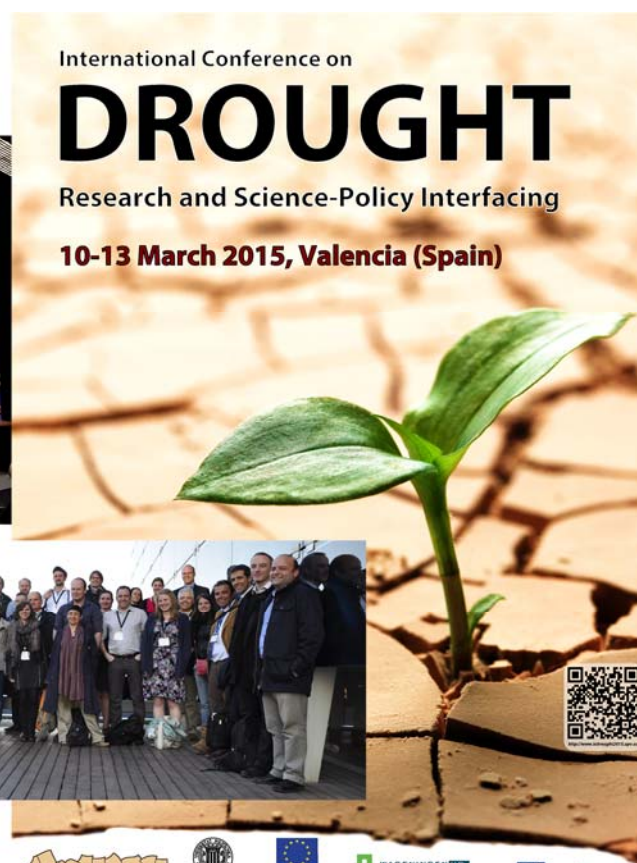




Technical Report No. 23

DROUGHT CONFERENCE



Author names: David Haro Monteagudo, Andrea Momblanch Benavent, Joaquín Andreu Álvarez, Abel Solera Solera, Javier Paredes Arquiola, Henry van Lanen

Date: 30-03-2015

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Title:	DROUGHT CONFERENCE
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Organisations:	Universidad Politecnica de Valencia (UPVLC) Wageningen University (WU)
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Deliverable	DROUGHT-R&SPI Deliverable D4.2

Photos: Pictures taken during the International Conference on DROUGHT: Research and Science-Policy Interfacing

Abstract

This document provides a brief overview of the organisational processes and outcomes of the “International Conference on DROUGHT: Research and Science-Policy Interfacing”. The conference was held from 10th through 13th March 2015 in Valencia, Spain. With a total number of 135 participants, it included 61 oral presentations and 36 posters. A total of 73 of these contributions were also compiled in a book published by CRC/Balkema. A technical visit was organized on 13th of March. It included a technical visit to several water resources management facilities (e.g. reservoir, advanced irrigated agriculture, drinking water plant, waste water treatment plant, irrigated rice fields with re-used irrigation water, downstream wetland) within the Jucar River Basin with emphasis in the role they play in drought management and mitigation, and decrease of vulnerability and increase of resilience.

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1. Introduction

The “International Conference on Drought Research and Science-Policy Interfacing” was the final event of the EC-funded project DROUGHT-R&SPI: Fostering European Drought Research and Science-Policy Interfacing. The event aimed to discuss drought related research and the advances on response policies in order to foster the development of Drought Policies and Plans to reduce risk and vulnerability, and to enhance preparedness and resiliency. Specific objectives of the conference were to:

- Introduce the results of the DROUGHT-R&SPI project
- Give the floor to contributions that deal with the three drought aspects: identification, assessment and policies
- Integrate those aspects focusing on (i) the development of drought research, and (ii) policy implementation.

The conference addressed drought identification and characterization, drought assessment (impacts) and drought policies to develop drought management plans at different scales (river basin, national and international).

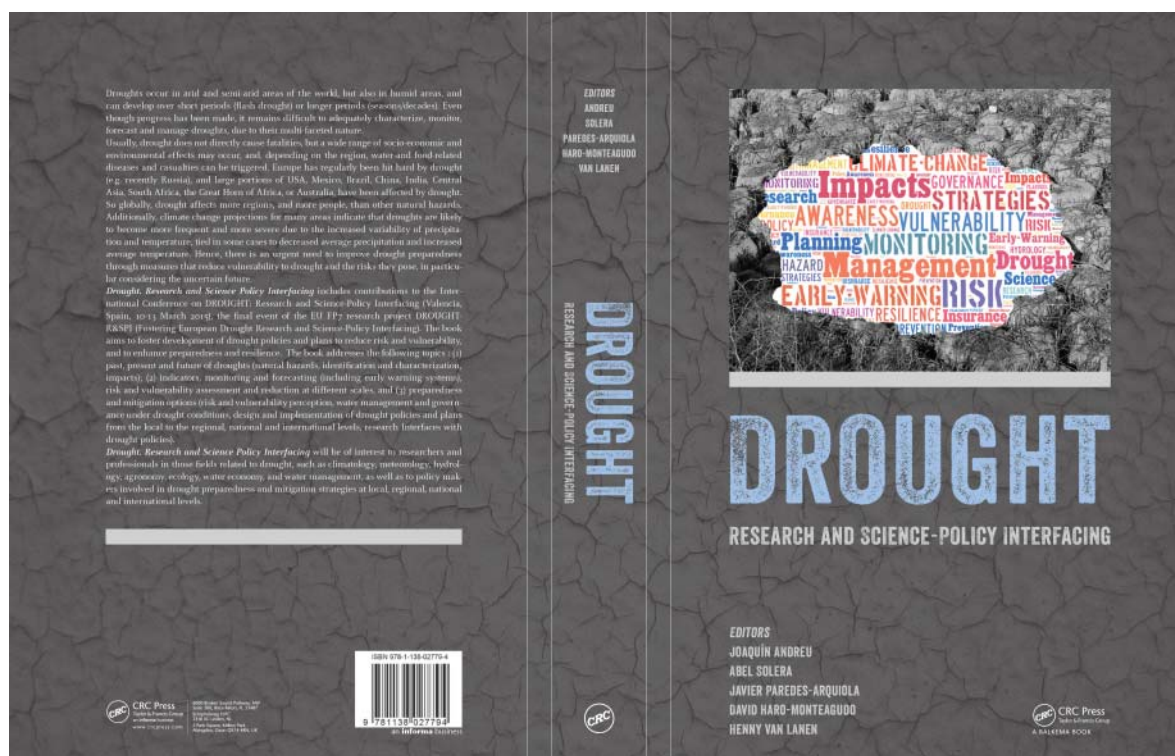
This conference served as a forum for discussion among scientists researching drought, stakeholders, water managers, experts and representatives of authorities on experiences, about the needs and challenges for drought management. Particularly, the conference addressed the topics of:

- Drought identification and characterization
- Drought indicators, monitoring and forecasting, and early warning systems
- Assessment of past and future drought impacts
- Drought risk and vulnerability perception and assessment
- Water management and governance under drought conditions
- Drought preparedness and mitigation strategies
- Development and implementation of Drought Policies and Plans from the local to the regional, national and international levels.
- Research and Science Interfaces with Drought Policies



Figure 1. Conference announcement in the DROUGHT-R&SPI website

The proceedings of the conference were collected in a book and a CD published by CRC/Balkema (Figure 2 and Figure 3). Based on the quality of the written contributions, the participants were invited to give an oral presentation or to show their work during the poster session. The index of the book can be found in annex C.



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Figure 3. Cover of the CD included with the proceedings book containing all the articles in digital format

2. Conference participants

The conference announcement was available at the DROUGHT-R&SPI project website as well as the website of the European Drought Center and of project's partners institutions (see conference flier in Annex A: Conference flyer). The event was also disseminated to several international mailing lists such as the IAHS, the Spanish Technological Water Platform, Mediterranean Network of Basin Organizations (MENBO), Network of Asian River of Basin Organizations (NARBO), and Office Internationale de l'Eau, and to the mailing lists of previous organized events and research projects, as well as to many other contacts in institutions across the world. Additionally, a website for the conference was created and hosted by Universitat Politècnica de València with updated information on the event, registration and participation process, and practical information (www.icdrought2015.upv.es).

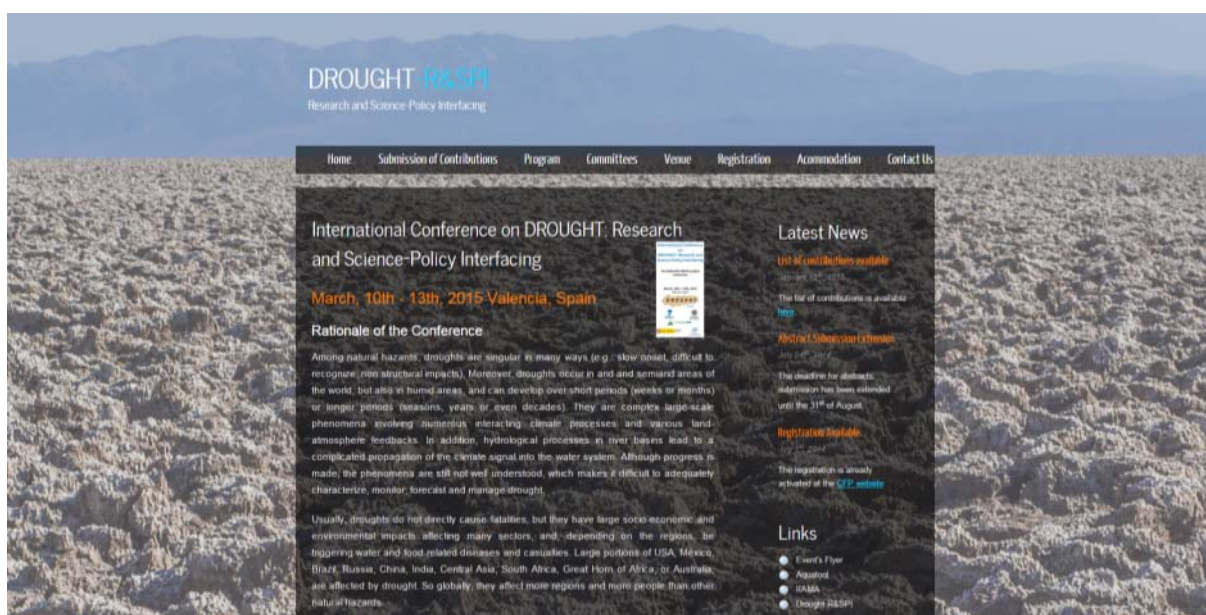


Figure 4. Home page of the conference's website hosted by Universidad Politècnica de València

Participants willing to present their work were asked to submit a 200 – 300 words abstract for its consideration by the Scientific Committee. Selected abstracts were invited to submit a 6-page article for its inclusion in the proceedings book, published by CRC/Balkema, which would be handed to all participants during the conference. The submitted articles went through a peer-review process by the scientific committee prior to their acceptance for publication in the proceedings book. Papers not passing the peer-review process were still invited to present their work in the poster session. The selection of oral presentations among the submitted and published papers was done following criteria of research quality and interest within the topics of the conference, participant's presentation preferences, and time distribution of the sessions. The papers that did not receive an invitation for an oral presentation were invited to participate as posters. Annex B: Abstracts contains the abstracts of the finally participating works.

2.1. Participants

In total, the conference had 135 participants (90 men and 45 women) from 31 different countries that covered all the 5 continents (Figure 5 and Figure 6).



Figure 5. Map of nationalities attending the International Conference on DROUGHT: Research and Science-Policy Interfacing

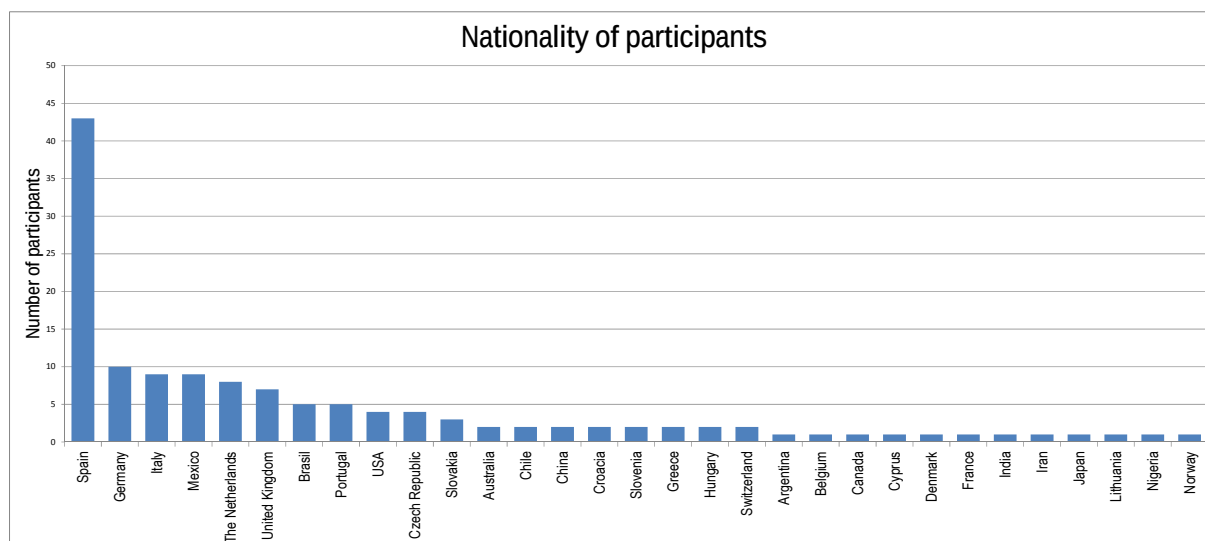


Figure 6. Number of participants by country

2.2. Organization committee

The organization of the conference laid mainly on four different institutions namely Universitat Politècnica de València, Wageningen Universiteit, Confederación Hidrográfica del Júcar, and Aguas de Valencia. The members participating from these institutions were:

- Joaquín Andreu, David Haro, Abel Solera, Javier Paredes-Arquiola and Andrea Momblanch-Benavent, from Instituto de Ingeniería del Agua y Medio Ambiente - Universitat Politècnica de València, Spain.
- Henny van Lanen and Linda Oud, from Wageningen Universiteit, Netherlands
- Javier Ferrer-Polo, Teodoro Estrela-Monreal, and Pedro Marco Segura, from Confederación Hidrográfica del Júcar, Spain
- Javier Macián Cervera, from Aguas de Valencia, Spain

2.3. Scientific Committee

The scientific committee of the conferences was formed by the principal investigators of the partner institutions of DROUGHT-R&SPI and by the members of its external advisory board. Additionally, also members of the organizing committee with a professor position were included in this committee. Table 1 collects the names and institutions of the members of the scientific committee.

Table 1. Members of the scientific committee

Name	Institution	Country
Joaquín Andreu	Universitat Politècnica de València	Spain
Dionysis Assimacopoulos	National Technical University of Athens	Greece
Lucia De Stefano	Universidad Complutense de Madrid	Spain
Teodoro Estrela –Monreal	Confederación Hidrográfica del Júcar	Spain
Javier Ferrer -Polo	Confederación Hidrográfica del Júcar	Spain
Emmanuelle Garnier	Université de Caen	France
Gregor Gregoric	Environmental Agency of Slovenia	Slovenia
Henny Van Lanen	Wageningen Universiteit	The Netherlands
Dennis Lettenmaier	University of Washington	USA
Antonio Massarutto	Università Commerciale ‘Luigi Bocconi’	Italy
Zoran Nakic	University of Zagreb	Croatia
Javier Paredes-Arquiola	Universitat Politècnica de València	Spain
Francisco Rego	Instituto Superior de Agronomia	Portugal
Mohsen Saravi	University of Tehran	Iran
Irmi Seidl	WSL	Switzerland
Sonia Seneviratne	ETH Zürich	Switzerland
Mark Svoboda	National Drought Mitigation Centre	USA
Abel Solera	Universitat Politècnica de València	Spain
Kerstin Stahl	Albert-Ludwigs-Universität Freiburg	Germany
Milada Štátná	Mendel University	Czech Republic
Lena Tallaksen	Universitetet i Oslo	Norway
Donald Wilhite	University of Nebraska Lincoln	USA
Wouter Wolters	Alterra	The Netherlands
Eric Wood	Princeton University	USA

3. Conference programme and material

The four days of the conference included (Table 2; Annex C: Conference programme):

- Sessions with a total of 61 oral presentations, of which 11 were invited presentations
- One poster session with 36 participant posters
- One closure session with summary of the conference and a final panel with the member of DROUGH-R&SPI's External Advisory Board
- An optional technical visit to several spots in the territory of the Jucar River basin key in the management of drought events

Table 2. Programme outline

	Tuesday 10th	Wednesday 11th		Thursday 12th
8:30	Registration	<u>Parallel session 5.1: Drought Indicators, Monitoring and Forecasting (1)</u>	<u>Parallel session 5.2: 4th Pan European Drought Dialogue Forum (1)</u>	<u>Session 9: World Bank Panel</u>
9:00	<u>Opening Session</u>			
9:30				
10:00				
10:30	Coffee break	Coffee break		Coffee break
11:00	<u>Session 1: Drought as a Natural Hazard and its Impacts (1)</u>	<u>Parallel session 6.1: Drought Indicators, Monitoring and Forecasting (2)</u>	<u>Parallel session 6.2: 4th Pan European Drought Dialogue Forum (2)</u>	<u>Session 10: Drought Risk and Vulnerability</u>
11:30		<u>Session 6: Drought Indicators, Monitoring and Forecasting (3)</u>		
12:00				
12:30				
13:00	Lunch	Lunch		Lunch
13:30				
14:00	<u>Session 2: Drought as a Natural Hazard and its Impacts (2)</u>	<u>Session 7: Drought Indicators, Monitoring and Forecasting (4)</u>		<u>Session 12: Drought Policies, Water Management and Governance</u>
14:30		<u>Poster Session + Coffee break</u>		
15:00				
15:30	Coffee break			Coffee break
16:00	<u>Session 3: Drought Identification and Characterization</u>	<u>Session 8: Early Warning Systems</u>		<u>Conclusions and Closing session</u>
16:30				
17:00				

On Friday 13th March, an optional technical visit was organized to several spots of the Jucar River Basin (one of the cases of study of DROUGHT-R&SPI project). The participants visited key infrastructures for water and drought management within the river basin such as the Tous reservoir, the Jucar-Turia Canal with its drought emergency pumps, the drinking water treatment plant of Manises-La Presa, the waste water reclamation plant of Pinedo and the facilities for waste water reuse in rice fields, and the Albufera wetland and its green filters experimentation facilities.

A conference bag was given to the participants with:

- A book of abstracts with the conference program
- The book of proceedings published by CRC/Balkema
- A pen drive with institutional data from Universitat Politècnica de València
- A folder with DROUGHT-R&SPI flyers
- Information material for Universitat Politècnica of València and the City of Valencia

4. Conclusive remarks

The International Conference on Drought: Research and Science-Policy Interfacing as a whole was a successful event. The amount of participants and quality of presentations provided an excellent platform for disseminating the DROUGHT-R&SPI project to a wide audience on several fields related to drought research, planning and management. The conference also represented a good final event for the DROUGHT-R&SPI project.

The book published as conference proceedings represents a good state-of-the-art of currently ongoing research on drought drivers, monitoring and early warning, mitigation and risk minimization measures assessment, and policy, management and governance of droughts

The technical visit allowed participants to see the various water and drought management facilities and practices that are applied in the Jucar River basin, and which have been mentioned in other deliverables of this project.

