coherence, and also with citizens.
- A better control of water demands and abstractions, through, for instance, better metering, is essential in the shift towards demand management.
- Water authorities should use market-based instruments and apply pricing policies that truly incorporate the value of water and that address the impacts of economic activities.
- Authorities should prioritise measures that are cost-effective and climate proof, such as green infrastructures and natural water retention measures.

There are several innovative ideas throughout the presented publications and their conclusions, but two main aspects are the fact that the author indicates areas to take into account in the review process of the WFD, and gives recommendations at the national level to improve integration of climate change effects in water management and participative processes.

5 Discussion

As described in the introduction the core work of the thesis is composed of six publications, four of them already published (or accepted) in scientific journals and two published as chapter of recent books. The author has followed the initially presented methodology and established objectives. Most of the questions set have been answered, although, as expressed in section 7, additional studies would be required for instance to decrease uncertainty in determining expected impacts or to better implement existing environmental policy.

To develop presented works, the author has carried out an evaluation of various studies on the effect of climate change on water, which used or were based on climatic and hydrological models and made use of historical data series. Also, European and national adaptation policies were reviewed, a specific study was done on droughts, and policies interlinkages, gaps and administration limitations were assessed. Works have been described in chapters 3.1. through 3.6., which also provide case studies, specific examples at national and river basin scales and introduce economic assessments (impacts in different sectors, economic tools, and financial instruments at EU and national levels).

The answers to the main research questions are provided below:

5.1 Mediterranean countries: water resources, access and policy.

While countries of the Mediterranean basin share climatic characteristics, and face similar challenges, such as water stress, drought episodes and high natural variabilities and distribution of water resources, there are major differences in terms of policy, administration and access aspects. The situation of Mediterranean countries regarding water resources is therefore quite different, especially between EU and non-EU MS, and the major assessment in this area is provided in chapter 3.1.

The establishment of EU policy has allowed an important degree of harmonisation in terms of methodologies and goals for water protection, but also for public water supply. In addition, it has favoured the consolidation and empowerment of water administrations, and promoted management at the river basin scale. The situation for non-EU MS, and especially of those of the southern and eastern Mediterranean areas is quite different, being the most acute problem the access to water sanitation and potable sources. However, there have been relevant progresses in the past years, and for instance, about 86% of the population in the Maghreb-Mashreq areas had access to drinking water in 2009 (UNited Nations Development Programme, 2009). Furthermore, as nations have progressed economically, the contribution of agricultural practices to national GDPs has decreased, as well as the dependency of water for this sector.

These regional assessments are important to understand progresses achieve at the EU level and in Spain for water management and protection, as well as to existing mismanagement practices and policy gaps.

5.2 Climate change effects in water resources and EU policies

Climate change effects have, are and will affect water resources. Areas already facing water scarcity are actually pointed out as the most vulnerable ones. While EU policies pursue a common strategy and present certain flexibility to address the existing disparity between MS in terms of water resources, their fully implementation still needs to occur. The WFD, for instance, does not explicitly mention risks posed by climate change to the achievement of its environmental objectives. Several factors have influenced the degree of policy implementation, including lack of political will, limited human and economic resources, complex administrative organisation and share of competences or lack of data and technical tools.

Spain for instance, is considered one of the most vulnerable countries to climate change within the EU, due to its geographic and socio-economic characteristics. Forecasts obtained from models place it in an area where a further increase in temperature and decrease in precipitation is expected (Estrela et al., 2012; European Commission, 2009b).

These effects will be critical to adjust and adapt planning strategies, water infrastructures, and more importantly prioritise water allocation and uses for different economic sectors, while preserving dependent ecosystems.

5.3 Management tools to address climate change.

Different management tools are presented throughout chapter 3, but a more in-depth assessment is done on national strategies and sectorial climate change plans, RBMPs, DMPs and indicator systems. Within RBMPs and strategies applied at larger scales, mitigation and adaptation measures are studied, as well as the role of cross-sectoral initiatives and administrative structures.

