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Integration of research advances in modelling and monitoring in support of WFD river basin management planning in the context of climate change

Philippe Quevauviller [a,*,1], Damia Barceló [b], Martin Beniston [c], Slobodan Djordjevic [d], Richard J. Harding [e], Ana Iglesias [f], Ralf Ludwig [g], Antonio Navarra [h], Alícia Navarro Ortega [b], Ole Mark [i], Roberto Roson [j], Daniel Sempere [k], Markus Stoffel [c], Henny A.J. van Lanen [l], Micha Werner [m,n]

[a] Vrije Universiteit Brussel (VUB), Dept. Hydrology and Hydrological Engineering, IUPWARE, Pleinlaan 2, B-1080 Brussels, Belgium
[b] Dept. Environmental Chemistry, IDAEA-CSIC, Jordi Girona, 18-26, 08034 Barcelona, Spain
[c] Université de Genève, 24 rue du Général Dufour, 1211 Genève 4, Switzerland
[d] University of Exeter, North Park Road, Exeter EX4 4QF, United Kingdom
[e] Centre for Ecology and Hydrology of the Natural Environment Research Council, Maclean Building, Wallingford, OX10 8BB, United Kingdom
[f] Universidad Politecnica de Madrid, 7 Avda Ramiro Maeztu, 28040 Madrid, Spain
[g] Ludwig-Maximilians-Universitaet Muenchen (LMU), Dept. Geography, Luisenstr. 37, D-80333 Munich, Germany
[h] Centro Euro-Mediterraneo per i Cambiamenti Climatici, 44 Viale Aldo Moro, Bologna, Italy
[i] Agern Allé 5, DK-2970 Hørsholm, Denmark
[j] Universita' Ca' Foscari di Venezia, Dipartimento di Scienze Economiche, Cannaregio S.Giobbe 873, 30121 Venezia, Italy
[k] Centre de Recerca Aplicada en Hidrometeorologia, Universitat politècnica de Catalunya, Gran Capità, 2-4, 1exus-106, 08034 Barcelona, Spain
[l] Wageningen University, Centre for Water and Climate, Hydrology and Quantitative Water Management, Droevendaalsesteeg 4, Wageningen, The Netherlands
[m] Deltares, Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands
[n] UNESCO-IHE Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands

HIGHLIGHTS

► The paper provides a snapshot of EU water policies and the way they integrate climate change considerations.
► Milestones of the EU Water Framework Directive are studied in the light of future climate change adaptation requirements.
► Research trends are illustrated by a number of selected research projects funded by the EU Framework Programme and national projects.
► Recommendations arising from research are provided on various water-related aspects concerned by climate change.
► Perspectives for strengthening links among the scientific and policy-making communities in this area are also highlighted.

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ABSTRACT

The integration of scientific knowledge about possible climate change impacts on water resources has a direct implication on the way water policies are being implemented and evolving. This is particularly true regarding various technical steps embedded into the EU Water Framework Directive river basin management planning, such as risk characterisation, monitoring, design and implementation of action programmes and evaluation of the "good status" objective achievements (in 2015). The need to incorporate climate change considerations into the implementation of EU water policy is currently discussed with a wide range of experts and stakeholders at EU level. Research trends are also on-going, striving to support policy developments and examining how scientific findings and recommendations could be best taken on board by policy-makers and water managers within the forthcoming years. This paper provides a snapshot of policy discussions about climate change in the context of the WFD river basin management planning and specific advancements of related EU-funded research projects. Perspectives for strengthening links among the scientific and policy-making communities in this area are also highlighted.

1. Introduction

The river basin management planning as a key tool adopted by the Water Framework Directive (WFD, European Commission, 2000) is based on a stepwise approach including risk characterisation, monitoring and programmes of measures (Chave, 2001; Quevauviller et