Annex A: Conference flyer

International Conference on DROUGHT: Research and Science-Policy Interfacing The DROUGHT-R&SPI project conference March, 10th – 13th, 2015 Valencia, Spain LAST CALL  	Rationale of the Conference Among natural hazards, droughts are singular in many ways (e.g.: slow onset, difficult to recognize, non structural impacts). Moreover, droughts occur in arid and semiarid areas of the world, but also in humid areas, and can develop over short periods (weeks or months) or longer periods (seasons, years or even decades). They are complex large-scale phenomena involving numerous interacting climate processes and various land-atmosphere feedbacks. In addition, hydrological processes in river basins lead to a complicated propagation of the climate signal into the water system. Although progress is made, the phenomena are still not well understood, which makes it difficult to adequately characterize, monitor, forecast and manage drought. Usually, droughts do not directly cause fatalities, but they have large socio-economic and environmental impacts affecting many sectors, and, depending on the regions, they can be triggering water and food related diseases and casualties. Large portions of USA, México, Brazil, Russia, China, India, Central Asia, South Africa, Great Horn of Africa, or Australia, are affected by drought. So globally, they affect more regions and more people than other natural hazards. In Europe, these multi-faceted impacts happen both in water-stressed areas of Southern EU Member States, but also in countries where water availability has never before been a major concern. Over the last 25 years, droughts covered more than 800,000 km² of EU territory (37%) and affected more than 100 million people (20%). The total cost of droughts over the past 30 years amounts to more than 100 billion Euros. As in other regions of the world, climate change projections for some areas of Europe indicate that droughts are likely to become more frequent and more severe due to the increased likelihood of warmer Northern winters and hotter Mediterranean summers, together with decreases in precipitation and increases in evaporation and transpiration. Hence, there is an urgent need to improve drought preparedness through measures that reduce vulnerability to drought and the risks they pose, in particular considering the uncertain future.	The DROUGHT conference The International Conference on Drought Research and Science-Policy Interfacing is the final event of the EC-funded project DROUGHT-R&SPI. The event aims to discuss drought related research and the advances on response policies in order to foster the development of Drought Policies and Plans to reduce risk and vulnerability, and to enhance preparedness and resiliency. Specific objectives of the conference are to: • Introduce the results of the DROUGHT-R&SPI project • Give the floor to contributions that deal with the three drought aspects: identification, assessment and policies • Integrate those aspects focusing on (i) the development of drought research, and (ii) policy implementation. Conference Topics DROUGHT-R&SPI addresses drought identification and characterization, drought assessment (impacts) and drought policies to develop drought management plans at different scales (river basin, national and international). This conference will serve as a forum for discussion among scientists working on drought, stakeholders, water managers, experts and representatives of authorities on experiences, about the needs and challenges for drought management. Particularly, the conference will address the topics of: • Drought identification and characterization • Drought indicators, monitoring and forecasting, and early warning systems • Assessment of past and future drought impacts • Drought risk and vulnerability perception and assessment • Water management and governance under drought conditions • Drought preparedness and mitigation strategies • Development and Implementation of Drought Policies and Plans from the local to the regional, national and international levels. • Research and Science Interfaces with Drought Policies
Submission of Contributions No more full papers are allowed. Nevertheless, you have the opportunity to submit an extended abstract (2 pages) before February 15th 2015 in order to participate with a poster contribution to: icdrought2015@upv.es Scientific Committee Joaquín Andreu, <i>Universitat Politècnica de València, Spain</i> Dionysios Assimacopoulos, <i>National Technical University of Athens, Greece</i> Lucía De Stefano, <i>Universidad Complutense de Madrid, Spain</i> Teodoro Estrela-Monreal, <i>Confederación Hidrográfica del Júcar</i> Javier Ferrer-Polo, <i>Confederación Hidrográfica del Júcar</i> Emmanuelle Garnier, <i>Université de Caen, France</i> Gregor Gregoric, <i>Environmental Agency of Slovenia</i> Henny van Lanen, <i>Wageningen Universiteit, The Netherlands</i> Dennis Lettenmaier, <i>University of Washington, USA</i> Antonio Massarutto, <i>Università Commerciale 'Luigi Bocconi', Italy</i> Zoran Nakic, <i>University of Zagreb, Croatia</i> Javier Paredes-Arquiola, <i>Universitat Politècnica de València, Spain</i> Francisco Rego, <i>Instituto Superior de Agronomia, Portugal</i> Mohsen Saravi, <i>University of Tehran, Iran</i> Irmid Seidl, <i>WSL, Switzerland</i> Sonia Seneviratne, <i>ETH Zürich, Switzerland</i> Mark Svoboda, <i>National Drought Mitigation Centre, Lincoln, USA</i> Abel Solera, <i>Universitat Politècnica de València, Spain</i> Kerstin Stahl, <i>Albert-Ludwigs-Universität Freiburg, Germany</i> Milada Stastna, <i>Mendel University, Czech Republic</i> Lena Tallaksen, <i>Universitetet i Oslo, Norway</i> Donald Wilhite, <i>University of Nebraska Lincoln, USA</i> Wouter Wolters, <i>Alterra, The Netherlands</i> Eric Wood, <i>Princeton University, USA</i> Registration and fees Access to registration is available at the conference website: http://www.icdrought2015.upv.es Registration fees are: • Normal: 250€ (Early bird -before Dec. 1st: 225€) • Young scientist (not older than 35 years): 200€ • Students: 150€ Fees include printed materials and book, coffee breaks and lunches of the three conference days, and the conference dinner. Additionally, there is a chance to attend a technical visit on March 13th for an extra fee of 50€ including transportation, coffee break, and lunch.	Conference program This three days conference will include an opening session, a closing session and consecutive thematic sessions which focus on these main drought issues: (1) Drought as a Natural Hazard and its Impacts; (2) Drought Identification and Characterization; (3) Drought Indicators, Monitoring and Forecasting; (4) Early Warning Systems; (5) World Bank Panel; (6) Drought Risk and Vulnerability; (7) Drought Policies, Water Management and Governance. On Wednesday 11 March, a special session will be devoted to the 4th pan-European Drought Dialogue Forum. The fourth day will be devoted to a technical visit to critical facilities for drought planning and management, and environmental spots of the Júcar and Turia basins. The detailed program is available on the website: http://www.icdrought2015.upv.es/program.html The DROUGHT-R&SPI project Drought is a natural hazard that has hit Europe hard over the last decades. Likely it will become more frequent and more severe due to the increased likelihood of warmer northern winters and hotter Mediterranean summers. There is an urgent need to improve drought preparedness through increased knowledge, drought management plans and an improved science-policy interfacing that will reduce vulnerability to future drought and the risks they pose for Europe. Drought-R&SPI strives to address this pressing need. Drought-R&SPI aims to enhance the understanding of the: (i) drought as a natural hazard, incl. climate drivers, drought processes and occurrences, (ii) environmental and socio-economic impacts, and (iii) vulnerabilities, risks and policy responses, incl. the further development of drought management plans in support of EU and other international policies, e.g. UN/ISDR-HFA. The project addresses the past and future climate, link science and science policy dialogue across scales and across a range of affected sectors.	Organizing committee Joaquín Andreu David Haro Abel Solera Javier Paredes-Arquiola Andrea Momblanch Henny van Lanen Linda Oud Javier Ferrer-Polo Teodoro Estrela-Monreal Pedro Marco Segura Javier Macián-Cervera Instituto de Ingeniería del Agua y Medio Ambiente - Universitat Politècnica de València Wageningen Universiteit Confederación Hidrográfica del Júcar Aguas de Valencia Conference Venue Ciudad Politécnica de la Innovación (buildings 8B and 8E) Universitat Politècnica de València Camino de Vera s/n 46022, Valencia, SPAIN Valencia is a livable city that combines vanguard's architecture with historic buildings, art museums, gastronomic culture, beaches, sunshine, and many other attractions and traditions. Weather in Valencia is usually good in March, with an average temperature of 19°C (66°F) during the day. Additionally, from 14th to 19th in March the most important festivity of the city, "Las Fallas de Valencia", takes place. Contact for further information Water Resources Engineering Group Institute of Water and Environmental Engineering Universitat Politècnica de València ph. +34 963 877 000 (ext.76143) – (David Haro) fax +34 963 877 618 icdrought2015@upv.es http://www.icdrought2015.upv.es

Annex B: Abstracts

Fostering Drought Research and Science-Policy Interfacing: Achievements of the DROUGHT-R&SPI project

H.A.J. Van Lanen¹, L.M. Tallaksen², D. Assimacopoulos³, K. Stahl⁴, W. Wolters⁵, J. Andreu⁶, S.I. Seneviratne⁷, L. De Stefano⁸, I. Seidl⁹, F.C. Rego¹⁰, A. Massarutto¹¹, E. Garnier¹²

1Wageningen University, the Netherlands, 2University of Oslo, Norway, 3National Technical University of Athens, Greece, 4Albert-Ludwigs Universität, Freiburg, Germany, 5Alterra, Wageningen, the Netherlands, 6Universitat Politècnica de Valencia, Spain, 7Eidgenössische Technische Hochschule Zurich, Switzerland, 8Universidad Complutense de Madrid, Spain, 9Eidgenössische Forschungsanstalt, Birmensdorf, Switzerland, 10Instituto Superior de Agronomia ISA-CEABN, Lisbon, Portugal, 11Università de Commerciale 'Luigi Bocconi', Milan, Italy, 12CNRS, UMR CNRS LIENSs, Université de La Rochelle, France

The DROUGHT-R&SPI project adopted a transdisciplinary approach that combined drought analyses for six selected Case Studies across Europe with drought analyses at the pan-European scale both for past and future climates. Achievements on drought as natural hazard, drought impacts, responses and science-policy interfacing are reported. These include the European Drought Reference (EDR) database that consolidates information about historical large-scale drought events and the first pan-European Drought Impact report Inventory (EDII) database that was populated with reports of thousands of impacts that occurred in Europe. More detailed outcome on historic and future droughts were obtained both for Europe and the six Case Studies, including both economic and environmental impacts, evaluation of past and future possible practices to cope with drought, vulnerability and drought risk. The results from the Case Studies show that there is no “one size fits all” solution for drought policy, risk reduction as well as management. This confirms the follow-up proposed in the “Blueprint to safeguard Europe’s waters”. The Case Study Dialogue Fora and the pan-European Dialogue Forum showed that drought management strategies have to be context-specific, cost-effective, and at the same time should protect ecosystem services. Successful science-policy interfaces only can develop over time, if based on specific circumstances and drought characteristics.

Characteristics and drivers of drought in Europe – a summary of the DROUGHT-R&SPI project

L.M. Tallaksen¹, J.H. Stagge¹, K. Stahl², L. Gudmundsson³, R. Orth³, S.I. Seneviratne³, A.F. Van Loon⁴, H.A.J. Van Lanen⁴

1Department of Geosciences, University of Oslo, Norway; 2Institute of Hydrology, University of Freiburg, Germany; 3Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland; 4Hydrology and quantitative Water Management Group, Wageningen University, The Netherlands

A prerequisite to mitigate the wide range of drought impacts is to establish a good understanding of the drought generating mechanisms from their initiation as a meteorological drought through to their development as soil moisture and hydrological drought. The DROUGHT-R&SPI project has contributed to increased understanding of: (i) drought as a natural hazard through analysis of historical large-scale droughts in Europe, (ii) drought-controlling mechanisms for various scales, including large-scale climate drivers and local-scale processes, (iii) the potential for drought early warning and forecasting, and (iv) suitable drought indicators. The results provide new insight into key characteristics and drivers of major historical droughts as well as projected future drought. The paper summarises the main outcomes of these studies and identifies further research needs.

European historic droughts beyond the modern instrumental records 16th-20th centuries

E. Garnier

UMR-I CNRS-LIENSs, University of La Rochelle, France

The results presented in this chapter fall within the framework of the EU project FP 7 'Fostering European Drought Research and Science-Policy Interfacing' (project number 282769). The project aims to reduce Europe's future vulnerability and risk of drought by innovative in-depth studies that combine drought investigations in case study areas in water stressed regions with drought analysis at the pan-European scale. In this perspective, it grants in particular an important role to the historical approach in helping us to understand better the frequency and severity of the droughts during the last 500 years as well as the reactions of the ancient societies.

Indeed, droughts are a factor of historic durability and because of their impacts on societies; they left multiple indicators in the archives of the last 500 years. In this presentation we will show how the combination of textual and instrumental data recorded in the archives since the 16th century can improve our knowledge of European droughts between 1500 and 1950. We will present results based on a specific method well adapted to the content of our sources. In this prospect, we study several cases in Britain, France, Jucar Basin, Upper Rhine valley and Syros in order to better understand the fluctuations of these climatic extreme events during the last 500 years and their social and economic impacts on European ancient societies.

A comprehensive drought climatology for Europe (1950 - 2013)

L. Gudmundsson, S. I. Seneviratne

Institute for Atmospheric and Climate Science, ETH Zurich, Universitaetsstrasse 16, 8092 Zurich, Switzerland

We present a newly developed drought climatology for Europe that covers the second half of the 20th century and extends to the recent decade. The drought climatology is based on comprehensive gridded observations of precipitation and temperature. These are used to derive the Standardized Precipitation Index as well as the Standardized Precipitation and Evaporation Index for the entire continent. Both indices are derived on time scales ranging from 1 to 36 months, allowing for an in-depth analysis of short term events as well as multi-year droughts. The derived drought climatology is analysed with respect to severe drought events in the past and its relation to fresh water resources. Finally emerging trends of increasing and decreasing drought hazards in southern and northern Europe are quantified and discussed.

An Assessment of Past and Projected Future Hydro-Climatic Extremes over Key Watersheds within Western Canada

B. R. Bonsal

Environment Canada, Saskatoon, SK, Canada

Since human activities and ecosystem health are dependent on adequate, reliable water supplies, hydro-climatic extremes, including the occurrence of severe droughts and excessive moisture pose a serious threat to society and the environment. Western Canada is a region with high natural hydro-climatic variability, including the periodic occurrence of drought and excessive moisture conditions, however, recent dramatic shifts between extreme drought and extreme wet conditions have suggested that this variability may be increasing. This investigation assesses the occurrence and atmospheric causes of both the past and projected future hydro-climatic variability and extremes over key watersheds within western Canada. Incorporation of the Standardized Precipitation Evapotranspiration

Index (SPEI) reveals considerable decadal-scale variability in hydro-climate over many regions of western Canada with no discernible long-term trends. In addition, an assessment of the mid-tropospheric (500 hPa) circulation patterns associated with identified hydro-climatic extremes indicate that major drought episodes were associated with significantly higher frequencies of circulation types that included distinctive ridging patterns over the Prairie region, and lower incidences of zonal and mid-tropospheric troughing patterns. Excessive moisture conditions had opposite responses. Model output from a suite of Regional Climate Models (RCMs) from the North American Regional Climate Change Assessment Program suggests a drier summer climate in the region with likely increases to inter-annual hydro-climatic variability. In addition, preliminary results indicate that those atmospheric circulation patterns associated with extreme dry and wet conditions will continue to occur in the future and in some cases, increase in frequency. Results from this analysis have increased the understanding of historical synoptic-scale controls of hydro-climatic extremes in western Canada and have provided insight into potential future changes to these extremes as driven by changes to key, synoptic-scale atmospheric circulation patterns.

Climate change and drought in the South of Carpathian basin and transboundary implications

B. Meyer¹, G. Mezösi², V. Blanka², Zs. Ladanyi²

1Universität Leipzig, Institut für Geographie, Germany; 2University of Szeged, Department of Physical Geography and Geoinformatics, Hungary

Drought and the accompanying severe natural hazards and economic damages were observed in the Carpathian Basin in the last decades. Over the next century drought periods are expected to be one of the most serious natural hazards in the region. Motivated by this, the analysis presented outlines the spatial and temporal changes of the drought hazard through the end of this century (for 2021-2050 and 2071-2100) using the REMO and ALADIN regional climate models simulation data. The vegetation response to drought years was also assessed to outline the effects of drought using remote sensed vegetation index, yield data and SPI drought index. By highlighting critical drought hazard areas and by the calculation drought indices and vegetation response, the results are useful for spatial and landscape planning or land and water management to better adapt on the increasing drought hazards affecting the land functioning e.g. in primary production, habitat qualities etc.

Ex-post evaluation of the socio-economic impacts of drought in some areas in Europe

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The objective of this paper is to analyse the socio-economic impact of past drought events making use of the theoretical approach provided by the consumer surplus theory. The paper is then focused on the main outcomes of the ex-post evaluation of the socio-economic impact of the drought events occurred in some areas in Europe (Po basin in Italy, Jucar Basin in Spain, Portugal) realized for the DROUGHT&R-SPI project. The findings refer in particular to the impacts on agriculture, the most relevant and vulnerable economic sector identified in these areas. In the first paragraph, the theoretical approach (consumer surplus theory) and the relevant literature is shortly presented. The second paragraph is dedicated to the illustration and discussion of the results of the evaluation of the socio-economic effects of drought events on agriculture in the above mentioned case study areas, starting from an extensive illustration of the results concerning the Po river basin. In the third and last paragraph some conclusive remarks, including also some reflections on policy implications, are drawn.

Analysis of Guadalquivir droughts 2004-2012 based on SEEA-W tables

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The purpose of this contribution is to study the efficacy of SEEA-W tables to analyse the evolution of water use in agriculture in the period 2004-2012 in Guadalquivir basin, including the impact of meteorological and hydrological droughts. Results show that hybrid tables can be used to estimate basin water productivity values (GVA/water consumed). The evolution of this ratio in the period 2004-2012 shows that some useful knowledge of water productivity evolution and the role of supplied irrigation water (blue) and soil water (green) can be obtained with the added value of a common methodology according SEEA guidelines allowing knowledge sharing. On the other hand, our research also found that it is difficult to determine the aggregate economic impact of meteorological and hydrological drought based upon basin SEEA Accounts.

Impact of drought on the inhabitants of the Cuvelai watershed: A qualitative exploration

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Drought is a recurring threat to the inhabitants of the Cuvelai watershed in Namibia and Angola. This is especially true for rural households whose livelihood depends on subsistence agriculture. This paper presents the results of a qualitative household survey to understand the impact of drought and identify key parameters that determine households' vulnerability. This paves the ground for a follow-up quantitative assessment. Within the survey, 26 semi-structured interviews were conducted to shed light on (i) local water use patterns, (ii) the impact of drought in rural and urban environments and (iii) coping strategies in drought situations. The results show primary impacts on households' ability to meet water and food requirements. Impacts of this kind lead to second-order effects on physical and mental health, social life and livelihood maintenance. Furthermore, several coping mechanisms could be identified on the individual-, community- and national level. Based on our results, we outline the general structure of a tool to quantify drought impact – the Household Drought Vulnerability Index.

Rainy season pattern and impacts on agriculture and water resources in Northeastern Brazil

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High variability in rainfall distribution, characteristic of the semi-arid climate in Northeastern Brazil, deeply affects its socio-economic environment. In this study we analyzed the impact of rainy season patterns and dry spells on rain-fed agriculture and water resources in the state of Ceará. Analyses of ten years of data show that the number of dry spells was higher and their duration was longer during dry years. However, rain-fed crop production was more sensitive to the total duration of dry spells along the season than the number of events. Crop losses higher than 50% were related to dry periods lasting up to 75 days. The quantity of dry spells was, in turn, negatively correlated to water inflow in the reservoirs.

As expected, inflows were higher during wet years. The results suggest that the monitoring of dry spells could subsidize planning and decision-making process in agriculture and water resources sectors.

Drought effects on rainfed agriculture using standardized indices: A case study in SE Spain

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Multiscale relationships between different drought indices have been explored in two areas dominated by herbaceous crops and vineyards in SE Spain. SPI and SPEI values were computed as meteorological drought indices, while raw values of the NDVI from MODIS-Aqua, their anomalies and standardized values at 1, 3, 6, 9 and 12-month timescales were used as agricultural drought indices. At the end of the growing season herbaceous crops showed more reliance on the accumulated rainfall inputs during the agricultural year than on the meteorological water balance, whereas vineyards were less sensitive to rainfall inputs and drought conditions. Overall, SPI was found a better predictor of agronomical indices. Highest multiscale correlations for herbaceous crops were found at short timescales (SVI1 vs SPI6), while in vineyards were found at medium timescales (SVI3 and SPI9). Results confirm that the impact of meteorological drought has a larger delay in vineyards than in herbaceous crops. Drought monitoring systems should include algorithms that are able to distinguish among plant functional types in order to anticipate adequately to the adverse effects of meteorological droughts on rainfed agriculture.