Taking for instance the example of DMPs, they are highlighted as a useful tools to better plan for drought episodes, to shift from a traditional crisis approach, and as a type of plans that are flexible enough to adapt measures as more knowledge on climate change impacts is available. They have been proven to be suitable to anticipate to drought events and establish tailored prioritised measures.

However, considering the different examples provided, one of the predominantly obtained conclusion is the lack of integration and coordination of these tools. They are often developed by different administrations, and while they often present synergies and overlapping goals, the integration of goals and measures is usually missing. This is the case for instance on the integration of DMPs as complementary plans of RBMPs.

The existence, robustness and application of water management tools is essential to better cope with climate change variations and minimise expected impacts.

5.4 The readiness of Spain to develop sectoral adaptation plans

Spain presents a long historical tradition in hydrological planning and a high control of water management, due in part to the limited availability of this resource, especially in Mediterranean areas. The traditional management however, has focused on providing water to all existing demands, even if these were unsustainable in the long-term. The draft second river basin management plans (RBMPs), according to the WFD do not show major improvements in this sense. Proposed measures are quite similar to the first plans, and focus on satisfying current demands. In addition, the identification of gaps to achieve good ecological status, the link of water management to protected natural areas or the establishment of planning strategies to improve aquatic ecosystems in the long-term still need large improvements. Measures for better metering and controlling all abstractions have not been extended in most river basins as it could be expected, and a stronger link of environmental flows with good water status should take place (WRc plc, 2015). Therefore, while there is a large technical capability and knowledge on water resources, there are still important gaps and problems at the WFD implementation level that can directly affect the applicability of sectorial plans. That is, if RBMPs, the main tools to achieve good ecological status, still present weaknesses, the capacity at the national level to develop adaptation sectorial plans that are fully integrated in water planning is uncertain.

On the other hand, and linked to the historical tradition of water management, the existing policy in Spain is quite robust, and sectorial plans have been implemented addressing to certain extent climate change effects. Also national and regional strategies at regional and national level have been developed and agreed by several administrations. For instance, Spain was one of the first MS in adopting a National Plan on Climate Change Adaptation (PNACC) (Ministerio de Medio Ambiente, 2006) and specific water management tools such as DMPs (Water Scarcity and Droughts Expert Network, 2008).

Spain, as all MS, should make an enhanced use of the cyclical approach of the WFD, which encompasses specific steps, envisions periodic revisions, and integrates other Directives domains within its text (habitats, agricultural development) to better adapt to and manage climate change impacts. In this context, it will be important to assess the degree into which the new RBMPs, will be aligned with the PNACC and the guidelines recommended by the European

Commission (European Commission, 2009c), or as mentioned, with complementary plans such as DMPs.

5.5 EU policies adequate to pursue a common strategy, given disparities among MS

The EU environmental acquis is quite advance, ambitious in terms of protection and long-term goals, and specific directives usually have well defined strategies and tools. The WFD is a key piece of legislation that was developed taking into account drivers, pressures on water, water status, impacts (such as decreased quality) and responses (e.g. plans). That is, it can easily follow the DPSIR framework of the EEA (shown in figure 1) (Quevauviller, 2014). The directive calls for a risk assessment, to analyse existing drivers and pressures, to establish comprehensive monitoring networks to fully assess water status and impacts, and sets high environmental objectives. Moreover, the economic analysis of environmental objectives is embedded in the 6-years management cycles. The directive presents flexibility, includes periodic revisions at the end of each cycle, and allows continuous integration of scientific and technical progresses.

Thus, the implementation strategy is common and goals can be achieved by all MS regardless their specificities. However, it is true that quantitative issues are less addressed in the Directive, and that some quality objectives might be harder to achieve in areas where water is very scarce, and where variabilities can challenge management or monitoring. In this sense, the Directive was complemented by a comprehensive strategy on water scarcity and droughts, and specific studies on policy gaps, water efficiency targets, or water accounting among other (European Commission, 2015a, 2012a, 2012b, 2007). All these combined policy tools should be adequate to pursue common water protection goals and take into account climatic impacts.