* Corresponding author.
E-mail addresses: philippe@quevauviller.be (P. Quevauviller), Ole.Mark@dhigroup.com (O. Mark), sempere@crahi.upc.edu (D. Sempere).
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al., 2008). Besides “classical” risks of water quality deterioration and overexploitation (which have to be considered in the light of “good status” achievements by 2015), discussions are on-going at EU level about climate change-related risks and their implications on water management, as well as on the need to better integrate scientific knowledge into policy developments (Quevauviller, 2011). This issue is particularly acute in the light of the Blueprint to Safeguard Europe's Water Resources which includes options for making the 2nd river basin management plan of the WFD “climate-proof”. In particular, the integration of knowledge about possible climate change impacts on water policy implementation concerns many technical aspects such as risk characterisation, monitoring, action programmes, as well as the evaluation of the “good status” objectives of the WFD. These questions have been and are currently discussed within comprehensive working groups of experts and stakeholders in the framework of the so-called WFD Common Implementation Strategy (CIS), which was launched in 2001 at the request of the EU Member States and which is now in its 4th stage (2010–2012). This paper provides insights into key issues which are discussed within this framework. The second part presents specific research advances, as described by EU-funded projects, which have a link with policy developments. The paper concludes by discussions on perspectives for strengthening links among the scientific and policy-making communities in this area. Considerations expressed in this paper built upon recent publications (Quevauviller et al., 2011; Quevauviller, 2011).

1.1. WFD and climate change

The WFD implements a stepwise approach with the aim to achieve good water status by 2015 (chemical status for all waters, ecological status for surface waters, and quantitative status for ground waters). As will be discussed later in this paper, the different policy milestones (issued from legal requirements of the WFD, in particular Articles 5, 8, 11 and related annexes) which are summarised below may be directly or indirectly impacted by climate change:

- Delineation and characterisation of water bodies (considered as reporting units in the directive) within River Basin Districts — this step directly relies on water system understanding (and a proper analysis of pressures and impacts), which may be influenced by climate change impacts. This classification was carried out by Member States between 2004 and 2005 and results were reported to the European Commission. A report giving a synthesis of Member States' reports was prepared by the European Commission and published in March 2007[2] and a “fitness check” will also be published before the end of 2012.
- Establishment of registers of protected areas within each River Basin District — these areas are designated as requiring specific protection of their surface and ground waters or for the conservation of habitats and species directly dependent on water. These include water bodies used for the extraction of drinking water and all protected areas covered under the following directives: the Bathing Water Directive,[3] the vulnerable zones under the Nitrates Directive,[4] the sensitive areas under the Urban Wastewater Directive,[5] and the areas designated for the protection of habitats and species including relevant Natura 2000 sites designated under the habitat[6] and wild bird[7] directives.
- Design of monitoring networks based on the results of characterisation and risk assessment (performed in 2004–2005) — the monitoring programmes are aimed to provide a comprehensive overview of water status, which is an essential step of the overall management cycle, considering that monitoring data together with the characterization of the water bodies will constitute the backbone of status assessment.
- Development of a River Basin Management Plan (RBMP) for each river basin district in the European Union (including transboundary river basins). The plans include a presentation in map form of monitoring results, and summarizes pressures and impacts of human activity on water status, economic analysis of water use, protection programmes, and control and remediation measures. The first RBPM is operated over the period 2009–2015 with a review planned by the end of 2015 (prior to the launching of the second river basin management plan) and every six years thereafter.
- Consideration of the principle of recovery of costs for water services, including environmental and resource costs in accordance with the polluter pays principle.
- Design of a programme of measures for achieving WFD environmental objectives that should be operational by the end of 2012. Basic measures include, e.g. controls of groundwater abstraction, controls of point source discharges and diffuse sources liable to cause pollution etc. Supplementary measures include for example taxation, research (a full list of measures is available in Annex VI of the WFD). The programme of measures has to be reviewed and if necessary updated by 2015 and every six years thereafter.

The WFD does not classify climate change as an anthropogenic pressure in the narrow sense that the related impacts cannot be mitigated by current WFD programmes of measures (linked to the implementation of various EU directives), which are essentially directed towards anthropogenic pressures (mainly pollution but also overexploitation of water resources). It is, however, increasingly assumed that climate change might influence different steps of WFD implementation, and thus possibly the status objectives (Wilby et al., 2006; Ludwig et al., 2009; Quevauviller et al., 2011). These possible impacts are discussed in a guidance document published by the European Commission, which examines river basin management in a changing climate (European Commission, 2009a). It is noted that possible hydrometeorological risks affecting water management (mainly related to floods and droughts) are not specifically addressed in the WFD but that the directive nevertheless provides a framework to include climate change impacts into the planning process. In particular, ‘significant pressures’ affecting waters (to be characterised as required by the WFD) could be considered as including climate change (Wilby et al., 2006), which could lead to impacts on e.g. river flow regimes, precipitations and water level fluctuations (Wilby et al., 2006; Ludwig et al., 2009). In addition, climate change might exacerbate existing or future anthropogenic pressures and should hence be considered within the policy framework. Other impacts might for instance occur in relation to extreme floods and droughts. Potential climate change impacts on WFD milestones are discussed in the above referred guidance document (European Commission, 2009a) which has been built upon principles of the European Commission's White Paper on ‘Adapting to climate change’ (European Commission, 2009b). One feature of this document is the identification of adaptation strategies to increase the resilience to climate change of a wide range of sectors, including by improving the management of water resources and ecosystems.