Integration of climate time series and MODIS data as an analysis tool for forest drought detection

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Drought, a phenomenon that has a strong impact on natural ecosystems, is a main topic for land management and policy making. The effects of drought on forests have received less attention than in agricultural systems as are not as well understood yet. Drought can have harmful effects on forests regarding occurrence of fire episodes or deterioration of ecosystem services. Thus, understanding spatio-temporal drought patterns is a key input in forest-related management. Monthly Standardized Precipitation Evapotranspiration Index was computed for Spain to identify climate anomalies which may become droughts. However, climate-based patterns did not entirely explain the real state of vegetation; therefore, vegetation indices derived from MODIS sensor were calculated as indicative of physiological forest parameters. An exploratory analysis was conducted based on time-series of climatic and MODIS data. Results showed the capability of the methodology to identify and characterize drought patterns on forests and its potentiality for the identification of vulnerable areas.

Using standardized precipitation and runoff indices for the identification of extraordinary drought events in Chile

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Chile has a wide variety of climates due to its geographical location, which covers over 4000 km from tropical regions in the north to the south Polar Regions. Drought of varying size and durations affecting different parts of the territory are commonly observed, including areas such as the arid Atacama Desert, the semi-arid central region, and the humid and very humid areas in the south. Despite the diversity of climates and weather conditions, the management of water resources in Chile is centralized. Thus, prior to making management decisions to cope with drought, the central water authority, must declare a drought as extraordinary. It is only after this declaration that the state can use public money to deliver aids, provide subsidies, allocate resources and implement other management tools. Recently the Standardized Precipitation Index (SPI) and the Standardized Runoff Index (SRI) were proposed as common indices to declare drought in the entire country. We studied the behavior of these indices throughout the territory for different durations (i.e., from 1 to 12 months), in order to identify the values that can be used to effectively declare extraordinary drought conditions in each region of the country. These indices were incorporated to the DGA's regulation for declaring drought in 2012, and have become common and objective tools to deal with drought in Chile.

Improving operational drought definitions – taking them to basin scale

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The occurrence of droughts and especially their recurrent character ask for comprehensive monitoring to manage drought events and to minimize negative environmental, societal, and economic impacts. Responsible drought management supports and enhances continuous improvement of monitoring and forecasting tools. One remaining obstacle for adequate drought management is the lack of a satisfying operational drought definition for decision makers. Drought indices are used as tools to define drought patterns, but they are mainly based on hydro-meteorological or satellite data, and do not reflect regional properties like perceptions, management, and demand aspects. This paper presents a discussion on existing drought definitions and explores the idea of establishing drought definitions on basin scale to improve drought management. This objective follows the idea of Integrated Water Resource Management (IWRM), which would enhance the linkage between drought and water management.

On the use of modelled soil moisture for drought assessment over Europe

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Drought can be monitored by identifying unusually dry soil conditions through land-surface schemes. The capability of the models to capture the numerous interactions among the surface budgets in the land-atmosphere interface is limited by several factors (model complexity, input data accuracy, etc.); in addition, a reliable statistical representation of soil moisture behavior is challenging due to its peculiarities (i.e. double-bounded skewed probability distribution). This paper shows an intercomparison of different models (LisFlood, CLM and TESSEL) over the same study domain, with the aim of identifying the areas where the modelled outputs are less reliable; successively, modelled timeseries

are used to detect a statistical method to quantify anomalous soil moisture statuses based on statistically robust metrics such as the mode and the median-absolute-difference. Analysis are performed over Europe, illustrating the potential of the methodology for the assessment of the main drought events observed in the last two decades.

Chronology of drought termination for long records in the Thames catchment

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Drought termination has been relatively neglected in the scientific literature, despite its importance for water resource managers and the often disruptive nature of this transitional period. There is a pressing need to systematically assess the nature of drought termination events in the historical record, and the use of long records potentially provides valuable information on the mechanisms of recovery. In this study, a novel approach for objectively defining and characterizing drought termination is applied to long records of river flow and groundwater level in the River Thames catchment. Chronologies of hydrological and groundwater drought termination are presented for 1883-2013 and 1933-2013, respectively. The chronologies show good agreement with known historical drought termination events, and examination of associated metrics allows the quantification of termination characteristics previously not possible. The parallel application to river flow and groundwater level data enables the assessment of propagation of drought termination through the hydrological cycle.

Variability and patterns of drought characteristics Based on SPEI in the Huang-Huai-Hai Plain between 1981 and 2010

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To assess the variability and pattern of drought characteristics in the Huang-Huai-Hai (HHH) Plain, the daily Standardized Precipitation Evapotranspiration Index (SPEI) data is used, Annual Total Drought Severity (ATDS), Annual Total Drought Duration (ATDD) and Annual Drought Frequency (ADF), which were calculated from 1981 to 2010 at 28 meteorological stations. We used the indices(ATDS, ATDD and ADF), Hovmöller diagrams and the reliable statistical methods of the Mann-Kendall to assess the variability and pattern of drought characteristics for the period from 1981-2010 in the HHH plain. The results suggested that severe drought events occurred in 1981, 1986, 1997 and 2002. Decreasing trends for both ATDS and ATDD were found, and the drought situation did not worsen under global warming in the past 30 years. The results of the study can provide a scientific understanding for drought.

Application of the Standardized Precipitation Index (SPI) in Hawke's Bay, New Zealand

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Drought is a relatively common occurrence in New Zealand. The weather in New Zealand is influenced by changes in large scale atmospheric circulation patterns. The most

significant of these patterns is the El Nino/Southern oscillation phenomenon (ENSO) which is typically associated with drier than average condition in Hawke's Bay. The objective of the present study is the

drought analysis Hawke's Bay. The Standardized Precipitation Index (SPI) is used in the analysis. In this study the data from 20 stations in Hawke's Bay Region, covering the period 1969-2013 and for time scales of 1, 3, 6, 8 and 12 months were used. The comparison between the calculated drought classes based on the SPI and the historical recorded droughts in the study area are found to be in a good agreement.

Assessment of runoff generation in high elevation Andean catchments to improve drought management in Central Chile

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At present Northern Central Chile is facing the longest and most severe drought period since 150 years. This has increased the awareness that there is still a strong demand for consistent long-term and short-term drought management measures and alert products to the stakeholders. These need to be based on reliable information about climate, hydrological processes and water extractions.

Export oriented irrigated agriculture is the main economic sector in the Limarí river basin which entirely relies on the mountainous hydrology and cryosphere originating in the high Andes Cordillera.

However, no hydro-meteorological information is available for the Cordillera above 1250 m of elevation. To improve the understanding of high elevation hydrology, hydrogeology and snow processes, a distributed, a semi-distributed and a conceptual hydrological model were applied to three mountainous subcatchments at an elevation ranging from 1250-6000m to establish a water balance and evaluated regarding their suitability for this complex mountainous environment. The modelling performance and calibration was validated with high elevation climate monitoring, flow measurements, geochemical and stable isotope tracer and other in situ data collected during 2012 and 2013 in two Andean headwater catchments.

Based on the results, water availability scenarios are simulated as decision support for irrigation management and other stakeholders.

Despite decreasing water availability, there is an increasing agricultural water demand of perennial crops in the region which by far exceeds water availability especially in dry periods. The Recoleta irrigation system was analyzed regarding its operational rules, irrigation efficiency and water losses. The objective of the applied research project "Increasing water use efficiency in the Limarí basin" (www.hidro-limarí.info) is to provide a web-based information system offering standardized and user-friendly information on climate, water availability and irrigation efficiency to the stakeholders. Drought-related early warning tools will be developed for decision making in water management and policy.

European experience with Science-Policy Interfacing to cope with drought

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Drought is a natural hazard that has hit Europe hard over the last decades. The DROUGHT-R&SPI project (2011-2015) advances on drought research and associated science-policy interfacing. This FP7 project works at various scales, ranging from local to the pan-EU level. In addition to the European level, the project works in six Case Studies, in Greece (local), Spain, & Italy (river basin), Portugal, Switzerland, and The Netherlands (national). In the paper, the various drought science-policy interfacing approaches are described. An overall finding is that Science-Policy interfacing at detailed scales (i.e. specific to sector, context and territory) is easier than at pan-European scale. Another important conclusion is that successful science-policy interfaces develop over time, based on their specific (socio-economic, historic and institutional) circumstances and specific drought characteristics. As well, stakeholders appreciate to be engaged in science-policy activities, they express a benefit from being involved. The functioning of the science-policy interfaces has been observed to refine and improve in the case of prolonged or successive droughts.

Drought monitoring in a transboundary river basin in North America

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Droughts can cover extensive areas with durations ranging from months to years and having devastating impacts such as massive migration, high fatality rates and forest fires, among others. Also, drought can threaten water and food security, and in transboundary regions, this can become a national security issue due to their implications for socio-economic and environmental governance. For the assessment and monitoring of drought, several methodologies have been proposed, with drought indexes being a common approach. Drought indexes can include a broad spectrum of meteorological, hydrological and vegetation observational data, and therefore, can provide insights about its intensity, duration, and spatial extent. This work tests 4 different drought severity indexes based on soil moisture and total water storage deficits across the Rio Bravo/Grande river basin, which is commonly shared between Mexico and the USA. The drought indexes are estimated using datasets of assimilated soil water storage, observed shallow soil moisture, observed variation of total water storage and a combination of them. Although the four methods are able to detect an increase in the water deficit, the indexes calculated with satellite-based data underestimate the severity and spatial extent that occurred during the exceptional 2011 drought, when compared to the North American Drought Monitor. Possible causes for this underestimation are the lack of consideration of irrigation activities, the attenuation of drought severity throughout the hydrological system and the space-time variability of drought propagation across the river basin.

A preliminary assessment of meteorological and hydrological drought indicators for application to catchments across the UK

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Standardised indicators for drought are widely used for drought monitoring and early warning, but have found only limited application in the UK. Important questions remain concerning the choice of appropriate probability distributions for their application. Here, we present a first pass appraisal of the Standardized Precipitation Index (SPI) and Standardized Flow Index (SFI) for application to UK catchments, using a diverse set of 121 near-natural catchments. In general terms, the Pearson type 3 distribution is most appropriate for precipitation and the Generalised Extreme Value distribution for flow.

We also explore relationships between SPI and SFI accumulation periods across a range of catchments, using Base Flow Index (BFI) as a surrogate for storage. Unsurprisingly, longer accumulation periods are more appropriate for high-storage catchments, but the relationship with BFI is not straightforward, suggesting more work is needed using a wider range of catchment descriptors.

An approach to monitoring drought events and food security conditions

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Early Warning Systems (EWS) for drought are currently underdeveloped compared to other hazards. In fact, the multifaceted nature of drought (i.e. hydrological, meteorological, and agricultural) necessitates a number of different ways to measure this phenomenon and its effects. In the present study an approach to identifying and monitoring drought events is presented. The EWS developed is based on the early detection and monitoring of vegetation stress on a global scale. Moreover, a simplified vulnerability model, applied to the hazard data, yields the food security conditions for the investigated area. The model includes agricultural indicators and socio-economic factors linked to people's strategy to supply the food they need. The performance of the proposed EWS is reported for a case study which confirms its potential usefulness for decision-makers and humanitarian actors operating in the context of drought and famine crisis.

Improving resilience to drought of the Apulian water resources system – a hydroeconomic model

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The paper presents a hydro-economic model of the Apulian water resources system, in southern Italy, i.e. a mathematical programming model of the allocations explicitly accounting for the different values of water and for hydrological variability at the appropriate time scale. Traditionally a water-scarce region, Apulia is now supplied by extra-regional regulated surface resources as well as by a coastal aquifer; altogether, they constitute a multipurpose system with conflicting uses: municipal, irrigation and, to a lesser extent, industrial supply. The system is at present affected by high streamflow variability and by a high level of water losses along the urban distribution networks. In the model, the variability of surface water resources is accounted for by a 30-yr. time series of seasonal streamflow into the reservoirs. The model provides the means to assess the effectiveness of different supply and demand side measures to improve the regional water balance and reduce drought impact.

Water scarcity cost as a drought indicator through hydroeconomic modelling. Application to the Jucar river basin

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The Mediterranean region is facing rapid socioeconomic and environmental changes; this together with the uncertainty about the availability of resources under climate change conditions is challenging the sustainability of many water resources systems, increasing the potential impact of droughts.

Hydroeconomic models simultaneously analyze engineering, hydrology and economic aspects of water resources management. The combination of these aspects is essential for the effective adaptation of water resources management to mitigate droughts. In this contribution, water scarcity cost is proposed as a drought indicator, showing the economic impact of droughts at the different users and at the river basin scale. The indicator allows to evaluate the efficiency of different policies for tackling droughts, including economic instruments such as water pricing policies and water markets. An econometric model is also applied to evaluate the influence of the most relevant sources on droughts impacts in the irrigated agriculture. All this is applied to the Jucar River Basin case study (Spain).

A simple method to estimate irrigation date for soil moisture modeling and agricultural drought monitoring in irrigated regions

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In this paper, we estimated irrigation date based on Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) soil moisture retrievals and meteorological data, and then simulated soil moisture through DSSAT (Decision Support System for Agrotechnology Transfer) soil water balance model and applied SMI (Soil Moisture Index) for agricultural drought monitoring during the growing season of winter wheat, 2002 -2011. Statistical crop growth stage and simulated soil moisture were used to evaluate the irrigation date estimates. The results illustrate that the main irrigation date estimates are overwintering, returning green and jointing stages, which are in accordance with local planting system and climatic characteristics. Compared with simulated soil moisture under rainfed conditions, the results that considered the irrigation date and amount have lower RMSE with observations, and the RMSEs were reducing 27.3%, 25% and 14.2% in 10, 20, 50cm depth respectively. As a whole, SMI based on simulated soil moisture have good correspondences with PDSI and SPEI in the drought levels, especially in root-zone depth, and the drought event in 2009 can be well recognized.

Integrated modelling to assess low flow risk in the coastal area of the VuGia ThuBon River Basin, Central Vietnam

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Drought periods with severe impacts on agricultural production are occurring more frequently in South East Asia. Also in the coastal area of the VuGiaThuBon river basin in Central Vietnam, seasonal irrigation water shortage and salt water intrusion in recent years has caused significant economic losses in rice production, especially during the dry season between March and September. Besides the increasingly occurring heat waves and extended periods without rainfall, hydropower development and over-extractions of water due to demographic and socioeconomic development are the main causes for drought disasters. In the Vu Gia Thu Bon River Basin with a size of 10,350 km², six large dams with more than 100 MW of installed energy generation capacity each were recently build, are under construction or planned. Adding several smaller dams, the total storage capacity of reservoirs accounts for 2,7 billion m³ and a total planned capacity of 1,3 GW. This has severe impacts on the downstream hydrology and potentially increases the risk of droughts and salt water intrusion during dry periods.

Precipitation and runoff time series before the hydropower development period from 1982 until 2012 were assessed regarding their drought severity applying the SPI and SRI.

In the scope of the LUCCi project (www.lucci-vietnam.info), the impacts of the hydrological alterations on drought risk are quantified by integrating the hydrological model J2000, the reservoir operation tool HEC ResSim and the River basin model Mike Basin and simulating the inflow to the coastal system. The salt water intrusion and flood behavior in the flat coastal area is represented by the hydrodynamic Mike 11 model to define thresholds for salinity and flood levels in the system.

Based on the demand of the key stakeholders on provincial and district level, risk scenarios for drought and salt water intrusion are developed addressing climate change driven seasonal drought periods, further hydropower development and future land uses for the years 2020, 2030 and 2050.

The results are used to recommend an improved, coordinated IWRM in the VGTB including all water related stakeholders. With the project a comprehensive toolbox for such assessment studies and Integrated River basin management with the option to address drought risk issues is established to be applied in other catchments in Vietnam or other similar settings.

Definition of optimal drought-oriented reservoir management policies combining stochastic programming and fuzzy logic

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System operating rules are vital for coping with droughts. System analysis techniques for deriving operating rules include simulation and optimization. Optimization algorithms do not usually offer optimal policies, but time series of optimal decisions, which must be transformed into management rules through statistical approaches as regression. However, their performance depends on the policy form (hedging rule, etc.), and this procedure usually involves long trial-and-error processes without guaranteeing success. The objective of this contribution is to develop a method that combines stochastic dynamic programming (SDP) and fuzzy logic to obtain optimal management rules. The SDP results are used to build a fuzzy rule-based system based on the optimal decisions. The case study of the Mijares river basin (Spain) was used to illustrate the methodology. The results show that the proposed methodology is suitable for obtaining optimal management rules against droughts.

Decision support system for drought management in a transboundary context

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There is a growing sense of urgency to build resilience towards droughts as an integral part of managing water resources among countries, basin organizations and other end users such as irrigation authorities, industries and utilities in transboundary contexts.

A generic decision support system integrating flood and drought management tools is developed in the context of this project with the objective to support planning activities at transboundary and local scale. The aim of the project is to ensure that water planning at both a basin and a local level, specifically with urban water utilities, addresses drought issues, resulting in solutions that are robust and resilient in planning and mitigating drought impacts.

The project is a global initiative funded by the Global Environmental Facility (GEF), and three pilot basins have been identified for development and testing of the methodology prior to promotion and application in other basins.

Applying the WARGI DSS to optimise water supply systems under drought conditions: Analysis of the South-Sardinia water system

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Optimising the management of water supply systems under drought conditions represents a common problem in the Mediterranean regions. Related to this topic and specifically referring to the Sardinia island (Italy), this article describes the results obtained from modelling the design choices planned for the Sulcis-Iglesiente water supply system. Using the WARGI DSS simulation module, planned infrastructures in the present and some future scenarios considering actual and middle terms configurations of water system has been considered. The WARGI simulation module belongs to the multiple-modules DSS developed by the Water Research Group at the DICAAR – University of Cagliari. WARGI allows for the simulation of the management of multi-reservoirs and multi-user systems, considering the resource priorities and preferences of users under hydrological droughts and, consequently, water scarcity conditions. The WARGI simulation allowed for the optimisation of design alternatives and the determination of the right dimensions for planned infrastructures.

Drought and water scarcity in Iran: How to cope with and prepare for it?

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This research aims to represent the problem of drought and water scarcity in Iran and different approaches for coping with and preparing for it. Iran is located in an arid and semi-arid region with 250 mm average annual precipitation (varies from 50 mm to more than 1600 mm). Due to the unfavorable distribution of rainfall and water resources and growing need for fresh water, to fulfill water demands and recover the yearly and seasonal fluctuations, it is needed for the country to prepare for drought and provide a better condition for utilization of water. Fast growing rate of the population, climate change, over-use of water resources, frequent droughts, desertification, mismanagement of water resources (supply and demand gaps), demand of more water in different sectors, decreasing of water quality and using traditional methods of irrigation, are the main reasons of water scarcity in the country. In order to prepare for drought and cope with it, some of the main directives of past and present experiences are discussed in this presentation; those are: developing national strategies and action plans, developing monitoring and early warning systems, developing temporal sequences patterns between different stages of drought, and finally developing drought mitigation strategies, which are the chains of drought preparedness strategies.

Enhancing drought monitoring and early warning by linking indicators to impacts

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Monitoring and early-warning (M&EW) systems are crucial for reducing societal vulnerability to drought. While there are a range of extant M&EW systems globally, such systems are typically based on physical (hydro-climatic) indicators, and they have rarely been linked to societal or environmental impacts. This is the starting point for the international, transdisciplinary project DrIVER (Drought Impacts and Vulnerability thresholds in monitoring and Early warning research). This paper introduces the DrIVER project and presents early research highlights including a review of current M&EW capacities and knowledge gaps on the three continents, preliminary results of indicator-to-impact analyses and an overview of the novel social learning framework being developed by the project.