5.6 Economic considerations and impacts linked to water resources

Economic considerations and impacts linked to water resources, while often reflected in EU and national legislation, have not been sufficiently tackled. Climate change is expected to have important impacts in many economic sectors, a high effect on the value of assets through, for instance changing agriculture and commodity prices, creating a greater scarcity of water, or provoking important damages to infrastructures (e.g. flood control dikes), while it could also bring market opportunities for investors (Abramskiehn et al., 2015).

The WFD urges MS to carry out an economic analysis of water use, including recovering costs of water services, determining the most cost-effective measures for water use, in addition to applying the polluter-pays principle.

The EC has recommended using market-based instruments to address water scarcity problems in addition to developing an economic assessment of water uses, determining water's value and promoting efficiency and saving measures whenever possible. Some of the instruments recommended include block tariffs, metering to determine real consumptions, pricing policies that favour savings and penalise overconsumption, allocating water funding more efficiently, improving drought risk management, applying stricter control of consumption (demand) or using water accounts (European Commission, 2015a, 2009c, 2007).

However, in Spain the way in which water is charged, varies among sectors and even among river basin authorities, and cost recovery has not yet been achieved in certain areas. Block tariffs for water consumption are not systematically applied for domestic use, and cross-subsidies are common for agricultural practices (European Environment Agency, 2013).

Future steps and works in the water field should focus on better integrating existing management tools and applying policy coherence. It will be also important to use the flexibility that management plans present to incorporate climate change aspects and economic assessments. These actions will be essential to better cope with expected climate change impacts (e.g. intense extreme events and less water availability), and to ensure a long-term water and environmental protection.

The following figure links the discussion points and recommendations made throughout the publications, and serves as introduction to the presented conclusions in the next section.

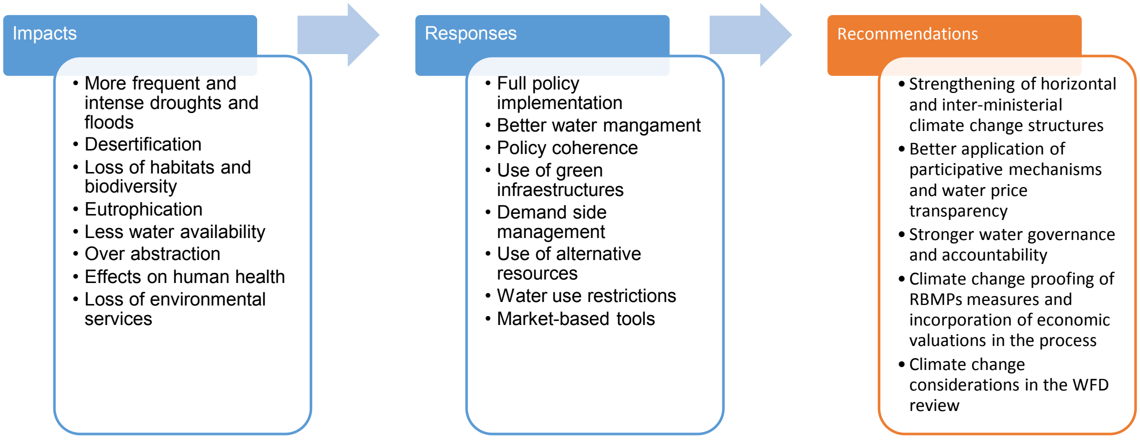

Figure 2. Impacts and responses based on the DPSIR framework, and some of the proposed recommendations. Source: own elaboration based on the causal framework developed by the EEA (extended from previous OECD Works), that links society and the environment.

6 Conclusions

6.1 Climate change effects

It can be concluded that the effect of human activities in the climate system are evident (IPCC WGII AR5, 2014). Climate change is affecting and will affect water resources in a significant way, and in turn will have socio-economic and environmental implications that cannot be underestimated. Expected impacts will definitely challenge water managers, regions, citizens and politicians, since it will not be possible to sustain demands, as they currently exist, and will exacerbate pollution problems. One of the most recent and comprehensive studies on climate change impacts in water resources in Spain (Centro de Estudios y Experimentación de Obras Públicas, 2011), predicts a generalised reduction of precipitation and water availability, which will increase through time (near -5%, -9% and -17% during the periods, 2041-2070 and 2071-2100 respectively). In addition, the greatest variability are expected to occur in Mediterranean coastal areas and in the southeast of the country. Given the importance of water for practically all socio-economic activities and to sustain ecosystems and biodiversity, economic implications will be more and more evident in the upcoming years.