Complementing the WFD management framework, flood prevention and management are tackled by the Flood Directive (2007/60/EC), which requires EU Member States to assess and manage flood risks, with the aim to reduce adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in Europe (European Commission, 2007a). This directive has to be coordinated with the implementation of the WFD from the second river basin management plan onward. It therefore provides a comprehensive mechanism for assessing and monitoring

[2] Commission Water Framework Directive report, March 2007.
[3] Directive 76/160/EEC, OJ L31 of 5.02.1976.
[4] Directive 91/676/EEC, OJ L375 of 31.12.1991.
[5] Directive 91/271/EEC, OJ L135 of 30.05.1991.
[6] Directive 92/43/EEC, OJ L206 of 22.07.1992.
[7] Directive 79/409/EEC, OJ L103 of 25.04.1979.

increased risks of flooding, taking into account the possible impacts of climate change, and for developing appropriate adaptation approaches. Water scarcity and droughts are also considered in the policy context (European Commission, 2007b). In particular, an annual European assessment of water scarcity and droughts is conducted by the European Commission in the framework of the Water Scarcity and Drought Communication to monitor changes across Europe (European Commission, 2010) and to identify where further action is needed in response to climate change. A review of the strategy for water scarcity and droughts as well as policy options are currently developed at EU level in the context of the Blueprint to Safeguard Europe's Water Resources due to be published at the end of 2012. It may, therefore, be considered that the successive steps of the WFD River Basin Management Planning (RBMP) and the related flood and drought policy framework may conveniently incorporate adaptation to climate-related water risks through risk assessment, monitoring, environmental objective setting, economic analysis and action programmes to achieve well defined environmental objectives (European Commission, 2009a).

The need for policy and management responses to tackle climate change impacts on water is recognised worldwide (Bates et al., 2008; Field et al., 2012). Some recommended policy principles include the need to anticipate changes to water systems that are climate sensitive, to understand the extent and causes of variability and change at reference sites (in particular, the most vulnerable ones), to assess direct and indirect influences on pressures due to climate change, and to identify and closely monitor climate change “hot spots”. Guiding principles for adaptation favour options that are robust to the uncertainties in climate projections and integrate cross-sectoral delivery of adaptation measures (in line with the river basin management planning). At EU level, it is well recognised that the climate change dimension will increasingly have to be integrated into WFD river basin management planning (European Commission, 2009a). As said before, climate change impacts indeed interact with and potentially aggravate other anthropogenic pressures, e.g. changes in precipitation and hotter/drier summer periods alter both the availability of water and the demand for water for uses such as agriculture and tourism. Lower water levels may lead to an increase in the concentration of pollutants (less dilution) and higher surface water temperatures. The integration of climate change considerations into WFD river basin management planning is discussed in details in the above mentioned guidance document (European Commission, 2009a) and in recent publications (Wright et al., 2011; Quevauviller, 2011).

1.2. Taking account of the knowledge base

The WFD and its parent legislation provide a policy platform that enables building up communication and best practice exchanges among all actors involved in water management at EU level (policy implementers, technology providers, scientific community, industrial stakeholders, NGOs etc.). This is done in the context of the Common Implementation Strategy (Quevauviller et al., 2011). Besides policy discussions, research activities strive to support the WFD implementation and related water policies, actually following trends that have started in the early days of the Framework Programmes (FP) for Research and Technological Development (RTD) (Schmitz et al., 1994) and which have been pursued within the Sixth (2002–2006) and Seventh (2007–2013) Framework Programmes.

Examples of research areas relevant to water policies address pressures on environment and climate, impacts and feedbacks, environment and health, conservation and sustainable management of natural resources (including groundwater), evolution of marine environments, environmental technologies, understanding of natural hazards and improved preparedness, forecasting methods and assessment tools, and earth observation (Quevauviller et al., 2011). In the area of climate policy, research related to climate change and water strives to improve understanding and modelling of climate changes related to the hydrological cycles at scales that are relevant to decision-making (preferably linked to policy-making). Scientific information about water-related impacts of climate change has grown, but it is still not sufficient, especially with respect to water quality, aquatic ecosystems and groundwater, including their socio-economic dimensions, and this requires increasing research efforts. Current research into climate-change impacts on the water cycle and related extreme events (in particular floods and droughts) is developing knowledge to better understand and assess key drivers and their interactions for improving the management and mitigation of risks and uncertainties. Examples of climate-related research projects funded by the 6th and 7th Framework programmes, with focus on modelling and monitoring are described in the following paragraph.