Evaluation of Ensemble SPI Forecasts for Ceará, Northeastern Brazil

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Drought is a natural phenomenon that develops basically due to below average precipitation over some time period. It often impacts large areas and many sectors of the economy, especially water resources systems and food production. It is widely understood that a drought preparedness plan is a good strategy to minimize the losses due to the occurrence of a drought. One important component of such a plan is the existence of an early warning system based on monitoring and forecasts of the variables involved so decision makers can have enough time to take appropriate measures. The goal of this paper is to evaluate the quality of the probability forecasts of the Standardized Precipitation Index (SPI) for three main river basins in the State of Ceará, northeastern Brazil. Results show that SPI (3 months) with at least 2-month leadtime perform better than climatology and might provide useful information for drought management.

Drought in South-Eastern Europe: monitoring and management

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Droughts impacts are causing frequent economical damage in south-eastern Europe, especially in agriculture. In the majority of countries in the region drought management is still mainly focused on crisis management. The development of an effective drought monitoring system requires that stakeholders in the region synchronize data dissemination, methodological approaches and tools to support integrated drought management. This paper presents an overview of drought monitoring in the frame of Drought Management Center for South-Eastern Europe, reviews some methodological and technical advances of DMCSEE platform, monitoring tools, drought warnings and forecasts as well as integration of combined multiple layers for better regional drought management.

Improved rainfall-runoff modelling tools for low-flow forecasting: application to French catchments

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Hydrological droughts are a major concern for decision makers throughout Europe. This paper presents the main lessons learnt from developments carried out at Irstea (France) to build hydrological tools and fulfil the needs of decision makers for improved low-flow forecasting and management. We address the

issues of selection and comparative assessment of hydrological models, predictive uncertainties and application to reservoir management. The main challenges in developing improved tools for operational services are discussed.

Developing a framework for drought forecasting and warning: Results of the DEWFORA project

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Drought forecasting and warning is increasingly recognised as a key element in a comprehensive drought management strategy. This was clearly underlined in the Final Declaration of the High Level Meeting on National Drought Policy (HMNDP) held in Geneva in March 2013. From 2011 through 2013 a consortium of 19 partners collaborated within the context of the EU-FP7 DEWFORA project on developing a framework for drought forecasting and warning, with a focus on Africa. The framework recognises four key questions/stages in developing forecasting and warning capabilities; (i) what is the science available? (ii) what are the societal capacities? (iii) how can science be translated into policy? and (iv) how can society benefit from the forecast? This paper presents selected results developed in the DEWFORA project in the context of these four steps. Advances made in the science of drought forecasting, in particular over the four pilot catchments; the Oum-Er-Rbia basin in Morocco, the Niger basin, the Eastern Nile basin, and the Limpopo basin are presented. These show that while predictability of drought with lead time varies significantly across the African continent, skilful forecasts can be developed to provide key information on meteorological and hydrological drought. The paper will additionally discuss the approach developed to assess drought vulnerability, as well as the importance of policy and society in enabling drought warning to be implemented effectively such that it is a benefit to those that require it most.

El Niño/La Niña events as a tool for regional drought monitoring in southern South America

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The aim of this study is to identify support tools for the regional monitoring of drought conditions over Southern South America (SSA). The standardized precipitation index (SPI) was used to characterize rainfall variabilities through the 1961-2008 period. The SPI was calculated at two time scales (3 and 12 months), which represents short- and long-term droughts, respectively. Rotated principal components analysis was used to identify spatially homogeneous regions with different precipitation temporal variabilities. We obtained two different sets of seven homogeneous and climatically consistent regions for the respective two time scales (SPI3, SPI12). In order to identify the months or seasons that are prone to drought, we calculated the regional drought frequency at both time scales. This analysis showed that regional drought occurrences possess the same probability in all months of the year and seasons. Then, a continuous drought monitoring system should be performed in SSA, taking into account the different physical forcings that triggers drought conditions. Some of these forcings are the El Niño and La Niña events, one of the key factors that influence the interannual variability of precipitation over SSA. In order to identify the regional influence of these events on the SPI time series, we calculated lagged correlations between the Oceanic Niño Index, a well-known ENSO indicator, and

regional rainfall series. We found coherent and significant SPI responses to ENSO phases in most of the regions considered for the respective SPI time scales. However, there were some divergent responses in some regions, and for instance the North West region did not show any relationship with the considered ENSO index for SPI. The precipitation response to La Niña events is characterized with regional deficits, identified with negative values of the SPI during the end of La Niña year and the year after. During El Niño events the precipitation response is reversed and more intense than during La Niña ones. This signal has some regional differences over precipitation regarding its magnitude and timing, and the quantification of these features provided critical baseline information for the water resources and agricultural sectors and for its use in seasonal drought forecasts.

Seasonal Hydrologic Forecasting Under Drought Conditions in the Upper Jucar River Basin, Spain

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The seasonal hydrologic forecasting to the major reservoirs of the Jucar River Basin, Alarcón and Contreras, is developed based on the use of a hydrologic model. The Mediterranean area recurrently is under drought conditions, so a more accurate prediction of future river flows is a very useful tool for the water managers in this river basin. This methodology significantly reduces the prediction uncertainty (30-60%) from other classical models, such as the monthly AR(1) model, and obtains a more precise prediction of future river flows under drought conditions, because the stochastic model could significantly overestimate future contributions.

Seasonal forecasts of hydrological drought in the Limpopo basin: getting the most out of a bouquet of methods

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Early warning is needed to help mitigate socio-economical and environmental impacts of droughts. Seasonal streamflow forecasts have been dominated by statistical methods in the past. Recently, dynamic physically based seasonal forecasts from global climate models have become available operationally and can be used to drive detailed hydrological models. Our forecast scheme for the Limpopo combines statistical methods for longer lead times with a distributed hydrological model forced with a seasonal meteorological forecast for shorter lead times (<6 months). The statistical model is set up and tailor-made for prediction at stations of interest, it is straightforward and has little infrastructure requirements. The second approach provides a great array of hydrological information, offering flexibility to predict different indicators. It achieved higher and more stable skill scores than the statistical forecast. A combined system is feasible and supplements drought early warning systems.

Use of seasonal climate predictions in the water sector - preliminary results from the EUPORIAS project

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While droughts have been traditionally managed taking into account past observations, the use of climate models and predictions makes possible to forecast and adapt to drought more proactively. This paper describes the potential use of seasonal climate predictions in the water sector studied in the FP7 project EUPORIAS - European Provision Of Regional Impacts Assessments on Seasonal and Decadal Timescales and presents the preliminary results of the project for two applications in Spain, which are aimed at dam inflow forecast and urban water demand predictions. The results confirm the opportunities in using seasonal prediction but also identify the current limitations to use them in Spain. The methodology for incorporating forecasts in the decision making is currently being developed through collaboration between a multi-disciplinary team including water managers, meteorologists, regulators and researchers.

An impact perspective on pan-European drought sensitivity

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In the past decades, Europe experienced several severe drought events with diverse environmental and socio-economic impacts. The EU FP-7 project DROUGHT R&SPI has investigated past drought impacts across different European countries and geoclimatic regions based on different approaches: participatory techniques, the collection and analysis of reported drought impacts, and quantitative impact data. This article gives a summary of the work on impacts and shows detailed results of a comparison of stakeholder perception on drought impacts with data from the European Drought Impact report Inventory (EDII), the new database established within the project. The data largely confirm the perceived importance of impacts on agriculture, water supply, and energy production, with data on reported impacts suggesting a slightly higher relative importance of agriculture in the South and East, of public water supplies in the South and West; the importance of energy and industry impacts appears to be country-specific. The differences in relevance of the affected sectors and in type of impacts even within the same broader category support the need to determine impact-specific indicators for monitoring and management. The EDII database is now publicly available online for use and for contribution from the community, and the patterns found will have to be reassessed as it expands over time.

The U.S. Drought Monitor: Evolution and Recent Achievements

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While many things have changed over the past 15 years with the U.S. Drought Monitor (USDM) (Svoboda et al., 2002), the fundamental process of the USDM remains true today, which integrates multiple inputs, a percentile approach and expert input from experts in the field. It is obvious why there isn't, and shouldn't be, just one definition (Wilhite et al. 1985 and Lloyd-Hughes, 2013) of drought being applied today around the world, yet many think that there can be, or should be, just one drought index or indicator that addresses all types of drought. The fact is, the timing, region, intensity and duration are

different each time and thus require a uniquely flexible way of detecting and depicting drought through a diligent drought early warning system (DEWS).

We don't have the luxury of seeing a drought approaching via satellite or radar, and forecasts are still very limited in their skill horizon, so it behooves us all to establish and utilize an early warning system that can diligently watch and wait for drought to emerge. Although drought indices and indicators have been around for nearly a century, we have only recently begun to use new technology and integrated approaches as a means of helping us address a hazard as complex as drought. When combined, these new tools and approaches have helped us advance our drought monitoring and early warning system capacities around the world. In turn, many of these tools and derivative products have been integrated into the USDM process leading to a more accurate and precise product over the years. This paper will outline the process, key milestones and recent progress, applications and achievements of the USDM.

Institutionalizing proactive drought management approaches in Brazil

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Northeast Brazil has been engulfed in an extreme multi-year drought since 2012; a drought that has been the most severe in decades. Other areas like the metropolitan São Paulo region have also been fighting the impacts of recent record droughts, leaving many in the country searching for answers to how Brazil can be better prepared in the future for these events. There is renewed interest and leadership within Brazil to reform drought management and planning beyond the traditional crisis management mode. These efforts, supported by a cross-sectoral World Bank program, are being led by several federal and state institutions, particularly the Ministry of National Integration (MI), and aim to foster a paradigm shift toward more proactive drought policy and management across Brazil.

The program is divided into two tracks: (i) support for a national/regional and state policy framework and dialogue to move toward a drought policies that are based on drought preparedness; and (ii) a Northeast regional pilot program to demonstrate tangible tools and strategies for proactive drought management through the design and development of both a Northeast Drought Monitor network and early warning information system and operational drought preparedness plans across five selected case studies. The work has at its premise that institutionalizing drought preparedness will lay the building blocks for climate change resilience, particularly through the application of the “three pillars framework”: monitoring and early warning/forecasting; vulnerability/risk and impacts assessment; and mitigation and response planning and measures.

This presentation will discuss the current status of the program and illustrate how the World Bank is supporting Brazil in institutionalizing proactive drought management approaches.

World Bank programs and decision support tools on climate change and drought adaptation and resilience

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In recent years, the World Bank has ramped-up its commitment to helping developing countries build resilience to climate change. This includes the publication of a series of reports on anticipated climate impacts and vulnerabilities around the world and their implications for development (i.e., the World Development Report on Climate Change in 2010, and the three “Turn Down the Heat” reports 2012-2014), the development and implementation adaptation projects through the Pilot Program for Climate

Resilience, and most recently, the institution's commitment to screen all International Development Agency projects for climate risk.

This presentation will describe the current suite of World Bank programs and decision support tools on climate adaptation and resilience, and the strategy that supports them, to help developing countries prepare for and respond to climate change. There will be a particular focus on drought resilience throughout the presentation.

Exploring situations of vulnerability to drought from a sectorial perspective: a starting point for regional assessments

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Droughts produce a complex web of impacts in many socioeconomic sectors. In recent years, there has been a spike of activity in the assessment of vulnerability to drought, motivated by an increased awareness of the importance of risk mitigation and drought management. At a pan-European level, vulnerability to drought comprises many elements and unfolds in different ways depending on sectors. At that scale, however, a too broad definition of the assessment could hamper the production of results useful to decision makers, who need to understand where and why action is needed. In this paper, we use vulnerability situations to delimit the scope of the regional assessment. The starting point for the selection and analysis of vulnerability situations is found in the historic drought impacts identified in the European Drought Impacts Report Inventory (EDII). Past impacts help to identify a) for which systems vulnerability needs to be assessed and b) to what specific perturbation are they vulnerable. To illustrate the approach, the vulnerability to drought of the industrial sector is considered.

The dynamics of vulnerability to drought from an impact perspective

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Understanding vulnerability is a key to analyse and understand region- and sector-specific risk to drought. Even though vulnerability is understood to be a dynamic process, present approaches derive vulnerability indices at a particular time without accounting for potential changes after drought events or in consequence of legislative changes. To quantify characteristics of vulnerability over time, data on reported drought impacts were used as a proxy. For regions with data on selected drought events, an ex-ante-and ex-post drought analysis was carried out. Results show changes in spatial and temporal impact occurrence-patterns confirming the dynamic character of vulnerability to drought. This study improves the understanding of vulnerability as a dynamic component in drought risk research for the example of three European countries spanning different geoclimatic regions. It highlights the need for monitoring relevant drivers and processes beyond standard static analyses and offers suggestions for improved vulnerability monitoring. Furthermore it demonstrates the potential of centralized multithematic databases.

Drought vulnerability assessment and potential adaptation options in the Aegean islands

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Drought events of increasing frequency, duration and intensity are expected to seriously affect the Mediterranean region in the following decades, and particularly its arid insular areas. In the Greek islands of the Aegean Archipelago, which are highly vulnerable to drought due to their specific natural, physical, and socio-economic conditions, significant water deficits are expected, which are likely to cause severe impacts on local economy and society. This paper aims to assess the drought vulnerability of the Aegean islands and to identify the potential contribution of supply enhancement options in vulnerability reduction. The proposed methodology is applied in the islands of Syros, Milos and Naxos, which were selected for their diverse water systems, combined with high population and tourism development. Proxy indicators were used to identify the underlying drought vulnerability factors, while an overall vulnerability index was estimated, to assess the anticipated contribution of water reuse options to drought vulnerability reduction.

Vulnerability to drought: mapping underlying factors across Europe

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The assessment of vulnerability plays a key role in the design of drought mitigation strategies. This study maps several factors that contribute to increase or decrease vulnerability to drought at a pan-European level. The mapping exercise started from the selection of vulnerability factors through the analysis of specific situations of vulnerability in different economic sectors. The resulting factors were further supported and framed through an extensive review of vulnerability studies. Then they were described using specific variables and, finally, they were combined to characterize sensitivity and adaptive capacity at the NUTS-2 scale. The results of the study allow the identification of 'hotspots' for these vulnerability components and, at the same time, provide an insight into the root causes of vulnerability, hence helping to guide decision-making processes for the mitigation of drought impacts at a pan-European level.

Drought and agricultural insurance in Spain

J.C. Cuevas García

Agrupación Española de Entidades Aseguradoras de los Seguros Agrarios Combinados S.A.. Agroseguro. Madrid, Spain.

Numerous documents that date back to 2,300 B.C. tell the incidence of "terrible drought" in the Iberian Peninsula, with a multitude of consequences. Being the entity responsible for the management of the private insurance business in the field of agricultural insurance, Agroseguro has considered that the best contribution to the study of drought in Spain and its effects on agricultural activity consists of bringing our experience. This experience is based on the results to ensure a wide range of crops, against the risk of drought, throughout the Spanish territory since 1983 in which this warranty is introduced into our insurance system. In more recent times, when it has been able to have the information necessary and adequate technical knowledge, new products have been developed to give a new level of protection. The insurance industry is ready to tackle the task and commit as it has done since 1983.

Water markets in Spain: a tool for drought mitigation

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Over the past decades, water markets have been suggested as a policy instrument to provide water sustainability and efficiency, also becoming an effective and relevant mechanism in addressing water-shortage problems in some arid and semi-arid regions of Australia, California and Chile. In Spain, Law 46/1999 incorporated formal water markets into the Spanish legal and regulatory framework in 1999, allowing spot water markets and the creation of water banks. Despite the low number of water transfers and users participating in water markets, the volume of water traded in each transfer was significant. In fact, in some river basins the water trading activity recorded added up to 5.0% of their water use during droughts. This paper shows the potential barriers that have affected water market performance in Spain as well as some guidelines to how to overcome those obstacles.

Criteria to assess urban water supply systems resilience to droughts and scarcity

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Scarcity and drought episodes represent situations of stress that affect water supply systems. Those episodes constitute a risk for water service provision very much link to system characteristics and preventive and reactive management policies. Droughts have immediate impacts, too, on some other water uses, environment, society and economy.

Climate change is increasing the risk of droughts in many zones of the planet and rise many voices claiming for resilience improvement. It seems that resilience is a significant attribute of a system and in consequence It is important to set a common method to assess resilience of any system and to be able to quantify improvements of different options. But it is not an easy task.

The first problem to resolve is that there are several approaches to resilience concept. The most frequently used is the capacity of a system to absorb stresses and respond to perturbation. To quantify this capacity a variable like lasting perturbation time, could be appropriate.

Next problem is to decide what perturbation should be considered, natural surface hydraulic conditions, full urban water demands supplied, average water stored in reservoirs, natural groundwater storage, full watershed water demand supplied or average economic balance of management entities.

There is an additional problem, specific of drought episodes. For some water uses, shortages and limitations are an operational decision relay on local policies or decision making.

Resilience will depend on the characteristics of the system and the kind of likely threat episodes and additionally it will depend on operational policies (preventive and reactive) jointly with the adaptive capabilities of society and water users.

Plans to prevent and mitigate drought impacts on water supply systems must take into account this characteristic of the system. Resilience with respect to the severity of drought episodes may be an attribute of the water supply itself, but can also be conditioned by the company's strategy, investments, demand management policies, etc.

In order to assess the resilience of a system is a need to know its reliable effective and affordable management policies and fix criteria to its calculus. To set reliable management (preventive and reactive) policies is necessary to build them on the basis of an empiric and updated information of water demands and their potential of reduction on a current immediate time interval.

Evaluation of when and how will the global system recover from a drought event in aspects such as quality of service, water demand, quantity and quality of surface and ground sources

of water, and ecosystem in general is not a trivial task. Some of these aspects may be in some way inelastic, which means that they may not fully recover to its original state.

The final assessment will need to differentiate, service, reserves, environment and economy and make and updated evaluation.

Securing drinking water supply during extreme drought – learnings from South Australia

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The Murray-Darling Basin, Australia's largest river system, experienced the most significant drought ever recorded from 2001 to 2010 – the Millennium Drought. With record low flows and storage volumes, authorities struggled to meet the demands of irrigators, drinking water supplies and aquatic ecosystems, especially in the system's lower reaches in South Australia.

The South Australian Water Corporation (SA Water) provides water to the 1.5 million population of South Australia, often claimed to be the driest state in the driest inhabited continent on Earth. Historically, during low flows and drought in its local surface water catchments, SA Water has relied on the River Murray as the major water source, for up to 90% of its raw water. When inflows to South Australia's reservoirs decreased by 40 % in the late-2000s however, River Murray flows also diminished and water levels in the end-of-system Lower Lakes fell to below sea level. This resulted in slow salinization of these freshwater lakes and the River Murray immediately upstream, wetlands drying, and the exposed shorelines of wetlands and lakes oxidizing and acidifying.

This paper describes how SA Water informed Government policy decisions using its 3D hydrodynamic, salinity and acidification modelling for near real-time water quality risk assessments, identification of targeted interventions and development of contingency plans to balance environmental, cultural and water security values. A suite of actions was implemented to meet water demand and ensure water quality as presented herein. These actions included: water restrictions, building 'emergency' water supply pipelines, lowering water offtakes in the river, fast-tracking the construction of a desalination plant, increasing water treatment for river water and expediting recycled (waste) water usage for non-potable supplies. The post drought 2010 flood challenge of managing flushing flows through dried and acidified wetlands with the potential to produce high organic material loads through return flow 'blackwater events' is also illustrated.

SA Water's experiences from the Millennium Drought have led to adoption of future planning concepts that embrace resilience through a diversified water source 'portfolio' including: surface water; groundwater; storm- and waste water recycling options via aquifer storage and recovery; as well as the supply from a desalination plant as the ultimate, but still costly, drought insurance.