6.2 Uncertainty

While predictions are useful and indicative, the degree of uncertainty in climatic models is high, especially for downscaling techniques (e.g. to determine effects at river basin scale). It will be also difficult to determine if extreme events are cause of natural variabilities in climate and water cycles, or if they are a direct result of climate change effects. Future trends in population pressures and water consumptions for the different economic sectors also present uncertainty. It is evident then, that more robust research and studies on climate change and for the predictions of expected impacts are necessary, as well as greater investments in adaptation strategies and training for water professionals. In addition, research should address management problems and technical knowledge gaps. Thus, a closer collaboration between researchers and managers would be required. Furthermore, mechanisms to link research and policy development and implementation (i.e. science-policy interfacing) are necessary if research progresses and results are to be fully used and incorporated, for instance in determining the most appropriate and resilient measures at the river basin scale.

6.3 Management shift

Regardless the existence of certain uncertainty, it would be expected that predicted climatic impacts in water should be influencing water management, alert decision makers and create greater awareness in terms of water saving, prioritisation of uses and overall thinking of how water should be better used. They should also help in building adaptive capacity and a culture of resilience, and contribute to shifting management practices from supplying any water use, to reducing demands, and to using cost-efficiency and smart solutions. The traditional use of 'grey' infrastructures such as dams should be fading, not only due to their high environmental impact, but also given the uncertainty of their future usefulness if lower river flows are expected. Predictions should also be translating into the use of smarter and greener solutions, which are often less costly and present higher resilience to climatic changes.

Some studies point out a beginning of economic grow in Spain only in 2014, after three years of acute recession (European Commission, 2015b). This economic recession has not contributed to the abovementioned expected shifts or to better prepare regions and river basins to face climate change challenges. Budgetary cuts have had an important effect in water management, and proposed measures within the updated RBMPs that would have contributed to better water protection and climate change adaptation, might not find the required economic support. Examples of these measures include proposed river restorations or the development of natural water retention measures. However, useful tools exist to help water managers in prioritising measures and projects, and determining the cost effectiveness of restoration (Scemama and Levrel, 2015).

The presented publications in this thesis, cover a time period of about four years in which the recession has influenced political priorities, managers' decisions and public perceptions towards existing problems. One of the most affected pillars could be considered EU policy implementation.

6.4 Non-conventional resources

In countries where water resources are limited, and climate change effects predict decreases in their availability (i.e. Spain), a main increase in supply might be expected from non-conventional resources, such as wastewater reuse and desalination. Spain witnessed a very high increase of both techniques in recent years, and desalination production between 2004 and 2009, placed the country as the fourth world largest producer (Ministerio de Medio Ambiente y Medio Rural y Marino, 2009).

The production of non-conventional resources usually imply new infrastructures and their maintenance, high costs of energy, and in some cases environmental impacts that should be considered. The application of these techniques should therefore be assessed case by case, in areas well suited to them, and where other alternatives might have fewer socio-economic and environmental benefits.

Water managers should also keep in mind, that increasing supplies to growing economic sectors and populations, when precipitation and river flows will progressively decrease due to climate change, will not provide any long-term solution. In fact, with these techniques major scarcity problems will remain unsolved. Efforts should centre on applying a demand side management, on refocusing the most water demanding sectors (i.e. agriculture), and on maximising efficiency and savings.

6.5 Economic tools

There have been three main areas of economic aspects considered throughout the thesis' chapters: funding opportunities, market-based instruments applied to water resources, and valuation of economic impacts generated by climate change.

Funding opportunities have been highlighted both for EU and non-EU countries, to promote regional cooperation, support research activities or finance measures and projects. Thus, they are pointed out as support tools to improve water management and address technical knowledge gaps.