2. Current research

2.1. Introduction

As mentioned above, a range of EU-funded and national research projects are directly or indirectly supporting water and climate policies, in particular the scientific challenges posed by the WFD and other policies. Some of these are used as examples in this paper. For a more exhaustive list of projects, the reader is invited to consult available project catalogues produced by the European Commission and related papers (European Commission, 2009c; Quevauviller, 2010a, 2010b; Quevauviller et al., 2011; European Commission, 2011). Projects presented in this paper were selected according to their current status (either just terminated at the stage of writing of this paper or on-going).

2.2. Climate change impacts on the water cycle and ecosystems

2.2.1. Investigating climate change impacts on the global water cycle

The aim of the EU F6 funded project, *Water and Climate Change* (WATCH[8]) was to produce consistent analyses of components of the terrestrial water cycle (runoff, soil moisture etc.) for the past (20th C) and the future (using GCM outputs) (Harding et al., 2011). While these have global coverage they also have considerable use regionally — particularly across Europe. The WATCH Forcing Data provides consistent meteorological driving data at a 50 by 50 km grid for the 20th C (Weedon et al., 2011). When used with a suitable hydrological model this data set has been shown to perform well at the basin scale, when compared to locally derived forcing data sets (Van Huijgevoort et al., 2010; Prudhomme et al., 2011). Climate model outputs are known to have considerable biases in rainfall (and other meteorological variables). The WATCH Forcing Data has been combined with outputs from a number of climate models to derive consistent bias corrected forcing data sets for 21st C and, using a range of hydrological models, predictions of runoff etc. All these data sets are publically available, see http://www.eu-watch.org/data_availability.

Performing an inter-comparison of land surface and hydrological models has shown a considerable spread in the outputs — this illustrates the need to choose carefully the hydrological model used for climate impact analyses. If possible it is preferable to rely on a number or ensemble of models (Haddeland et al., 2011), especially when considering future water availability. For its regional assessment WATCH collated daily time series of over 400 river flows from small near-natural basins across Europe. These data show a climate change signal — with consistent changes to summer low flows in many European basins, except the Nordic countries (Stahl

[8] http://www.eu-watch.org/.

et al., 2010). These data have also been applied to a range of hydro-climatic regions within Europe, which provides a basis for drought and flood atlases. These atlases provide spatial–temporal evolution of droughts (and floods) for the past and future across Europe in a single diagram. However the availability of flow data used in this study is patchy across Europe and there is a need to intensify efforts to digitise and make available such river flow data (Hannaford et al., 2011; Stahl et al., 2012).

The WATCH experience has shown that by uniting hydrologists and climate scientists it is possible to produce robust and consistent estimates of components of the hydrological cycle (river flow, soil moisture, evaporation etc.). A climate change signal is already evident across Europe — although it is often masked by large variability and other anthropogenic interventions. The influence of rising greenhouse gas (GHGs) emissions will increase in the future, causing regionally increased water scarcity and extremes. There are many research challenges – one in particular is to improve the representations of a range of processes in our large-scale hydrological models – to include, for example, groundwater, water extractions and dams. A second pressing challenge is to better co-ordinate the collection of, and access to, hydrological data across Europe (and worldwide) to support water vulnerability assessments (see also Beniston et al., 2012).

The WATCH results will underpin policy developments across Europe by providing estimates of river flows, water availability and scarcity which are consistent (in scale and methodology) for 20th and 21st centuries and across countries and basins.

2.2.2. Regional assessment of climate change impacts in the Mediterranean

The CIRCE project has developed for the first time an assessment of climate change impacts in the Mediterranean and their consequences to society and the economy (Navarra and Tubiana, 2012). CIRCE (EU 6th Framework Programme project) involved 64 partners from Europe, Middle East and North Africa working together to evaluate the best strategies of adaptation to the climate change in the Mediterranean region. Beyond research, in CIRCE, the role of public engagement was fundamental, especially at the local level. To identify the best policies to help Mediterranean communities adapt to the effects of climate change on water supply, a team of CIRCE scientists (Iglesias et al., 2011a, 2011b) has created a methodology that links science outputs to water management policy options. Water demand often exceeds supply in Mediterranean areas and, as climate change is predicted to raise temperatures by 2–4 °C in southern Europe and reduce river flows and surface runoff, the problem is likely to worsen.