The Australian experience in managing through protracted drought

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Australian climate is characterized by extremes including longer and more severe droughts than is experienced on other continents. Most recently, the Australian Murray-Darling Basin experienced the most severe drought on climate record, now known as the "Millennium Drought" (1997-2009). While

damage costs experienced by agriculture, the environment and municipal industrial water consumers ran into the billions, absent significant water policy reforms that occurred prior to the drought, costs would have been much higher. This chapter provides an overview of meteorological and hydrological drought dimension, and reviews post drought damage cost estimates. The characteristics of innovative policy that was in place to reduce impacts, especially provisions allowing for market water transfers, are reviewed and estimates of how these policies reduced drought damage costs are discussed. The chapter concludes with discussion of key lessons from the Millennium Drought experience relevant to future drought preparedness policy applicable in Australia, Europe and beyond.

Implementing the National Drought Policy in Mexico: challenges and strategies for a sound water resources management

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Since 2013, the Government of Mexico began the implementation of the National Drought Policy, changing the paradigm for drought management. Its main objective is reducing vulnerability through the implementation of actions planned under a preventive, holistic and participatory approach. Its fundamental elements are drought monitoring and alert on a fortnightly basis, the formulation and implementation of a Preventive and Mitigation Measures Programme for Drought for each Basin Council, a research program, a training program, the creation of technical and operative staff to coordinate drought response, a communication strategy and securing water supply to impacted populations. The creation of a Commission for the attention of droughts and floods gives the institutional and budgetary viability to the implementation of the policy. The shift to a proactive drought management is difficult and requires time to consolidate, however, given the historical background of Mexico and the effects of climate change, it is indispensable.

From drought planning to drought management: administrative and follow-up tasks

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The implementation of the Special Plan of Alert and Possible Drought of the Júcar River Basin Authority, approved in 2007, has detected the beginning of a new drought episode in the spring of 2014. This article describes the current situation and compares it with the previous historical drought that occurred in 2005-2008. The measures adopted and foreseen to minimise the effects of the current scarcity are detailed.

Towards policy recommendations for future drought risk reduction

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The paper presents a research framework for supporting drought management on the basis of drought risk identification, assessment and management. While risk identification involves the analysis of past and future drought on the basis of climate projections, the assessment of risk follows a probabilistic approach and refers to the assessment of potential drought impacts. Finally, risk management concerns the selection and evaluation of measures for minimizing risk to an acceptable level. The analysis is performed in six Case Studies (The Netherlands; Portugal; Switzerland; Po River Basin, Italy; Jucar River Basin, Spain; and Syros Island, Greece), representing a wide range of climate and socio-economic conditions. All these activities are supported by stakeholder input through the organisation of theme-specific workshops. As the Case Studies are spread over Europe, the results show that risk reduction cannot follow a “one size fits all” approach, as it was pointed out also by the EC “Blueprint”.

Modelling of last hypothesis of climate change impacts on water resources in Sierra de las Cabras aquifer (Southern Spain)

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Having models that reflect the reality of a system operation becomes critical to the effective management of water resources in a watershed, especially considering the different scenes of climate change predicted for the Mediterranean regions by the Intergovernmental Panel on Climate Change (IPCC). The fifth Assessment Report of IPCC (AR5) estimates an increase in average temperatures and a precipitation decrease between 10 and 20% for Mediterranean region which could generate drought events in the study area. The present research tries to determinate the potential impacts that climate change may have on water resources. The Sacramento model has been used to model the water resources of an inertial aquifer, Sierra de las Cabras. In turn, IPCC forecasts of climate change for the study area (Mediterranean region) have been simulated taking into account the degree assessing of affection to the water resources opposite to eventual episodes of drought, and the social and environmental implications that will result have been also determined.

Multi-scalar drought and its impact on crop yield in the Republic of Moldova

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This study aims at assessing the crop sensitivity to drought at various time-scales during the growing season in the Republic of Moldova. The Standardized Precipitation Evapotranspiration Index (SPEI) was used as a measure to quantify the moisture conditions at 1 to 12-month lags for 4 representative meteorological stations, during the period 1951-2012. The annual series of crop yield of winter wheat, maize, sugar beet, and sunflower at national level as reported by the National Bureau of Statistics of the Republic of Moldova during the period 1962-2012 were used to assess the crop sensitivity to drought at various lags for each month of the growing season. The national yield series were compared with the high-quality crop yield experimental data on typical chernozem in the Balti steppe of Moldova, for the period 1962-2012.

Climate Change and the Increase of Wildfire Risk in the Upper Jucar River Basin, Spain

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The Mediterranean area is one of the most vulnerable areas to the climate change. The IPCC's fifth report (AR5) predicts an increase in temperature and a reduction in precipitation to the Southern Europe. Results from two Global Climate Models (HadGEM2-ES and MPI-ESM-MR) and four Representative Concentration Pathways (RCP: 2.6, 4.5, 6.0 and 8.5) scenarios are used to assess the increase on wildfire risk in the Upper Júcar River Basin, Spain. Two indexes are applied: the Fire Weather Index (FWI) and the Keetch-Byram Drought Index (KBDI). FWI is better correlated than KBDI to the number of wildfires registered during the period 1972-2012. The wildfire risk will increase: from high to very high in August (in the short-term) and July and August are always under very high risk of wildfire at the end of the century. The potential number of wildfires per season could increase from 40% (short-term) to 80-100% (long-term).

Comparing low moisture availability and relative crop yields on the pan-European scale using the FAO water production function

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This paper presents an approach for assessing low soil moisture availability and crop yields on the pan-European scale. It builds on the FAO water production function, linking evapotranspiration reduction simulated with a set of large-scale hydrological models to observed crop yields. Evapotranspiration data of almost 7000 grid cells (0.5°x0.5°) covering Europe were transformed to 94 NUTS-1 regions to enable comparison with crop yield data and to account for cropland distribution. The multi-model ensemble median evapotranspiration reduction was calculated to accommodate differences between large-scale models. Obviously, Southern and Southeastern Europe showed higher reductions. The evapotranspiration reduction was connected to the relative crop yield (ratio of observed crop yield and simulated potential yield) for six major crops. More significant relationships occurred, for instance, for wheat, maize and potatoes than for rye. No significant relationships occurred in a substantial number of NUTS-1 regions in eastern and northern Europe. Maps show distinct geographical clustering in the strength of the links across Europe in other regions. The R² of the regression equals 0.76 averaged over all crops, regions and models.

Impact of meteorological drought on crop yield on Pan-European scale, 1979 - 2009

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This study investigates the relationship between crop yield anomalies of five major crops and meteorological indices on the pan-European scale. The crop yield data were obtained from Eurostat for the EU administrative Regions (NUTS). The meteorological indices (Standardized Precipitation Index, SPI, and Standardized Precipitation and Evaporation Index, SPEI) were derived from the WATCH Forcing Data for the administrative regions. Linear regression and the moving average were applied to de-trend the crop yield data. Pearson correlation analyses were carried out to explore the relationship

between crop yield anomalies and SPI and SPEI. This study built upon an investigation on the relationship between crop yield losses and drought in Portugal.

Temperature Extremes, Moisture Deficiency and Their Impacts on Dryland Agriculture in Gujarat, India

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In arid regions, water scarcity poses a serious threat to dry land agriculture. High evapo-transpiration and limited water holding capacity of the soil hampers crop production. Falling under dryland agricultural region, India's Gujarat state often experiences moisture deficiency in soil and plants. The present study analyses the adverse effects of heat waves and temperature extremes on agricultural droughts in Gujarat. Data of maximum, minimum and mean temperatures, rainfall, potential evapo-transpiration and heat waves during 2001-2010 were analysed for 8 stations on seasonal and annual time scales, and correlated with crop cycles. The results showed that most parts of Gujarat suffer from frequent droughts, either due to low rainfall or high evapo-transpiration, or both. The study also revealed that moisture deficit was acute, particularly in the years of heat wave. Heat wave events were also found responsible for moisture-stress and thermal-stress in vegetation, leading to reduced crop yield and agricultural drought.

Analysis of drought episode in Borno State of North-Eastern Nigeria

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Drought is one of the most important environmental and socio-economic problems affecting northern states of Nigeria. Borno state in the northeastern part is prone to various climatic anomalies such as floods, storms, droughts and desertification. It is one of the 15 states in northern Nigeria that were prone to periodic meteorological/agricultural droughts. As precipitation decreases in the state, temperature increases and consequences of climatic drama include famine, increased heat waves which increases disease vectors, communicable diseases and epidemics; loss of forest vegetation which promotes soil degradation and desertification; increased evaporation that dries up streams and rivers. The state is one of the most threatened land areas of northern Nigeria. It suffered 15 years of drought incidence from 1960 to 1999. Between 1970 and 2000, the state was affected by late onset and early cessation of rainfall relative to the period 1941 to 1970 with present experience of warmer conditions compared to the period of thirty years ago. The study employed holistic use of 30 years (1981-2010) rainfall and temperature data acquired from Nigerian Meteorological Agency, Lagos captured at Maiduguri synoptic station. Based on the variability in the climate of the area using precipitation and temperature analysis, many years of severe and moderate drought episodes were detected. Ultimately, possible suggestions were made in the study to curb the negative impacts of the phenomenon in the area.

Did the windfall in November 2004 cause any runoff and drought occurrence changes in the Slovak part of the Tatry Mountains?

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An extraordinary windfall occurred on November 19, 2004 in the central and eastern part of the Tatry Mts., Slovakia. About 12 600 ha of woods were almost completely damaged in the southern and south-eastern part of the Vysoké and Belianske Tatry Mts. The deforested belt was app. 50 km long. Two people died, the economic losses reached almost 300 millions of EUR. Changes in runoff conditions and drought periods occurrence were studied using discharge time series at 13 discharge gauging profiles in both - affected (six) and unaffected (seven) catchments located in the Slovak part of the Tatry Mts. All the time series were longer than 30 years, most of them longer than 40 years. The last year included into the evaluation was the hydrological year 2012. The double-mass curve was used for time series inhomogeneity identification. The data were statistically processed, time series analysis was accomplished looking for seasonal and trend compounds. Discharge and base flow values (estimated by the local minimum method) were re-calculated into specific runoff and base flow in order to compare the catchments. Time series were divided into two parts and processed separately for the pre-windfall and post-windfall periods. Surface and groundwater drought occurrence was analyzed using the Threshold Level and the Sequent Peak Algorithm methods in all catchments for both periods. Research results for catchments affected and unaffected by the windfall were analysed and compared.

How drought affecting the rural economy of India? Empirical findings highlighting severity of drought impacts in Maharashtra State

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About 40% of the Indian State of Maharashtra falls under Drought Prone Area (DPA) with annual average rainfall less than 750mm. Agriculture and allied activities are the major income source of 80% of rural population. Recurring drought is one of the major challenges faced by farming community in the state, which needs prior attention and consideration. Thus, the main objective of this study is to evaluate the impacts of drought on domestic water supply, agricultural production, unskilled laborers and financial status of the farmers. The Bhima catchment in Maharashtra State is selected for this study. The study is based on both primary and secondary data collected by interviewing 223 rural farming households following a structured questionnaire survey.

Out of total 36 sub-districts in the catchment, 14, 15 and 7 sub-districts suffered severe, moderate and normal drought respectively in 2012. It resulted in devastating impacts on rural livelihoods. Majority of respondents managed to get domestic water to fulfill their demand, however, the access to water supply was cumbersome and time spent for water collection during drought year almost doubled that of normal year. As a consequence of drought, farmer's economic activities are threatened the most. On an average, a respondent household suffered loss of 86.3% in production of major crops. Further details reveal 85.8, 81.2, 84.8, 95.7, 84.6, 92.9, 98.5 and 90.3% loss in Bajara, Jowar, Wheat, Maize, Gram, Onion, Cotton and Sugarcane production respectively. High reduction in unskilled employment opportunity at own farm reported during drought year. However increase in percent of unskilled labor engaged in rural employment was observed. It is found that, about 69.6% of farmers have agricultural loans and 61.2% delayed repayment due to drought. This study shows that how a drought of moderate intensity threatened food security and had severe impacts on a rural agrarian economy.

Evaluation of drought occurrence in springs yields of the Nízke Tatry Mts.

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Regime and drought occurrence of spring yields were analysed in the paper. Six springs of Nízke Tatry Mts. and two precipitation gauging stations were evaluated. Spring yields were analysed by basic statistical methods, namely by: basic statistical characterization, evaluation of trend, seasonality and long-term - periodicity as the time components of the yields regime. Mutual relations were assessed by Spearman's rank correlation and cluster analysis. Additionally, drought analysis by threshold level method and sequent peak algorithm using HydroOffice 10 program was applied. Trends had a decreasing character in the Jarabá and Jasenie springs. Increasing trend was observed in Vyšná Boca, Liptovský Ján and both springs of Partizánska Ľupča. Maxima of spring yields were recorded in April and May and minima in February. Drought occurrence in spring yields was strongly influenced by meteorological drought.

Identification and frequency analysis of drought events in the Blanice river catchment (Czech Republic)

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This paper presents the results of a case study focused on identifying drought events. The catchment of the river Blanice was selected as the study area. The total area of this catchment is 534 km². The study investigated meteorological droughts, hydrological droughts and their coincidence. Data from two meteorological stations and three discharge gauging stations were used for the analysis. The data has a daily time step, and the length of the series varies up to 50 years. Simple procedures were applied, consisting in an analysis of drought duration, defined by threshold values, as preliminary work for further research. The results show that there is no major coincidence between the longest of hydrological drought events and the longest meteorological drought events in the study catchment. However, a coincidence was identified between hydrologic drought events of longest duration at each of the two stations.

Climate Change Impact on Water Resources and Droughts of AR5 scenarios in the Jucar River, Spain

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The Climate Change scenarios indicate that in the Mediterranean area will be an additional reduction in the natural water resources, to the reduction produced in the last decades (40% in the Upper Jucar River Basin from the water year 1979/80. The additional reduction will be around 5% in the short-term (2010-2030) and 13-27% in the long-term (2080-2100). Besides, the severity, duration and probability of occurrence of droughts will be increased. The probability of droughts with environmental and socio-economic consequences will be the double in the short-term (2010-2030) and 6-9 times more frequent in the long-term (2080-2100).

On the use of different data sources for drought analysis in cold climates

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For drought management and prediction, knowledge of causing factors and socio-economic impacts of hydrological droughts is crucial. This requires an interdisciplinary approach and consequently the use of different data sources. This is especially important in snow and glacier-dominated regions, where data is usually limited. In this presentation we will show how the combination of hard and soft data in drought research has improved our knowledge of drought in cold climates. We used data from historical archives and modern drought impact databases (soft data) and used this information side-by-side with hydrometeorological observations and outcomes of hydrological models (hard data). We will present results based on statistical analysis of causing factors of temperature-related hydrological drought types in 21 catchments in Austria and Norway and impacts of these hydrological drought types extracted from historical archives and drought databases for Europe and the US. Furthermore, we will discuss the pros and cons of using different types of data. The combination of quantitative analysis of causing factors and qualitative analysis of impacts of temperature-related droughts is a promising approach for other regions, especially if more data on drought impacts become available.

The drought indicator system in the Júcar River Basin Authority

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The applications of different drought indices have been compared in the Júcar River Basin District where they serve as an elemental tool for the detection of drought situations and for the evaluation of water scarcity conditions depending on the final users of the water resources. Particularly, the Status Index (SI), implemented in the interregional hydrological basins, has implied a significant contribution for the formal declaration of drought situations in Spain and essentially for the prevision and tracking of the drought risk evolution and mitigation of the devastating effects of all the classified types of these environmental phenomena. Strong correlations have been obtained within the Standard Precipitation Index (SPI) and the SI for long term accumulated precipitation periods and similar results prevail with the Palmer Drought Severity Index (PDSI). Overall, moderate correlations have been calculated within the edaphic indices PDSI and Normalised Difference Vegetation Index (NDVI) and are slightly improved for medium term accumulated periods (NDVI-3) associated to the seasonal behavior of the vegetation.

Assessment of drought indicators using gridded datasets for Monitoring and Early Warning at regional-scale in the UK

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The expected future increase in frequency and severity of droughts due to climate change has contributed to increased awareness amongst researchers, policy makers and water managers of the need for reliable, systematic and near-real-time operational spatial drought monitoring and early warning (M&EW) systems. The international project DRIVER (Drought Impacts and Vulnerability thresholds in monitoring and Early warning Research) adopts the novel approach of using reported information on

drought impacts to assess the capability of drought indicators to predict demonstrable impacts on society or the environment.

The UK has a well-established framework for drought management, but at present does not have a M&EW system focused on drought. The UK is therefore an ideal case study for assessing how the drought indicator-to-impact linkages can potentially lead to improvements in M&EW from the ground up.

In this context within the DRIVER project, a set of widely-used drought indicators (SPI, SPEI and various others) were calculated using a range of readily available gridded datasets to develop a prototype “drought portal” for the UK, which is primarily a tool for visualising spatio-temporal information on historical drought characteristics at present, but could form the basis of a M&EW system in future. These gridded datasets were used to examine the link between indicators and drought impacts using the European Drought Impacts Inventory (EDII). This talk will deliver some early results from this indicator-to-impact analysis, with a view to appraising the utility of these indicators for M&EW.

Possibilities on drought forecasting in Croatia

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Drought is a complex natural hazard that causes the highest economic losses in Croatia. Since damages caused by droughts are increasing, a development of a comprehensive drought monitoring should include a forecasting component in order to provide an in-time warning on drought. In this study the possibilities on drought forecasting are investigated using the Standardized Precipitation Index (SPI) which are calculated for 1- and 3-month time scales. The forecasted SPI values are calculated from the long-range ensemble precipitation forecasts by the European Centre for Medium-Range Weather Forecasts (ECMWF). They are validated by SPI values obtained from the observed monthly precipitation amounts at 23 stations, spanning the 2011-2014 period. The verification has been performed by employing Brier skill scores, as well as the reliability diagrams. The results have revealed a good skill for the one-month SPI forecast and considerably worse skill for three-month forecast.

IMPETUS: Improving Predictions of Drought for user Decision-making

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Droughts have severe impacts on societies, economies, agriculture and ecosystems. Droughts are complex events, with impacts dependent on meteorological, hydrological and land surface factors as well as on water demand and management. Consequently, drought forecasting has many components: forecasting meteorological drought (deficit of rainfall), agricultural drought (soil moisture deficit) and hydrological drought (decline in surface water and groundwater), forecasting the consequences of drought for water availability and forecasting the effects of drought management. All of these are uncertain and any improvement in decision-making needs to consider all aspects of the forecast process.

IMPETUS is an interdisciplinary project started in November 2014 that brings together environmental scientists from the meteorological, land surface, surface water and groundwater communities and social scientists from the water demand and forecast user communities. IMPETUS aims to improve the forecasting of UK drought on monthly to decadal timescales, which will lead to the development of improved decision-making processes. This will be achieved by improving meteorological, hydrological and water demand forecasts and how they are combined to produce drought forecasts. This contribution will present the aims and objectives of the project.

Climate Seasonal Forecast and derived Indexes for droughts in Ceará, Brazil

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This study carried out a comparative performance analysis on two climate indexes (flood and drought indexes) based on daily rainfall to determine the most appropriate for indicating the severity of drought conditions in the rainy season of Ceará. The paper examines the variance explained by such indexes of the observed maize yields for the period 1990 to 2012. The potential predictability of the flood index and drought index are evaluated using a multi-ensemble of 20 members forecast of the NCEP (National Centers for Environmental Prediction) Regional Spectral Model (RSM) nested into the ECHAM4.6 driven by persisted Sea Surface Temperatures (SSTs) in February-May (FMAM) season during the period 1974–2012. The analysis shows that the flood index explains better the variance of the maize yields in Ceará than the drought index. The RSM is able to predict the spatial-temporal variability of such index, showing higher correlation over the Sertão Central region, which is known as the driest region in Ceará. Our results indicate high predictability of the index for estimating maize yields. The paper also shows that persistence of SST over several months is sufficient for a good predictive capability of such scheme. It was also shown that the SST-forced component of climate variation does translate into the weather features that are important for crop yields.