Regarding market-based instruments, most of the thesis' publications address the problem of setting an appropriate and transparent water price that contributes to cost-recovery of management and sanitation practices. Unfortunately, Spain has very limited measures for cost-recovery within RBMPs, and still has a rather low price of water in comparison with other EU MS (European Environment Agency, 2013). Furthermore, the cost of water should better include environmental and resource costs associated with damage or negative impact on the aquatic environment (i.e. externalities), according to the polluter-pays principle. Thus, important steps and progresses are needed in these areas.

As remarked, climate change effects might impact economic sectors, affect food production and reallocation of water rights, or impact infrastructures such as dams or flood protection dikes. Thus, impacts will likely have a direct impact in water management measures, and more precisely in the programme of measures within RBMPs. Some of the missing steps identified in the publications and included as relevant recommendation is a better integration of climate change considerations in specific steps of the WFD cyclic implementation: gap analysis to achieve good ecological status, set-up of programme of measures, evaluation of planning cycle and status assessment (figure 1, chapter 3.6.).

6.6 EU and national policy

While the EU has one of the most advance and respected environmental legislation, which sets high standards for water protection, such as the Water WFD, its implementation, for instance in Spain, is far from being reached.

Required updates of water treatment facilities[9] has not taken place, nor an in-depth assessment of gaps to reach good ecological status in all water bodies coupled with tailored management measures. Furthermore, implementation efforts have not incorporated the appropriate interlinkages with climate adaptation. Thus, policy coherence with other sectors such as the agricultural one, is quite limited. In fact, the agricultural sector, is the most water demanding one in Spain, and provokes high pressures in terms of abstractions and diffuse pollution mainly by nitrates (Fuentes, 2011; Vargas-Amelin and Pindado, 2014). Most river basins affected by water scarcity also present intensive irrigation practices and could be even more vulnerable to climate change impacts. However, the Spanish draft RBMPs, do not provide a full picture of the link to the Nitrates Directive and the required measures to improve water protection. Over abstraction of groundwater and surface waters due to agricultural activities is an additional major risk for reaching the targets set by the WFD, but little progress has been attained in monitoring and prosecuting illegal water abstractions (European Commission, 2012b).

In Spain we are witnessing important delays in EU policy implementation and the continuity of traditional demand-driven approaches, while greater additional efforts would be needed to address the gaps to ensure ecological protection and climatic resilience. Again, budgetary restrictions in the environmental sector, and reduction of resources in river basin authorities, are hampering a shift in this trend. Political priorities have drifted apart from environmental protection, and essential tools such as modelling or water monitoring have witnessed decreasing funds. However, the economic recession cannot be blamed solely for not complying with policy's obligations. The complexity of water competences, the

[9] Updates and the well-functioning of urban waste-water treatment facilities are priorities of the Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. However, they are directly linked to the achievement of the goals set by the Water Framework Directive.

lack of accountability from administrations, or the limited coordinating efforts among different administrative scales are all part of the problem.

6.7 Water administrations

The complex Spanish network of administrations in charge of water management, protection, distribution and pricing, has contributed to some extent to the delays in policy implementation. This network is highly dispersed, competences are shared by public and private entities, and clashing political wills from local, regional, river basin and national based entities often shape water regulation. There is also a wide range of water prices for end-users, lack of transparency in prices, tariffs and subsides. These circumstances have for instance affected cost-recovery mechanisms, which are very limited for wastewater treatment and sanitation practices (European Environment Agency, 2013). While decentralisation and specialisation of competences could have had positive impacts in water management and protection, the lack of coordination among administrations and the limited combined sources of information have caused important gaps. For instance, the maze of authorities acting at different scales poses difficulties to easily access information related to water use or to its price, and has hampered the possibility of better coordinating participative processes, which would allow citizens to better engage in decision-making. When involving communities and stakeholders in water management, the degree of success in proposed solutions is more likely to increase (Stucker and Lopez-Gunn, 2015).