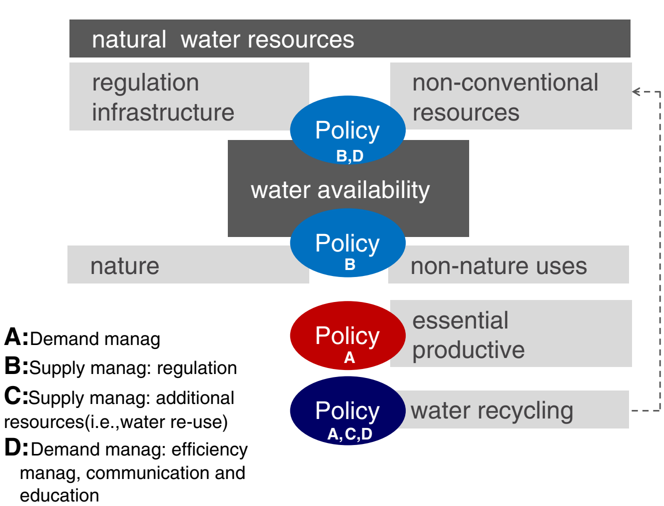

Fig. 1. Water availability and policy assessment model. Adapted from Garrote et al., submitted for publication.

As a result, communities living around the Mediterranean may need to make significant social and political changes to ensure water supply and demand are managed and that available water is effectively distributed to meet the needs of agricultural and urban users as well as ecosystems.

This adaptation will need new water management policies which also meet the requirements of the EU Water Framework Directive and the associated Common Implementation Strategy. However, translating scientific observations and analyses of changes in water availability into water management policy can be a challenge. To address this, a methodology was developed to identify policy options based on scientific evidence. A water availability and policy assessment (WAPA) model (Garrote et al., submitted for publication) that takes data on rivers, reservoirs, water flow, environmental conditions and agricultural and urban demand, is used to link supply, demand and management options (Fig. 1).

The results suggest that there was no single optimal management option for the area as the climate changed. Instead, more risk-adverse policymakers may prefer to reduce the supply of water for irrigation, whereas those willing to accept a greater level of risk could opt for a less reliable water supply. An indication of how socio-economic factors could affect a region's ability to adapt to climate change is estimated with an adaptive capacity index. For example, economic factors could determine whether a region could invest in new technologies for water treatment. The adaptive capacity index is based on specific policy-relevant indicators for each country, normalised against a baseline. When applied to seven Mediterranean countries the index suggested that France had the greatest adaptive capacity at 0.687 (on a scale of zero to one), followed by Italy at 0.599. At the bottom of the list was Syria, on 0.306. Finally, the research identified water scarcity thresholds based on reliability of supply and whether supply could meet demand and related these to policy options. From this, it is possible to prioritise a number of possible policy responses to different levels of water scarcity and adaptive capacity. For instance, where water scarcity is low (i.e. water is plentiful) and social and economic factors are the weakest component of adaptive capacity, the area requires supply management policies, such as infrastructure investments to ensure equal access to water. In contrast, when water is scarce the same region may need policies to ensure that water pricing and prioritisation do not disadvantage poorer people.

2.2.3. Assessing climate impacts on the quantity and quality of water in vulnerable mountain environments

The ACQWA project is investigating the vulnerability of water resources in mountain regions such as the European Alps, the Central Andes, or the Tien Shan range of Central Asia where declining snow and ice are likely to strongly affect hydrological regimes in a warmer climate. Current generations of state-of-the-art models are applied to various interacting elements of the climate system, namely regional atmospheric processes in complex terrain, snow and ice, vegetation, and hydrology in order to project shifts in water regimes in a warmer climate in these mountains (e.g., Beniston, 2011). Observations, targeted models, and methodologies from the social sciences are then used to analyze the impacts of changing water availability and seasonality on economic activities, in particular tourism, agriculture, hydropower or the mining sector.

These results are applied to assess how robust current water governance strategies are and what adaptations may be needed in order to alleviate the most negative impacts of climate change on water resources and water use, and to reduce the likely rivalries between economic actors that will be in strong competition for a declining resource (e.g., Beniston et al., 2011; Sorg et al., 2012). Because such a large proportion of surface waters in France, Germany, northern Italy and, via the Danube Basin, central and eastern Europe originate in the Alps, the strong focus of the ACQWA project on the source regions in the Swiss Alps will provide key findings of use to the EU Water Framework Directive. This will certainly require guidance through a portfolio of possible water governance strategies that should help alleviate future problems of water allocation and use, both in the upstream (i.e., mountains) and downstream (i.e., plains) regions.