Drought vulnerability assessment for different hydrological conditions based on standardized runoff index and flow duration curve in Lithuania

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The comparison of surface water resources and surface water consumption is enough good measure for the assessment how the decline in water resources may affect the water demand coverage and the river basin vulnerability to droughts in water resources sector. The vulnerability has been estimated as the surface runoff and surface water consumption ratio for different administrative areas and different river catchments in Lithuania.

The drought vulnerability measure seems to be comparable with water exploitation index, however water availability in this study is represented as a function of different hydrological conditions. Different duration (1, 3 and 12 months) of Standardized Runoff Index and Flow Duration Curve probability parameters were used to represent different hydrological conditions. SRI is a standardized index, thus the same Standardized Runoff Index values have the same probability in different basins. The Flow Duration Curve has the same properties as Standardized Runoff Index. The usage of Standardized Runoff Index and Flow Duration Curve allows to compare the vulnerability between different rivers and to estimate the probabilities of different water demand coverage for the different hydrological conditions.

Hydrological Reliability Assessment of Water Management Solution of Reservoir Storage Capacity in Conditions of Uncertainty

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The aim of the article is to introduce the concept of Monte Carlo method for incorporating the uncertainties into the all hydrological and operational data inputs, which are needed to design and operation of large open water reservoir. Incorporating uncertainties into data inputs during calculation of reservoir storage capacity, then the consequent active conservation storage capacity is loaded by uncertainties. In the same way the values of outflow water from reservoir and hydrological reliability are affected by these uncertainties as well. For these kind of calculations the reservoir simulation model has been built, which simulate behavior operation of reservoir and is able to evaluate the results of simulations and help to reduction risk of storage capacity failure, respectively reduction of water shortages during reservoirs operation during low water and dry periods.

Regional Governance Assessment for Drought Adaptation in North-West Europe: Case Study Results from the Analysis with a Governance Assessment Tool in the DROP-Project

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North-West Europe will increasingly face drought periods that may seriously affect inter alia agricultural production, natural ecosystems and fresh water supplies. In addition to implementing hard adaptation measures, enhancing regional water governance is crucial for effective drought adaptation. One of the objectives of the DROP project is to identify possible improvements to regional governance settings in six case study areas: Flanders (BE), Somerset (UK), Eifel-Rur (DE), Vilaine (FR), Vechtstromen (NL) and Groot Salland (NL).

The basis for the analysis is a Governance Assessment Tool adapted for the analysis of the resilience of the system to face droughts and water scarcity. This tool is elaborated from a concept of “governance” as a modification and extension of the concept of “policy”. The paper introduces this Governance Assessment Tool and presents insights of its application in the six case study areas.

Conjunctive use of surface and ground waters during drought and climate change assumptions. Duero River basin, Spain.

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The contribution of this work is related to the advantages obtained by the conjunctive water resources use, including surface and groundwater use, on the Duero River Basin (Spain), under climate change and drought effects. The main objective is to analyze the possible impacts in a complex water resources system under extreme phenomena. A brief analysis of drought recurrence through the SPI index (Standardized Precipitation Index) is made, focusing specifically into two contrasted exploitation systems with higher groundwater demand and surface interchange. Because of storage capability and low water movement speed, the use of aquifers as deposits and reservoirs is a high priority in the area. These natural deposits shall be used during drought periods and as extra guarantee against possible

climate change needs. However, the aquifer exploitation must attend a systemic study of actual and future water needs, considering a sustainable exploitation by extracting what is needed during scarcity and recharging during abundance. Finally, considering the flexibility added to a conjunctive water resources system by its management, some proposed scenarios are analyzed to contribute on the understanding of management in the system studied.

The Debate on Sustainable Water Management: Evidence from Drought in the Jucar Basin

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Global mismanagement of water resources calls for a reconsideration of water policies. Three general types of water policy instruments are water pricing, water markets and institutional instruments based on cooperation. Water markets have been implemented in Australia to confront water scarcity and droughts, and water pricing is advocated by the European Union to balance supply and demand. This paper compares the performance of these three types of instruments in dealing with drought for the case of the Jucar basin in Spain. The findings indicate that the outcomes from the current institutional setting are similar to those from water markets, demonstrating that the current institutional approach based on stakeholders' cooperation is quite close to the first best policy. Another important finding is that the outcomes from water pricing involve huge losses for farmers, which will make water pricing politically unfeasible.

Drought adaptation of African farmers in a changing climate

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Climate change is posing increased drought risks to the already high volatile agriculture in Africa affecting food security, livelihoods and ecosystems. Hence, in order to achieve a more resilient agricultural sector, it is important that farmers implement adaptation measures. It is therefore fundamental to comprehend the decision-making process, and the drivers and constraints of farmers to adapt to droughts. So far, however, this area is poorly understood.

A profound model that is able to explain adaptive behaviour in many cases is the so called Protection Motivation Theory (PMT) developed by Rogers (1975 - Journal of Psychology, 91: 93–114). It was first applied in the field of health risks and more recently applied to natural risks and particularly to adaptation. According to this theory, it is the perceived severity and probability of a threat's occurrence, the perceived efficacy and costs of a coping strategy/measure and the perceived self-efficacy of the individual which determine adaptive behavior. Hence, the PMT will be utilised in my research to investigate whether this theory can also give insight about drivers and constraints of African farmers to adapt to droughts.

Data derived from surveys carried out in 2002-04 in eleven African countries is used to characterize adaptation of farmers. Further, the data will be allocated to the PMT, as far as possible in order to investigate whether the theory can serve as an explanation for differences in adaptation. This data set was generated within the research project "Regional Climate, Water and Agriculture: Impacts on and adaptation of Agro-ecological Systems in Africa" led by the Centre for Environmental Economics and Policy in Africa (CEEPA) at the University of Pretoria.

This research will lead to a better understanding of drivers and constraints of farmers in different African countries to adapt to droughts. In a further step, recent policy developments are investigated and used as a starting point for an investigation of temporal changes in adaptive behavior.

Integrated Water Resources Management Strategy to Mitigate Drought Impacts in Mexico

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Due to severe socioeconomic and environmental drought impacts in Mexico, President Peña Nieto in 2013 established a six-year Program to Prevent and Mitigate Droughts. This paper summarizes research undertaken for the National Water Commission (CONAGUA) as part of this Program in an arid to semi-arid basin in north-western Mexico. The research objective was to formulate an integrated water resources management strategy (IWRMS) to ensure water availability, developed through interactive stakeholder processes, watershed parameters analysis, establishment of long term targets, strategic options development, scenarios assessment and policy recommendations. The research identified adequate water resources but drought impacts were exacerbated by a lack of water storage and very high demand. Recommendations included prevention and mitigation strategies, including Low Impact Design, and identification of resource requirements. Major benefits could be achieved by empowering the River Basin Committees to implement the IWRMS and optimizing water use efficiency, supported by ongoing research and education.

Improving operational drought definitions – taking them to basin scale

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The occurrence of droughts and especially their recurrent character ask for comprehensive monitoring to manage drought events and to minimize negative environmental, societal, and economic impacts. Responsible drought management supports and enhances continuous improvement of monitoring and forecasting tools. One remaining obstacle for adequate drought management is the lack of a satisfying operational drought definition for decision makers. Drought indices are used as tools to define drought patterns, but they are mainly based on hydro-meteorological or satellite data, and do not reflect regional properties like perceptions, management, and demand aspects. This paper presents a discussion on existing drought definitions and explores the idea of establishing drought definitions on basin scale to improve drought management. This objective follows the idea of Integrated Water Resource Management (IWRM), which would enhance the linkage between drought and water management.

Meteorological and hydrological drought: evaluation of effects face of climate change in Cuitzeo's lake basin

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Mexico has undoubtedly seen the effects of climate change over the last decade, which has resulted in extreme crisis events of various kinds, one of them drought. In 2011, the worst disaster occurred in the

country, affecting more than 70% of the population generating consequences in social, economic and environmental areas. The importance of this research is based on finding solutions to conserve the country's second largest lake, the Cuitzeo's lake. Before these types of events which by their nature are complex and erratic and lead to the generation of water scarcity providing a research gap by the consequences of global climate change and overheating which causes a noticeable drop of water for human consumption creating challenges for alternative solutions in the management of water resources.

The evaluation of drought will be both the historical period and the future, characterizing the type of meteorological and hydrological. Time series of precipitation and flow are evaluated using statistical tests of independence and dependence to verify the basic characteristics of such series. The indices employed for identifying droughts are the Standardized Precipitation Index (SPI) for meteorological drought and Standardized Flow Index (SDI) for hydrological drought. Once evaluated the historical period (1980-2010) climate change information will be obtained using the ensemble model for RCP 4.5, RCP 6.5 and RCP 8.5 scenarios for short-term (2015-2039) and long term (2075-2099). Information from the series of precipitation was validated by verifying their independence. Then the SPI was evaluated in a timely manner in 15 key areas of the basin. For hydrological drought in the 2 major reservoirs in the basin, flows were generated using the software EvalHid using the Témez' model. After obtaining the expenditure dependence of the series was analyzed and evaluated SDI.

It is expected that the results presented indicate the phenomenon more frequency, intensity and duration in the study area, affecting larger areas to include the effect of climate change affecting both the population and the amount of available water resources in the basin where the direct effect on the population will be limited to water supply reservoirs impacting human use and the productive sectors of the region.

Drought Risk Reduction Messages for Public Authorities, Businesses and Citizens

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Currently each year 17% of the total population of Europe is subjected to the impacts of drought each year (DROUGHT R&SPI, 2013) leading to serious economic, natural and societal damage. The threat of a drought can seriously hamper the international competitive (economic) position and security of the European community. As droughts often span areas outside national borders society needs to deal with drought in a wider context. The complex web of law and legislations related to water management, combined with various aspects related to droughts and the differences of water demand by the different stakeholders gives a slight indication of the complex nature of drought management. Despite the development of various initiatives to deal with water scarcity, protocols to deal with drought are varying from area to area and are often still in development.

The aim of the study was to identify drought risk reduction messages for different stakeholder groups to inform them on drought and drought management strategies and to support practical implementation of drought strategies in Europe. These messages create a basis for public authorities, citizens and businesses in Europe to develop strategies and mitigation options in order to increase preparedness, reduce vulnerability and lowering risks related to drought.

In order to identify these messages and target audiences a literature review has been executed. The literature review provided a basis for identification of different options and challenges for drought management in Europe. The literature review also showed the complex web of policies, laws, legislations and scales which creates a very difficult environment to operationalise drought management strategies in Europe. The literature assessed results of various documents and projects, ranging from policy documents to scientific journals and project results related to drought and water scarcity.

The messages have been developed for the most important stakeholder groups in Europe (based on the current focus of the European Union (Horizon 2020; Public Authorities, Businesses and Citizens) and the UNESCO WWDR3 report) these form the input for the survey in order to identify crucial stakeholder groups to consider for drought management.

Various projects have dealt with drought and many mitigation options are available to deal with water scarcity and drought. There are however significant differences between authors on the best way to deal with droughts. In order to identify which options from the literature review are the most suitable for drought management in Europe a survey has been developed and the respondents are requested to rank the importance of each measure and communication strategy.

The survey was developed using an online platform (Qualtrics) which allows for complex survey design and processing of an infinite amount of anonymous respondents within a brief timeframe. The survey has been launched on European scale and uses internal control question to test if the respondent fits the profile of the test subjects. In case the respondent is not fitting the profile the respondent is automatically sent to the closure of the questionnaire. The questions of the survey focus on five sections; 1) Personal background, 2) Identification the participant's vision on scales, levels, target audiences for drought measures and messages, 3) Specific measures (measures are clustered according to topic), 4) Identification of effective communication strategies, 5) Open questions to leave contact details and/or final remarks. The measures and strategies are based on the options identified in the literature study and the respondents are asked to rank the options using

Likert scales. Only very few questions are open questions in which respondents are asked to elaborate on an answer to make comparisons easier.

The literature review indicated issues and opportunities related to; 1) the definition of a drought, 2) the development of warning indicators, 3) issues related to valorisation of water resources, 4) applicability and suitability of water saving technologies, 5) differences in drought management in Europe, 6) issues with the development of drought management strategies, 7) issues related to operationalising knowledge to stakeholders. The survey included the results from the literature study to explore these topics further and identify crucial messages, stakeholders, scales and options for drought management in Europe.

The respondents of the survey indicated that the river basin was the most important unit size to reduce vulnerability to drought and 83% of the respondents indicated that implementation of drought management across scales is problematic. The respondents identified the policy makers at national level as very important audience to improve drought preparedness (9.26 out of 10) (the policy makers at other levels ranked slightly lower) followed by businesses (8.26/10 (industry) and 8.50/10 (farmers) and then the citizens were ranked as important (7.89/10). 83% of the respondents favoured a pro-active approach for drought management. Most of the options and measures dealing with drought were ranked relatively high (>7.0/10, ranging from important-very important to consider when dealing with drought). The following are ranked with the highest importance by the respondents;

- Development of Drought Management Plans (9.39/10)
- Development of Emergency Drought Protocols (9.11/10)
- Setting abstraction limits (during droughts, urban areas) (9.06/10)
- Developing Drought management plans (9.00/10)
- Water use efficiency improvement in Industrial processes (8.94/10)
- Implementing water saving technologies (8.94/10)
- Reducing of illegal abstraction/impoundments (8.94/10)

- Water loss reduction in distribution networks (8.89/10)
- Improved irrigation technology (8.89/10)
- Awareness raising projects on water consumption (8.89/10)
- Transboundary agreements on water allocation (8.83/10)

The section on information distribution focussed on the three horizon 2020 stakeholders and identified the most effective communication strategy for each group; 1) the use of conferences and meetings was preferred for public authorities, 2) for businesses information sessions and meetings were ranked highest importance and 3) for citizens the use of TV items, social media, newspapers and radio items were considered the most important to inform on drought and drought management.

After conducting the survey and literature review it became clear there is a need to develop effective drought measures using a pro-active approach for each river basin in which the stakeholder groups should be targeted with a specific communication strategy. The plans should integrate the various rules and legislation in place and be made understandable for the different target audiences. The drought management plans should be developed using an integrated approach during which there is room for debate to include the development of commonly agreed early warning and management strategies to reduce vulnerability to drought in Europe. Enforcement of rules and regulations and the development of efficient water use and production techniques (urban, agriculture and industry) and awareness raising campaigns are deemed very important in drought management.

Links between meteorological drought and wildfire extent in Europe

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Wildfires are a natural hazard most commonly associated in Europe with the semi-arid Mediterranean region, but which can affect all regions and cause significant impact and damage. Because vegetation dryness is a primary factor in both the ignition and spread of wildfires (Thompson and Caulkin 2011), it is assumed that there is a link between meteorological drought and wildfire extent. While this assumption has been tested at regional scales in Europe (Bifulco et al. 2014, Drobyshev et al. 2012, Pausas 2003, Trigo et al. 2013, Turco et al. 2013), it has rarely been investigated at the continental scale. This study addresses the issue by modeling wildfire response to meteorological drought anomalies at the state or province level across Europe. By analyzing areas independently, wildfire response to drought can be contrasted spatially and the most relevant drought predictors can be identified regionally.

Estimates of wildfire severity in this study are based on monthly area burned, as compiled by the European Forest Fire Information System (EFFIS) in the European Fire Database (EDF, European Commission 2011). The EDF contains information on the total monthly area burned at the NUTS3 resolution for the period 1/1979-12/2010. Burned area for this period was then aggregated to the NUTS2 level (Nomenclature of Units for Territorial Statistics), a resolution commonly used by the European Union for regional analyses and policies corresponding to sub-national regions, states, or provinces with between 800,000 to 3 million inhabitants. NUTS regions with more than 50% urban area were removed from analysis to minimize the effect of dense urban areas. In order to compare area burned across regions, all analyses were based on percent area burned, calculated by dividing total area burned by total forested area, obtained from CORINE 2006 land cover data.

Meteorological drought was quantified using two commonly used and recommended indices: the Standardized Precipitation Index (SPI, Guttman 1999, McKee et al. 1993) and the Standardized Precipitation-Evapotranspiration Index (SPEI, Vicente-Serrano et al. 2010, Begueria et al. 2014). These indices normalize accumulated anomalies in precipitation and climatic water balance (precipitation minus potential evapotranspiration), respectively, and indicate the number of standard deviations from typical conditions for a given month and location. For this study, SPI and SPEI were calculated for 1, 2, 3, 6, 9, 12, and 24 month accumulation periods, as in Stagge et al. (2015), and spatially averaged for each NUTS2 region, while using the period 1970-1999 as a 30-year reference period.

The relationship between wildfires and meteorological drought was evaluated by testing logistic regression equations using all possible SPI and SPEI accumulation variables as predictor variables to explain the proportion of the NUTS2 area burned. Fires have a strong seasonality, so a monthly spline function was included as a predictor using a Generalized Additive Model (GAM) approach. Annual splines were also included for regions with more than 20 years of fire data to account for long-term changes in fire behavior and prevention that can not be explained by climate. The best predictors for each NUTS2 region were selected based on the Akaike information criterion (AIC) and deviance explained using 5 year cross-validation periods to reduce over-fitting.

Meteorological drought was found to have a statistically significant effect on wildfire extent across nearly all tested NUTS2 regions by comparing deviance explained in the fitted model with that explained by the historical fire climatology, i.e. the monthly and long-term trends. Percent area burned follows consistent seasonal patterns organized spatially by climate zones, with the Mediterranean region dominated by a single large peak in late summer and the temperate regions of central Europe producing two distinct fire peaks occurring in the spring and again in late summer. For far northerly regions, there is no distinct peak, but rather a consistent likelihood for the period where land is not covered by snow.

Figure 1. Spatial map of the accumulation period (A, left) and the drought index (B, right) that best explains wildfire extent. Wildfire extent can best be explained for the majority of Europe by meteorological drought indices in the range of 1-3 months (Figure 1a), with some areas of eastern Europe explained by longer anomalies (9-12 months). The most relevant meteorological drought index is the SPEI for much of Europe (Figure 1b), particularly in the west and near the Mediterranean where shorter (1-3 month) accumulation periods are most important. With the primary wildfire peak occurring in late summer for most regions, the 1-3 month SPEI is important because it captures both a lack of rainfall and exceptional dryness due to high temperatures. For short periods in semi-arid regions, the SPI cannot adequately measure fire risk because it includes only precipitation, which may be negligible for the important summer period. However, the SPI appears to be a slightly better predictor of wildfires for regions with longer (9-24 month) accumulation periods, as evapotranspiration has a less important effect over annual scales.

For regions where the 1-3 month SPEI is significantly related to wildfire extent, particularly in southern Europe, there is also a competing pattern in which fires are related to long (12-24 month) wet periods. Severe fires in these regions are therefore best explained by a combination of short, extreme dry periods and long accumulated wet periods, which allows a build-up of vegetative fuel prior to drought conditions associated with fires. Similar findings have been identified in regional studies (Bifulco et al. 2014, Pausas 2003, Turco et al. 2013).

This research provides clear evidence that wildfire extent is closely related to meteorological drought in Europe and can therefore be estimated by appropriate meteorological drought indices. Wildfire extent follows seasonal patterns related to climate and landscape, but also has relatively consistent responses to meteorological drought once these patterns are accounted for. These findings could therefore be used in conjunction with drought forecasts to either forecast fire likelihood or to estimate future severity given changes in precipitation and temperature. Finally, there is a possibility to exploit known

seasonality and drought response to estimate fire vulnerability for regions where measured fire data has not been collected.