6.8 The role of society

Societal challenges are complex and would require further assessment, but the presented publications provide some insights on the existing problems. A deep cultural change in water exploitation perception should take place. Traditionally, in water scarce areas, the maximum possible use of water has been pursued, and water reaching the sea was perceived as wasted water. Unfortunately, this way of thinking is still quite rooted in the Spanish society. There is still a lack of basic environmental knowledge, and many water users do not fully understand ecosystems dependency on water, the necessity of respecting aquifer recharge requirements, or the need of sediments in coastal areas and deltas to provide environmental and societal services. Increasing dependency in water and practices that overexploit resources would only translate into unsustainable water use, and less resilient societies and ecosystems. Water systems that already present critical water balances and are water stressed would have little 'safety margins' to cope with unexpected extreme phenomena.

In Spain, it would be required to better transmit basic environmental needs to society as well as information on expected climatic changes. Local NGOs and Civil Society Organisations (CSOs) could play an important educational role in awareness raising, but also in promoting local actions to increase resilience and adaptive capacity. This is very rarely seen, which could be in part due to the slow and progressive on-sets of climate change impacts.

7 Scientific Contributions and Future Lines of Work

7.1 Science and policy

The publications presented provide an important assessment of policies in climate change and water resources. Some scientific contributions include the assessment of data series, expected climate impacts, or assessment of the progress of water policy and the integration of climate change considerations. The **science-policy interface** is also addressed through the publications, and important policy and implementation gaps are highlighted throughout the conclusions. Additional efforts are essential and still need reinforcement for instance in integrating policies such as agricultural development, land planning and water resources management. While **policy coherence** might be a priority for European institutions, the reality shows that the horizontality of water as a resource and the maze of competent authorities make hard its coherence even at the national levels. Thus, Spain still needs to better consider the nexus water-energy-food, or truly use the support of cross-sectoral entities or initiatives that aim at aligning water protection objectives among administrations and ministries. Additional studies and initiatives would be needed to provide useful recommendations and practical solutions for better policy coherence.

7.2 Management tools

Within chapter 3 there are comprehensive assessments of management tools, such as climate national strategies, RBMPs, DMPs, indicators, hydrological and climatic models. Data are also gathered from information systems fed by monitoring networks. Some of the highlighted findings include the lack of coherence and integration of plans (as for instance DMPs as complementary plans of RBMPs), as well as the couplement with national climate change plans and strategies (for instance, with the PNACC in Spain).

Future lines of work would include an in-depth **assessment** of management tools integrations based on the **second RBMPs** to be published by the end of 2015.

This assessment and the identification of best practices in certain MS, could be highlighted, and the transfer to other countries promoted.

On the other hand, the **fine-tuning of hydrological models** that would provide more robust results at smaller scales is needed. The necessity for this improvement is mainly linked to the scale of the measures included in RBMPs, which are often designed to address problems in a specific water body or groups of water bodies. Thus, the future use of better downscaling techniques, could provide better results for assessing climate change impacts per sector, and to better determine economic and environmental impacts, and identify required actions.

7.3 Economic considerations

As mentioned in the discussion, some recommendations have been provided on how to better incorporate climate change considerations in the WFD cycles, and how to couple them with economic analysis of measures. In the assessment of the upcoming RBMPs, also an evaluation should take place on how MS have coupled economic assessment and **climate change proofing** of management measures.

Regarding **resource cost and environmental cost**, while there are some introductory guidelines available (European Commission, 2003), additional works are needed on how to apply them and how to harmonise methodologies at the EU level.

Some insights of the use of non-conventional resources is provided in chapter 3, including advantages and disadvantages such as required energy inputs and possible environmental impacts. Additional economic studies would be required to justify and determine their efficiency case by case, considering environmental externalities.

As for economic tools and policy implementation, managers often lack figures that could help justifying proposed measures or infrastructures to back up requested investments (e.g. for environmental protection). Further assessment should done in the costs and benefits of applying water policy and better considering climate change impacts. It is estimated that the **cost of non-action** will in the long-term be much more costly to MS than applying management tools and implementing directives on time. For instance, it has been estimated that the cost to the EU of not adapting to climate change would be at least 100€ billion a year by 2020 and at least 250€ billion a year by 2050 (European Commission, 2014). These costs could be reduced if small gradual investments are applied to better implement water protection policies and for drought and flood prevention measures. In this context, studies on the **valuation of green infrastructures** and their effects would particularly helpful for water managers and administrations.