Main characteristics of droughts in Amazon region

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The objective in the present study is analyze the main characteristics of droughts in the Amazon region as: intensity, spatial extent, duration, start and end, in addition to their time scales, using a dataset reanalysis and precipitation products observed and satellite, and using the Standard Precipitation Index (SPI) in the Amazon region for the period 1979 to 2013. The reanalysis datasets will be: a) ERA-Interim, b) CFSR, c) Merra; Satellite a) TRMM and observed precipitation products will be used for analysis and comparison in this study: a) GPCC, b) GPCP and c) CPC. The region will be subdivided in groups of homogeneous precipitation, and will be analyzed the spatial and temporal variability of the frequency of dry events intensities (moderate, severe, extreme and very extreme) and scales SPI 3, 6 and 12 months in the region, whose scales are associated with meteorological and hydrological droughts. The results will provide drought climatology in the region and its main features. Finally, this information can be used as monitor droughts in the region.

Assessing drought vulnerability and risk in Sinaloa, Mexico

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Drought is a natural disaster originated by a long term deficiency in rainfall and it is an anomaly occurring in most climates even on those with normally high precipitation. In Sinaloa, drought occurrence and its geographic and time variability represent a severe restriction to social and economic development and jeopardize the sustainability of the ecosystems. A drought risk map for Sinaloa state was developed using a geographic information system (GIS). Different vulnerabilities to drought were accounted for among them those derived from structural factors (availability of superficial and ground irrigation, individual income, etc.) and dynamic factors (occurrence and severity of droughts, amount of water in dams, etc). The system is versatile and it allows the addition of new variables leading directly or indirectly to drought vulnerability. The development of the evaluation system for extreme risk of drought (SERES) was accomplished in a GIS environment in several steps which final product is a map of the geographic distribution of drought risks in a relative scale of 0 (no risk) to 100 (highest risk). The SERES program generates monthly risk maps automatically for drought analysis in river basin or counties. It allows to identify those areas with higher vulnerability and risk so adaptation, mitigation and resiliency mechanisms can be set in place. Considering the extreme drought registered in 2011/2012, a risk map for October 2012 was generated which allowed to identify counties with higher drought vulnerability factors and risk levels. Accordingly, based on that information drought contingency plans were established and reports were provided to the local government for decision-making.

Integrating Water cycle management: building capability, capacity and impact in Education and Business (I-WEB)

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Several reports have identified scarce reserves of renewable water within Kazakhstan and water scarcity has been highlighted as potentially limiting its potential to sustainably develop its natural resources and economy. Acute water shortages are included in the Kazakh Government's list of 21st century global challenges and implementing integrated approaches to water management is a regional priority. With only one of Kazakhstan's eight major river basins falling entirely within its national borders (see Figure 1), the sustainable use of the majority of its water resources is only possible if Kazakhstan and its neighbouring countries (Russia, China, Kyrgyzstan and Uzbekistan; the upstream sources of the major rivers entering Kazakhstan) co-develop and implement integrated water cycle management (IWCM) plans.

In common with all Central Asian countries, Kazakhstan has undergone major political, economic and social transformations following independence in 1992. Whilst under Soviet times the water sector was the 2nd biggest receiver of state funding, the global economic crisis and limited national funding substantially reduced the levels of finance directed towards the water sector. In combination with changes in funding, a prevalence of inefficient water management infrastructure, agricultural reforms and industrial developments has led to increased competition for water resources. Within the context of an inconsistently applied and hence chaotic water management approach, Kazakh water professionals are often required to focus on delivering practical solutions rather than institutional capacity building. Current water management practices are hence typically 'siloed' on a sector-by-sector basis, contributing to a range of impacts, from droughts to land degradation and floods, further exacerbating reported effects of climate change.

Currently Kazakhstan's fresh water reserves (surface water, groundwater and glaciers) are estimated to be 524 km³. Whilst on a national basis Kazakhstan is not experiencing water scarcity, there are regional deficits with trends in water availability strongly dependent on a range of factors including the volume of trans-boundary flows (26% decrease from 1998-2008), the state of water delivery infrastructure (transportation losses of 60%, 40% and 50% for agricultural, industrial and municipal consumptions, respectively), rates of evaporation (climate dependent) and infiltration (function of soil type and structure). With Kazakhstan experiencing significant growth in both agricultural and industrial sectors, it is predicted that Kazakhstan will face national water scarcity by 2030.

Recognition of the scale, complexity and diverse nature of the water management challenge facing the Central Asian region (one of the world's political, social and economic "hot spots") has received international attention (e.g. the development of a UN trans-Central Asian, Pacific and European partnership programme which includes water protection and climate change adaptation amongst its identified priorities for action). At a national level the need for change is also recognised, with a raft of policy measures (e.g. IWCM national plan and the development of river basin councils). Recognising the need for its people to develop the multidisciplinary skill sets required to underpin an internationally competitive sustainable economy, Kazakhstan's educational policy has also undergone several reforms. Its priorities include development of curricula using the European Credit Transfer System to enhance international mobilisation and knowledge exchange, equal access to higher education and development of stronger partnerships with industry. Whilst these priorities are applicable across all disciplines, the

Kazakh government includes environmental protection and water management as national and regional priorities. Thus educational reform which delivers a new generation of multidisciplinary experts on IWCM, with links to relevant industry and regulation sectors, is seen as key to enabling Kazakhstan to meet its identified needs of developing and implementing a more integrated, trans-boundary approach to managing water resources.

One initiative which is contributing to addressing the need to institutionalise IWCM in Kazakhstan is the EU TEMPUS I-WEB partnership. Bringing together representatives from a range of Kazakh and European subject specialist, industry, governmental, higher educational and training organisations, I-WEB has collaboratively developed Bologna-compliant Masters programmes at three Kazakh universities in the field of IWCM. A key first step was the development and nurturing of links with a range of relevant industry, practitioner and research organisations through the establishment of an International Advisory Board (IAB). Through iterative discussions with the IAB, the technical and communication skill sets sought by prospective employers were identified and achieving these learning outcomes made central to the programme development process, including the production of a multi-lingual supporting handbook and glossary of use to both practitioners and students. Set within a novel risk management framework developed to address Kazakh needs, an overview of the collaborative practitioner-driven process and subsequent make-up of the approved IWCM MSc programmes is presented.

Assessment of the Transpirative Deficit Index for the Lombardy Plain (Northern Italy)

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Water scarcity describes a situation of recurrent water imbalance, where water demand exceeds natural renewable availability, on a timescale of months, seasons or years. A recent report by the European Union [1] shows that, due to the effects of global (socio-economic and climate) changes on water resources, water scarcity shall affect by 2030 many areas of Europe characterized by large water availability but also by a high water consumption, such as the Po River Plain (Northern Italy) [2].

In the Po River Plain, irrigated crops cover more than 70% of the agricultural land, surface irrigation methods are largely applied, and massive amounts of water are diverted from rivers for irrigation. Additionally, an intensive agriculture coexists with highly developed industrial and commercial activities and with a considerable population, all requiring significant water volumes [2]. Nowadays, the Po River Plain is not a water scarce basin, but short-term water shortages (i.e. on a timescale of days or weeks) can occasionally occur in some areas, especially in years of drought (i.e. temporary, negative and severe deviations from average precipitation values on a mid-term timescale [1]) such as 2003. The Lombardy Plain covers a quarter of the Po River Plain, and represents the study area for this work.

The European Drought Observatory (EDO) focuses its efforts to drought predictability, by using statistical analysis of historical occurrences and numerical weather forecasts. The EDO working group regularly generates maps of drought indicators through all the EU, using both remote sensing and hydrological modelling. Simulations with hydrological models are always conducted in absence of irrigation inputs. However, a comprehensive analysis of water scarcity, which can be useful to agricultural water managers and farmers, requires a joint assessment of information about water availability and consumption. This analysis can not be conducted at the European scale, both for the coarseness of the hydrological modelling simulation conducted by EDO, and for the peculiarity of the Po River Plain irrigation system in which irrigation inputs provided by many irrigation water sources play a fundamental role in the soil water balance.

In this context, a study was started to develop a set of indicators for Water Scarcity and Drought (WS&D) suitable for the assessment of the state of irrigated agriculture in Northern Italy, to be used by regional policy makers, agricultural water managers and farmers. Indicators will be based on the synergic use of hydrological modelling and earth observation information applied at a spatial scale of interest for end-users (i.e. cells of 250 m).

As a first step, this work presents the implementation and the application to the entire Lombardy Plain of an agricultural drought index called Transpirative Deficit Index (DTx) [3]. DTx is based on the transpiration deficit (calculated as the difference between potential and actual transpiration) computed daily by a spatially distributed water balance model (IDRAGRA, [4, 5]) and cumulated over a period of x days (where x is 10, 30, 60 or 90). We firstly computed this index in absence of irrigation inputs.

The simulation model, IDRAGRA, is a distributed-parameters conceptual model, developed by the Section of Agricultural Hydraulics of the Department of Agricultural and Environmental Sciences (DiSAA) of the University of Milan, which allows the simulation of the irrigation water distribution and the computation of the hydrologic balance on a daily basis. The model core is a soil-crop water balance module, which accounts for spatial variability of soils, crops, meteorological and irrigation inputs by dividing the study area with a regular mesh (i.e. a 250 m resolution grid). Each cell identifies a soil volume, subdivided into two layers, modelled as non-linear reservoirs in cascade, where hydrological processes are represented as one-dimensional. Moreover, IDRAGRA includes modules devoted to the simulation of crop development as a function of air temperature, and of water sources conveyance and distribution over the territory.

We applied the model to the Lombardy Plain for the temporal horizon 1993-2007 (15 years), calculating DTx indices for each x value. We compared DTx series for each day of a specific year to the corresponding DTx values of the historical series. In particular, parameters of the normal distribution fitting the 15 DTx values were calculated, and the position of DTx for each year was obtained in term of probability of exceeding a threshold percentile of the distribution. In this work we present the results for two years, respectively characterized by drought (year 2003) and abundant rainfall (year 2008) throughout Northern Italy.

The DTx was computed conducting three simulations, each one for a hypothetical uniform land use: a reference crop (i.e. a hypothetical crop resembling an extensive surface of green grass of uniform height, actively growing and adequately watered), maize and permanent grass (these last two crops are very widespread in the Lombardy region). We supposed each crop uniformly distributed over the study area and considered and, for each simulation, only water supplied by rainfall (i.e. absence of irrigation). In that way, the distribution of DTx values reflects the potential water stress conditions for that crop linked to a specific pedo-climatic situation. For all the crops, the distribution of DTx reflects the intra-annual differences in crop growth during the vegetative season, based on the meteorological and soil variability. In May, maize do not emerge at the same time throughout the study area, and until June DTx values are usually lower than those of the reference crop. In July, as crops are completely grown, DTx become higher than the reference.

In conclusion, DTx can be a useful tool in the monitoring of the agricultural drought at the regional scale, reflecting the pedo-climatic variability throughout the study area. In the next future, we are planning to include the effective land use and the irrigation supply into the hydrological simulation, to evaluate the suitability of the DTx also for water shortage assessment.

Macro scale analysis of droughts in a climate change context

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We characterized droughts in La Plata Basin by using the SPEI (Standardized Precipitation-Evapotranspiration Index) for the period 1961 – 2100. La Plata Basin is located in the Centre-South of South America and comprises 3.100.000 km² and five countries. It stores one of the largest volumes of fresh water on the planet. Despite of the significant impact of droughts on agriculture, cattle, satisfaction of water demands, natural water courses and wetlands, droughts are still difficult to predict in the region, both in time and space. However, this information is highly required in order to accurately define specific measures and plans for drought prevention and mitigation.

This study was carried out in seven macro-basins which comprise La Plata Basin (Alto Paraguay, Bajo Paraguay, Alto Paraná, Bajo Paraná, Alto Uruguay, Bajo Uruguay, and Río de la Plata). We used the SPEI (Standardized Precipitation-Evapotranspiration Index) to characterize droughts based on Potential Evapotranspiration (ETP) and Precipitation (P) at a monthly scale. We studied the control (1961 – 2005) and future (2007 – 2040, 2041 – 2070 y 2071 – 2099) scenarios. Climate change effect was assessed from two complementary perspectives, calculating the SPEI based on the D series ($D=P-ETP$): i) of each of the analysed scenarios, and ii) of the control scenario. The SPEI was calculated based on the monthly ETP and P values provided by the National Institute for Space Research (INPE). ETP and P were obtained for all 10 x 10 km-size cells within the basin by using the regional climatic model Eta, under the boundary conditions of the HadGEM2-ES model and the CO₂ emissions scenario RCP 4.5. Cell to cell information was integrated into a basin level (i.e., each macro-basin) in order to show and analyse the results. For each i) calculation assumption, ii) macro-basin, iii) climate scenario, and iv) temporal scale of SPEI (1, 3, 6 and 12 months), we identified the beginning of each drought, calculated its duration, magnitude, and maximum and mean intensities, and the duration between drought events. Additionally, for each SPEI temporal scale and macro-basin, we described the spatial coverage of droughts for the temporal series of all climate scenarios.

Spatially, we found a decrease of ETP from North to South. Temporally, results showed a future increase of ETP for the Alto Paraguay, Alto Paraná and Bajo Paraguay macro-basins but similar to present values for the remaining basins. We did not find any spatial pattern for P. Results showed that P will be similar in the future for the Alto Paraguay, Alto Paraná and Bajo Paraguay (even we found a decrease of P during 2007 – 2040), but will increase within the remaining macro-basins. We also expect that during 2007 – 2040 scenario, whereas the northern macro-basins will suffer from several droughts, the southern ones will have wetter climate with few short drought events. As we analyse more distant future scenarios the wet climate spreads towards northern macro-basins and droughts become less intense. Similarly, the area with droughts for each macro-basin, in general, tends to decrease in the farther future. The situation gets better from South to North with time. Noteworthy that for many time periods which were not defined as drought according to the mean values for the macro-basin, a high percentage of the basin (between 5 to 20% of the area) did suffer water deficit. Therefore, if smaller basins were analysed, dry periods in certain areas may vary from those identified at macro-basin level.

Assuming true climatic predictions, our results highlight a significant heterogeneity of droughts (occurrence and drought characteristics) in La Plata Basin (Figure 1). La Plata Basin will require detailed studies which include hydroclimatic studies, water demand analysis, evaluation of existing infrastructures and the effect of potential investments, all to the current situation and future scenarios. This will provide the objective technical foundation for the drafting and implementation of water resources management plans and specifically for drought management plans.

Figure 1. Variation in droughts in the different scenarios (from left to right: 2007-2040, 2041-2070, 2071-2099) and macro-basins comparing with the control scenario (1961-2005). Red means an increase in number of droughts, and in their duration, magnitude and spatial coverage. Yellow means that the situation is similar or slightly wetter or drier relative to the control scenario. Green indicates a decrease in number of dry periods, and in their duration, magnitude and spatial coverage, as well as an increase of the number of wet periods.

Crop yields and prices as affected by drought

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Droughts are known to cause major impacts on yields of agricultural crops throughout the world and previous research made for Portugal also confirmed significant effects of drought (and precipitation anomalies in general as measured by the Standardized Precipitation Index SPI), in the production of different crops (wheat, maize, rice, rye, potatoes and olives). On the other hand, the effects of reduced yield on the increase of prices have been thoroughly investigated in the Po Basin, with the conclusion that, for some crops, a negative correlation between yields and prices is confirmed, as expected from economic theory.

In this work we investigated for the two study areas (Portugal and the Po Basin) and for three annual crops (wheat, maize and rice), the correlations between precipitation and production anomalies and between yields and prices. We hypothesized that anomalies in annual production resulting from drought would be detected after removal of the multi-annual trends associated with other factors but would also differ between mainland Portugal (drier conditions) and the Po river basin (rainy conditions). We also hypothesized that the correlations between yields and crop prices would be always negative but different between crops that have a global market and those associated to small local markets.

For the establishment of correlations between production and precipitation anomalies we selected three cereal crops that are important in both countries: wheat, as a winter crop common to all regions, and maize and rice, as summer crops more regionally distributed. For this analysis we used the NUTS 2 (Nomenclature of Territorial Units for Statistics) level, with the five units of mainland Portugal, ranging from the rainy northern region to the more arid south, and three regions of the Po Basin (Piedmont, Lombardy and Emilia-Romagna), which are responsible for ca 35% of the Italian agricultural production. We used the available data for yields from the EUROSTAT data base (1979-2007 for Po river basin and 1980-2012 for Portugal) and the precipitation anomalies using SPIs (calculated for 1,2,3 and 6 months accumulation periods using 1979-1999 as the reference period) computed with precipitation values based on the Watch Forcing Data ERA-Interim (WFDEI) for the duration of the crop yield series.

The anomalies in production were computed as the difference (in absolute values and in proportion) between annual observed values and average values for different reference periods. The selection of the “best” production anomaly was done for each crop by the comparison of the R² values obtained between the different SPIs and the different production anomalies computed. For wheat and rice the best correlations were found using the absolute difference to the reference period of two years before and two years after whereas for maize the best correlations were found using proportional difference to the average production of the previous two years. Using these best production anomalies we found the SPIs that were significantly correlated and developed by a stepwise approach a linear model for each crop and study area.

Anomalies in wheat production were found to be negatively affected by winter rains for both areas with a positive effect of more spring rains only for Portugal. For maize the models indicate always positive effects of excess rain anomalies (or negative effects of drought) for various periods from October to May in the two areas. For rice the two areas show very different effects: whereas for the Po Basin the excess rain has negative effects in summer and in the harvesting period (October), in drier Portugal the model detected a positive effect of extra rain (or a negative effect of drought) in early spring.

In order to understand the relationship between crop prices and production anomalies we also used EUROSTAT data. After detecting a very strong relationship between the price of the current year and the price of the year before, linear regressions to predict the price of the crop for a given year were developed based on the price of the previous year (Price YB) and the corresponding production anomaly (P. Anomaly).

Our results confirm that it is possible to relate the price of the current year for all crops and areas based on the price of the previous year and on the production anomaly. However, it is also concluded that, as with the effects of the various SPIs on crop production and in spite of the similarities, the relationships between production anomalies and prices differ between crops and areas. These findings seem to confirm the hypothesis presented.

Long-term drought severity variations in Northeast Spain

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Droughts are a recurrent phenomenon in the Mediterranean basin with negative consequences for the society, economic activities and natural systems. Nevertheless, the study of droughts in Spain has been limited so far to the relatively short instrumental period. In the present work, the drought events that occurred in North-East Spain during the period 1600–1900 have been analysed, using tree rings and historical documents.

In order to be able to make a climate reconstruction as long as possible with proxy data, *Pinus sylvestris* and *Pinus uncinata* have been chosen, as these are two of the most long-lived and species extended within the Ebro Valley. Therefore, 413 trees were sampled and 826 cores collected throughout the Iberian Range (10 sites) and the Pyrenees (12 sites). The age range of the trees varies between 80 and 420 years in order to collect the whole range of the forest structure. Once the processing and analysis of the samples has been completed, a first climate reconstruction of the Iberian Mountain range spanning the period 1650–2012 has been done. To calibrate the dendrochronological information, climate data from the grid of the CRU TS 3.1 has been taken using the 1940–2000 period as a reference.

In addition, the abundant documentation in historical registries and the detail of the meteorological event registrations allows us the systematic and continuous summary of the drought events from XVI to XIX centuries. Rogation (ceremonies to ask God for rain: pro-pluvia, or to stop raining: pro-serenitate) analysis is an effective method to derive information about climate extremes from documentary data. These documents are homogeneous information that permit the reconstruction of drought frequency series and create a continuous drought index. Weighted annual sum by levels has been a widespread technique to analyze such data but this analysis is liable to be biased to spring values as these ceremonies are strongly related to farming activities. The analysis of the length of pro-pluvia periods (the time span during which rogations are carried out in relation to a drought event) and the combination of annual and seasonal information offers a more objective criterion for the analysis of the drought periods and an increase in the resolution of the study.

First results show a cold period by the end of the 17th century and beginning of the 18th century, corresponding with the end of the Little Ice Age. At the same time, droughts in specific years coinciding with historical hungers and turbulent periods in the society. Two drought maxima appear during the 1650– 1675 and 1765-1795 periods, characterized by rogations during almost all the year, with a middle stage (1676–1710) when droughts were less frequent and their length shortened. Results indicate that drought evolution during the past four centuries often coincides in time with the evolution recorded in other Mediterranean areas. Between the sixteenth and nineteenth centuries the most important droughts were recorded in the last quarter of the eighteenth century, which coincided with a period of high climatic variability known as the “Maldá” anomaly. In general, the eighteenth century was drier than the seventeenth and nineteenth centuries.

Comparison of rainfall/drought records around Spain and the Western Mediterranean reveals the heterogeneity of their distribution in time and space as well as stresses the need of more and longer reconstructions. Better knowledge of drought variability would help to improve regional models of climate extremes and the understanding of atmospheric patterns related to their development.

Annex C: Conference programme

International Conference on **DROUGHT: Research and Science-Policy Interfacing**

March, 10th – 13th, 2015

Venue: Ciudad Politécnica de la Innovación. Universitat Politècnica de València, Spain

Conference Programme

Tuesday, March 10th, 2015

08:00-09:00 *Registration*

09:00-10:00 **Opening session**
FRANCISCO MORA, Rector of the Technical University of Valencia (UPV)
LIANA ARDILES, Water General Director, Spanish Ministry of Agriculture, Food and Environment
MARIA ÁNGELES UREÑA, President, Júcar River Basin Partnership
DIONISIO GARCÍA, Chief Executive Officer, Valencia Water Supply Company
HENNY VAN LANEN, Coordinator of the EU-funded project DROUGHT- R&SPI
JOAQUÍN ANDREU, Director of the Department of Hydraulic and Environmental Engineering at UPV

10:00-10:30 **INVITED: Fostering Drought Research and Science-Policy Interfacing: Achievements of the DROUGHT-R&SPI project**
H.A.J. Van Lanen, L.M. Tallaksen, D. Assimacopoulos, K. Stahl, W. Wolters, J. Andreu, S.I. Seneviratne, L. De Stefano, I. Seidl, F.C. Rego, A. Massarutto, E. Garnier

10:30-11:00 *Coffee break*

11:00-13:00 **Session 1: Drought as a Natural Hazard and its Impacts (1)**
Chairperson: L.M. Tallaksen

11:00-11:30 **INVITED: Physical characteristics and drivers of drought in Europe – a summary of the DROUGHT-R&SPI project**
L.M. Tallaksen, J.H. Stagge, K. Stahl, L. Gudmundsson, R. Orth, S.I. Seneviratne, A.F. Van Loon, H.A.J. Van Lanen

11:30-11:45 **European historic droughts beyond the modern instrumental records 16th-20th centuries**
E. Garnier

11:45-12:00 **A comprehensive drought climatology for Europe (1950 - 2013)**
L. Gudmundsson, S.I. Seneviratne

12:00-12:15 **An Assessment of Past and Projected Future Hydro-Climatic Extremes over Key Watersheds within Western Canada**
B.R. Bonsal

12:15-12:30 **Climate change and drought in the South of Carpathian basin and transboundary implications**

B. Meyer, G. Mezósi, V. Blanka, Zs. Ladanyi

- 12:30-12:45 Ex-post evaluation of the socio-economic impacts of drought in some areas in Europe
D. Musolino, A. Massarutto, A. de Carli
- 12:45-13:00 Analysis of Guadalquivir droughts 2004-2012 based on SEEA-W tables
M.M. Borrego-Marín, J.M. Perales, A. Posadillo, C. Gutiérrez-Martín, J. Berbel
- 13:00-14:00 *Lunch*
- 14:00-15:00 Session 2: Drought as a Natural Hazard and its Impacts (2)
Chairperson: F.C. Rego
- 14:00-14:15 Impact of drought on the inhabitants of the Cuvelai watershed: A qualitative exploration
R. Lütke-meier, S. Liehr
- 14:15-14:30 Analysis of the Pattern of Rainy Season and its Impacts on Agricultural and Water Resources Sectors in Northeast Semi-Arid in Brazil
M.S. Sakamoto, A.G. Ferreira, A.C. Costa, E.S. Olivas
- 14:30-14:45 Drought effects on rainfed agriculture using standardized indices: A case study in SE Spain
S. Contreras, J.E. Hunink
- 14:45-15:00 Integration of climate time series and MODIS data as an analysis tool for forest drought detection
C. Domingo, X. Pons, J. Cristóbal, M. Ninyerola, B. Wardlow
- 15:00-15:30 Session 3: Drought Identification and Characterization (1)
- 15:00-15:30 INVITED: Using standardized precipitation and runoff indices for the identification of extraordinary drought events in Chile
B. Fernández, J. Gironás
- 15:30-16:00 *Coffee break*
- 16:00-17:30 Session 4: Drought Identification and Characterization (2)
Chairperson: B. Fernández
- 16:00-16:15 Improving operational drought definitions – taking them to basin scale
M. Oertel, F.J. Meza, J. Gironás
- 16:15-16:30 On the use of modelled soil moisture for drought assessment over Europe
C. Cammalleri, F. Micale, J. Vogt
- 16:30-16:45 Chronology of drought termination for long records in the Thames catchment
S. Parry, C. Prudhomme, R. Wilby, P. Wood
- 16:45-17:00 Variability and patterns of drought characteristics Based on SPEI in the Huang-Huai-Hai Plain between 1981 and 2010
Q.F. Wang, J.J. Wu, G.P. Geng, H.K. Zhou, X.Y. Mo
- 17:00-17:15 Application of the Standardized Precipitation Index (SPI) in Hawke's Bay, New Zealand
L. Sadeghi, A.Y. Shamseldin

17:15-17:30 Assessment of runoff generation in high elevation Andean catchments to improve drought management in Central Chile
A. Nauditt, L. Ribbe, P. Álvarez, N. Kretschmer, C. Soulsby, R. Becker

Wednesday, March 11th, 2015

08:30-09:00 INVITED: European experience with Science-Policy Interfacing to cope with drought
W. Wolters, J. Andreu, D. Assimacopoulos, F. Puma, S. Dias, I. Seidl, H.A.J. Van Lanen

09:00-10:30 Parallel session 5.1: Drought Indicators, Monitoring and Forecasting (1)
 Chairperson: J.D. Connor

09:00-09:15 Drought monitoring in a transboundary river basin in North America
J.A. Breña-Naranjo, A. De Jesús, A. Pedrozo-Acuña

09:15-09:30 Definition of optimal drought-oriented reservoir management policies combining stochastic programming and fuzzy logic
H. Macian-Sorribes, M. Pulido-Velazquez

09:30-09:45 A preliminary assessment of meteorological and hydrological drought indicators for application to catchments across the UK
L.J. Barker, J. Hannaford, C. Svensson, M. Tanguy

09:45-10:00 An approach to monitor drought conditions and impacts
F. Perez, I. Angeluccetti, W. Cámara, A. Demarchi

10:00-10:15 Improving resilience to drought of the Apulian regional water supply system – a hydroeconomic model
C. Arena, M. Cannarozzo, A. Fortunato, I. Scolaro, M.R. Mazzola

10:15-10:30 Water scarcity cost as a drought indicator through hydroeconomic modelling. Application to the Júcar river basin
A. López-Nicolás, M. Pulido-Velazquez, A. Sales-Esteban

09:00-10:30 Parallel session 5.2: 4th Pan European Drought Dialogue Forum (1)
 Chairperson: W. Wolters
 How to implement the EU Guidance on Ecological Flows?
T. Petitguyot (from Brussels by Video Conference)
 Implementation of SPI results in the Júcar and in other Mediterranean River Basins
T. Estrela
 Experiences of the UK Environmental Agency
P. Smith
 Efficient use of water in irrigated agriculture, science-policy-implementation in Portugal
G. Leal

10:30-11:00 Coffee break

11:00-12:00 Parallel session 6.1: Drought Indicators, Monitoring and Forecasting (2)
 Chairperson: J. Paredes-Arquiola

11:00-11:15 A simple method to estimate irrigation date for soil moisture modeling and agricultural drought monitoring in irrigated regions
H.K. Zhou, J.J. Wu, Q.F. Wang, X.Y. Mo, T.J. Lei, G.P. Geng, X.H. Li

11:15-11:30 The Debate on Sustainable Water Management: Evidence from Drought in the Júcar Basin
J. Albiac, A. Dinar, M. Taher Kahil, E. Esteban

11:30-11:45	Integrated modelling to assess low flow risk in the coastal area of the VuGia ThuBon River Basin, Central Vietnam <i>L. Ribbe, A. Nauditt, T.Q. Viet, A.B.M. Firoz, T.T. Van</i>
11:45-12:00	Water markets in Spain: a tool for drought mitigation <i>S. Palomo-Hierro, J.A. Gómez-Limón, L. Riesgo</i>
11:00-12:00	Parallel session 6.2: 4 th Pan European Drought Dialogue Forum (2) Chairperson: W. Wolters Guided dialogue on how to move from S&PI to S&PI-I
12:00-13:00	Session 6: Drought Indicators, Monitoring and Forecasting (3) Chairperson: M.M. Saravi
12:00-12:15	Decision support system for drought management in a transboundary context <i>B. Richaud, O.Z. Jessen, K. Cross</i>
12:15-12:30	Applying the WARGI DSS to optimize water supply systems under drought conditions: Analysis of the South-Sardinia water system <i>G.M. Sechi, R. Zucca</i>
12:30-12:45	Enhancing drought monitoring and early warning by linking indicators to impacts - an international perspective <i>J. Hannaford, M. Acreman, K. Stahl, S. Bachmair, M. Svoboda, C. Knutson, N.D. Crossman, I.C. Overton, M.J. Collof</i>
12:45-13:00	Evaluation of drought indices forecasts in northeastern Brazil <i>E.A. Canamary, D.S. Reis, E.S. Martins</i>
13:00-14:00	<i>Lunch</i>
14:00-15:00	Session 7: Drought Indicators, Monitoring and Forecasting (4) Chairperson: L. de Stefano
14:00-14:20	INVITED: Drought in South-Eastern Europe: monitoring and management <i>G. Gregoric, A. Sušnik</i>
14:20-14:40	INVITED: Drought and Water Scarcity in Iran: How to cope with and prepare for it? <i>M.M. Saravi, R. Shahbazi, A. Malekian</i>
14:40-15:00	INVITED: Drought Monitoring and Forecasting for Africa and Latin America: Princeton's development towards a global capability <i>E. Wood</i>
15:00-16:00	POSTER SESSION (<i>Coffee break</i>)
16:00-17:30	Session 8: Early Warning Systems Chairperson: E. Wood
16:00-16:15	Improved rainfall-runoff modelling tools for low-flow forecasting: Application to French catchments <i>C. Perrin, M.H. Ramos, V. Andréassian, P. Nicolle, L. Crochemore, R. Pushpalatha</i>
16:15-16:30	Developing a framework for drought forecasting and warning: Results of the DEWFORA project <i>M. Werner, S. Vermooten, A. Iglesias, J. Vogt, G. Naumann</i>

- 16:30-16:45 El Niño/La Niña events as a tool for regional drought monitoring in Southern South America
J.A. Rivera, O.C. Penalba
- 16:45-17:00 Seasonal Hydrologic Forecasting Under Drought Conditions in the Upper Jucar River Basin, Spain
M.A. Pérez-Martín, M.A. Escudero, P. del Amo, S. Moll
- 17:00-17:15 Seasonal forecasts of hydrological drought in the Limpopo basin: Getting the most out of a bouquet of methods
M. Seibert, P. Trambauer
- 17:15-17:30 Use of seasonal climate predictions in the water sector
L. Pouget, T. Roldán, M. Gómez, A. Cabello, E. Rodríguez-Camino, B. Navascues, J. Voces, P. Comas, F. Pastor, M.C. García-Gómez, J.J. Gil, D. Gil, R. Galván
- 19:00-20:30 Valencia City center walking tour
- 20:30 Gala dinner: [Ayre Hotel Astoria Palace](#) (Plaza Rodrigo Botet, 5, Valencia)

Thursday, March 12th, 2015

- 08:30-10:00 **Session 9: World Bank Panel**
Chairperson: E. De Nys
The U.S. Drought Monitor: Evolution and Recent Achievements
M. Svoboda
Institutionalizing proactive drought management approaches in Brazil
I. Braga-Ramos, C. Molejón, E. De Nys
World Bank programs and decision support tools on climate change and drought adaptation and resilience
N. Engle
Institutionalizing proactive drought management approaches in Asia and Africa
M. Wijnen, N. Limones-Rodriguez
- 10:00-10:30 **Session 10: Drought Risk and Vulnerability (1)**
- 10:00-10:30 **INVITED: An impact perspective on pan-European drought sensitivity**
K. Stahl, I. Kohn, L. De Stefano, L.M. Tallaksen, F.C. Rego, S.I. Seneviratne, J. Andreu, H.A.J. van Lanen
- 10:30-11:00 *Coffee break*
- 11:00-13:00 **Session 11: Drought Risk and Vulnerability (2)**
Chairperson: K. Stahl
- 11:00-11:15 Exploring situations of vulnerability to drought from a sectorial perspective: A starting point for regional assessments
I. González-Tánago, M. Ballesteros, J. Urquijo, L. De Stefano
- 11:15-11:30 The dynamics of vulnerability to drought in Europe
V. Blauhut, K. Stahl, I. Kohn
- 11:30-11:45 Drought vulnerability assessment and identification of potential adaptation options in insular Mediterranean areas: An application in the Aegean islands
P. Stathatou, E. Kampragou

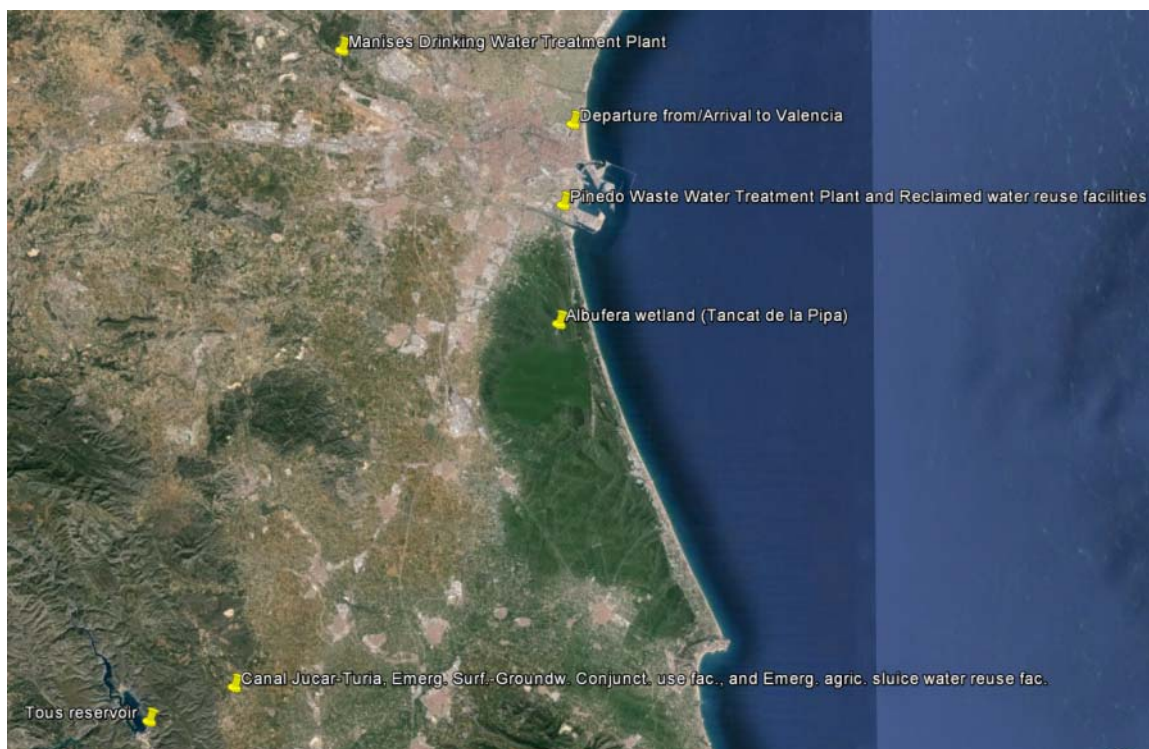
11:45-12:00	Vulnerability to drought: Mapping underlying factors across Europe <i>M. Ballesteros, I. Gonzáles-Tánago, J. Urquijo, L. De Stefano</i>
12:00-12:15	Drought and agricultural insurance in Spain <i>J.C. Cuevas</i>
12:15-12:30	Drinking water supply management for the metropolitan area of Valencia under drought conditions <i>J. Macián, J. Castillo</i>
12:30-12:45	Criteria to assess urban water supply systems resilience to droughts and scarcity <i>F. Cubillo, J.C. Ibáñez</i>
12:45-13:00	Securing drinking water supply during extreme drought – learnings from South Australia <i>J. Frizenschaf, L. Mosley, R. Daly, S. Kotz</i>
13:00-14:00	<i>Lunch</i>
14:00-15:30	Session 12: Drought Policies, Water Management and Governance Chairperson: J. Andreu
14:00-14:30	INVITED: The Australian experience in managing through protracted drought <i>J.D. Connor, J.M. Kirby</i>
14:30-14:45	Implementing the National Drought Policy in Mexico: challenges and strategies for a sound water resources management <i>F.I. Arreguin Cortés, M. López Pérez, F. Rosales Ángeles</i>
14:45-15:00	From drought planning to drought management: administrative and follow-up tasks <i>J. Ferrer Polo, N. Mondéjar Martín</i>
15:00-15:30	INVITED: Towards policy recommendations for future drought risk reduction <i>E. Kampragou, D. Assimacopoulos, L. De Stefano, J. Andreu, D. Musolino, W. Wolters, H.A.J. Van Lanen, F.C. Rego, I. Seidl</i>
15:30-16:00	<i>Coffee break</i>
16:00-16:30	INVITED: MSP & RSPI for Drought Planning and Management in the Jucar River Basin, Spain <i>J. Andreu</i>
16:30-17:30	CONCLUSION PANEL & CLOSING Chairperson: H.A.J. Van Lanen Discussion panel: Erik Wood, Gregor Gregoric, Mark Svoboda, Mohsen Saravi, Milada Stastna, Zoran Nakic

Friday, March 13th, 2015

TECHNICAL VISIT: Júcar-Turia River Basins: Drought planning and management - Critical issues and facilities to reduce vulnerability and to improve resiliency

08:30	Departure from UPV-meeting point no. 8 - Bus
8:30 - 9:45	<i>Travelling</i>

9:45 - 10:45	Tous reservoir
10:45 - 11:15	<i>Travelling</i>
11:15 - 12:45	Jucar-Turia Canal, Emergency Surface-Groundwater Conjunctive use facilities, and Emergency agricultural sluice water reuse facilities
12:45 - 13:45	<i>Travelling</i>
13:45 - 15:45	Manises Drinking Water Treatment Plant (includes lunch)
15:45 - 16:15	<i>Travelling</i>
16:15 - 17:30	Pinedo Waste Water Treatment Plant and Reclaimed water reuse facilities
17:30 - 17:45	<i>Travelling</i>
17:45 - 19:00	Albufera wetland (Tancat de la Pipa - green filter experimental facility)
19:00 - 19:30	<i>Travelling</i>
19:30	Arrival to Valencia UPV-meeting point no. 8



Annex D: Index of the proceedings book

Drought: Research and Science-Policy Interfacing – Andreu et al. (Eds)
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Drought indicators, monitoring and forecasting

Indicators and monitoring

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Annex E: Images of the conference