The use of **water accounts** to determine economic impacts per sector at the river basin level, should also be considered a future line of work. So far, most of the works developed on water accounts (European Commission, 2015a) lack the economic components, and thus the valuation of services provided by water, or the cost of the water degradation caused by economic activities. By using climatic estimations (e.g. reduction of precipitation inputs) and models, water accounts could determine the expected reduction of water availability per component in a river basin, which in turn would help in prioritising uses, taking into account economic and environmental factors, and water use reallocation.

Also, the more generalised use of **specific water and economic indicators**, such as the revised Water Exploitation Index (WEI+), the underground water depletion, or the Water use intensity by economic activity, could help in better determining the efficiency of water use and the level of protection among different EU MS.

Additional current studies are focusing on **valuing ecosystem services**, which would use as building blocks specific accounts (water, forest, biodiversity…). Outputs of such studies would allow to put monetary values on natural capital, increase awareness raising, help putting water as a priority in the political agendas, and overall contribute to environmental protection.

7.4 Societal challenges

Furthermore, there is need of better assessing **participative processes** and their impact in improving water management and incorporating climate change considerations. Additional studies would be required to consider and compare bottom-up approaches, their impacts and effectiveness. In addition, the role of NGOs and CSOs, could be better assessed and practical recommendations obtained. This could promote individual, local and community actions to increase knowledge on expected climate change impacts and build on adaptive capacity.

There is a maze of water administrations with competences at national, regional, local and river basin scale, while the implementation of climate change strategies often applied at national and regional level. Future studies should focus on how complementarities and administrations coordination could improve to better apply existing management tools.

8 References[10]

Abramskiehn, D., Buchner, B., Wang, D., 2015. The Landscape of Climate Exposure for Investors. The Climate Policy Initiative.

Arnell, N., 1996. Global Warming, River Flows and Water Resources. Wiley.

Arnell, N.W., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. Glob. Environ. Chang. 14, 31–52. doi:10.1016/j.gloenvcha.2003.10.006

Centro de Estudios y Experimentación de Obras Públicas, 2011. Evaluación del Impacto del cambio climático en los recursos hídricos en régimen natural. Resumen ejecutivo.

Dai, A., 2011. Drought under global warming: a review. Wiley Interdiscip. Rev. Clim. Chang. 2, 45–65. doi:10.1002/wcc.81

Estrela, T., Pérez-Martin, M.A., Vargas, E., 2012. Impacts of climate change on water resources in Spain. Hydrol. Sci. J. 57, 1154–1167. doi:10.1080/02626667.2012.702213

Estrela, T., Vargas, E., 2008. Water Issues, overview of available water resources, in: Aguas de las Cuencas Mediterráneas S.A. (Acuamed) (Ed.), La Desalación En España. Sociedad Estatal Aguas de las Cuencas Mediterráneas, Madrid, p. 324.

Estrela, T., Vargas, E., 2012. Drought Management Plans in the European Union. The Case of Spain. Water Resour. Manag. 26, 1537–1553. doi:10.1007/s11269-011-9971-2

European Commission, 2003. Guidance document nº1, Economics and the Environment. The implementation challenge of the Water Framework Directive. Produced by Working Group 2.6-WATECO.

[10] References included in this section belong to the thesis main text. Sections 3.1-3.6 include their own references embedded in each of the presented publications.

European Commission, 2007. Communication from the Commission to the European Parliament and the Council, Addressing the challenge of water scarcity and droughts in the European Union (No. COM(2007) 414 final). Brussels.

European Commission, 2009a. Natura 2000 in the Mediterranean Region. doi:10.2779/77695

European Commission, 2009b. Commission Staff Working Document, accompanying the White Paper. Adapting to climate change: Towards a European framework for action (No. SEC(2009) 387). Brussels.

European Commission, 2009c. Guidance Document No. 24. River Basin Management in a Changing Climate. European Commission, Brussels.

European Commission, 2012a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committe and the Committe of the Regions; Report on the Review of the European Water Scarcity and Droughts Policy. COM(2012) 672 final.

European Commission, 2012b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Blueprint to Safeguard Europe's Water Resources (No. COM(2012) 673 final). Brussels.

European Commission, 2013. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committe of the Regions, An EU Strategy on adaptation to climate change. COM(2013) 216 final.

European Commission, 2014. Adaptation to climate change. European Union. doi:10.2834/68959

European Commission, 2015a. Guidance Document No.34. Guidance document on the application of water balances for supporting the implementation of the WFD. Brussels.

European Commission, 2015b. European Economic Forecast Winter 2015. doi:10.2765/330642

European Court of Auditors, 2014. Integration of EU water policy objectives with the CAP: a partial success. Publications Office of the European Union, Luxembourg. doi:10.2865/15216

European Environment Agency, 1999. Technical Report No 25. Environmental indicators: typology and overview. Copenhagen.

European Environment Agency, 2013. Assessment of cost recovery through water pricing. Luxembourg. doi:10.2800/93669

Fuentes, A., 2011. Policies Towards a Sustainable Use of Water in Spain. OECD Economics Department Working Papers. doi:10.1787/18151973

IPCC, 2013. Summary for Policymakers, in: Socker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Sience Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

IPCC WGII AR5, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability; Summary for Policy Makers.

Magnan, A., Benjamin, G., Billé, R., Gemenne, F., Hllaegatte, S., 2009. The Future of the Mediterranean: From Impacts of Climate Change to Adaptation Issues. Paris.

Ministerio de Medio Ambiente, 2005. Informe Evaluación Preliminar General de los Impactos en España por Efecto del Cambio Climático.

Ministerio de Medio Ambiente, 2006. Plan Nacional de Adaptacion al Cambio Climatico; Marco para la coordinación entre administraciones públicas para las actividades de evaluación de impactos, vulnerabilidad y adaptación al cambio climático. Ministerio de Medio Ambiente.

Ministerio de Medio Ambiente y Medio Rural y Marino, 2009. Perfil Ambiental de España. Informe basado en indicadores.

Quevauviller, P., 2014. European water policy and research on water-related topics – An overview. J. Hydrol. 518, 180–185. doi:10.1016/j.jhydrol.2014.02.007

Scemama, P., Levrel, H., 2015. Using Habitat Equivalency Analysis to Assess the Cost Effectiveness of Restoration Outcomes in Four Institutional Contexts. Environ. Manage. doi:10.1007/s00267-015-0598-6

Stucker, D., Lopez-Gunn, E., 2015. Adaptation to Climate Change Through Water Resources Management. Capacity, Equity and Sustainability. Routledge, Abingdon.

UNEP/MAP-Plan Bleu, 2009. State of the Environment and Development in the Mediterranean - 2009. United Nations Environment Porgramme/Mediterranean Action Plan (UNEP/MAP)-Plan Bleu, Athens.

UNited Nations Development Programme, 2009. Arab Human Development Report 2009. Challenges to Human Security in the Arab Countries. United Nations Environment Porgramme, New York.

Vargas, E., López-Gunn, E., Huelva, G., Estrela, T., 2014. Adopting river basin planning as a framework for climate change adaptation in Spain, in: Dominic, S., López-Gunn, E. (Eds.), Adaptation to Climate Change Through Water Resources Management. Capacity, Equity and Sustainability. Earthscan/Routledge, p. 446.

Vargas-Amelin, E., Pindado, P., 2014. The challenge of climate change in Spain: Water resources, agriculture and land. J. Hydrol. 518, 243–249. doi:10.1016/j.jhydrol.2013.11.035

Water Scarcity and Droughts Expert Network, 2008. Drought Management Plan Report, including agricultural, drought indicators and climate change aspects. Luxembourg. doi:Technical Report-2008-023

WRc plc, 2015. Screening Assessment of Draft Second Cycle River Basin Management Plans. Swindon.