2.2.4. Assessing and predicting effects on water quantity and quality in Iberian Rivers caused by global change

The SCARCE Project (www.idaea.csic.es/scarceconsolider) is a Consolider-Ingenio 2010 project from the Spanish Ministry of Economy and Competitiveness. SCARCE aims to examine and predict the relevance of global change on water availability, water quality and ecosystem services in Mediterranean river basins of the Iberian Peninsula, as well as their socio-economic impacts (Navarro-Ortega et al., 2012). Four basins have been selected (Llobregat, Ebro, Júcar and Guadalquivir) because of their representativeness of the different factors operating in the Mediterranean area. Most of these basins were/are included in EU projects (the Llobregat in MODELKEY, the Ebro in AQUATERRA, the Júcar in DROUGHT-R&SPI, or the Guadalquivir in AQUAMONEY and RAMWASS). The project is structured in ten thematic work packages (WPs), each of them dealing with one scientific discipline, from hydrology, chemistry and biology to modelling, economy and river management. Many interactions have been established between the different WPs in order to allow a complete flow of results between WPs. The final goals of SCARCE are to complete the monitoring and to advance in modelling of several issues. Regarding monitoring, WP4 QUALITY analyses the biological and chemical quality through extensive monitoring campaigns. WP3 MORPH deals with the morphological and sediment characterization of the river basins. WP5 PROCESS details on the ecosystem responses to hydrological, geomorphological and chemical disturbances. These monitoring data and others available from the water authorities (assembled by WP1 DATA) feed models of WP6 UPSCALE and WP8 SERVICES. The TETIS-SCARCE hydrological model will be implemented in medium-sized watersheds. This combined model incorporates a dynamic vegetation sub-model as well as inorganic nitrogen dynamics coupled to the hydrological TETIS model. In addition, a new sub-model will reproduce the temporal and spatial dynamic of some emerging contaminants in selected river reaches. The Aquatool water resources and water quality management integrated model will be also developed for some basins. Finally the services provided by river ecosystems will be assessed by the InVEST model. The InVEST is being tailored to Mediterranean networks, therefore accounting for the climate change impacts on ecosystem services in Mediterranean river basins. The linkages between InVEST and AQUATOOL will be strengthened to improve the evaluation of ecosystem services in different climate change scenarios. The amount of data generated in the monitoring campaigns, together with the application of this variety of models will generate reliable management tools aimed to improve the river basin management plans demanded by the WFD.

2.3. Climate change impacts on water and security

A recently launched cluster on ‘Climate change impacts on water and security’ builds up cooperation among EU countries and neighbouring Mediterranean countries (Ludwig et al., 2011).

2.3.1. Water availability and security in southern Europe and the Mediterranean

WASSERMed is a three year Collaborative Research project, involving eight European research centres and four partners from South Mediterranean.[9] The project builds on current climate projections in order to address present and future uncertainties in hydrological budgets in the Mediterranean area. The overall approach entails high level interdisciplinary research, combining climatic/hydrologic scenario building, water system modelling, and macroeconomic analysis. Emphasis is placed on the most significant and at-risk sectors, namely agriculture and tourism, in order to assess impacts and propose technological solutions and management practices towards their mitigation. WASSERMed is characterised by a combined micro–macro approach. At the micro level, five case studies are analyzed in depth (Syros [Greece], Sardinia [Italy], Merguelil [Tunisia], Jordan river [Jordan], Rosetta [Egypt]) using a common software as a Decision Support System. Research on the case studies is also coordinated with other projects in the CLIWASEC cluster.[10]

Through the case-study approach and stakeholder engagement processes, WASSERMed explores potential security threats, infrastructure requirements and integrated adaptation strategies in the five areas of the Mediterranean, taking into account diverse drivers of change and anticipated environmental and socio-economic implications. Foreseen stakeholder involvement activities are expected to foster mutual learning processes, raising awareness on climate induced changes and impacts, and enhancing the relevance and uptake of the WASSERMed research. At the macro level, WASSERMed explores the implications of changing climate conditions and water availability for the whole Mediterranean, for the two strategic sectors (agriculture and tourism), and from a systemic, macroeconomic perspective.

Impacts on agricultural activities are especially difficult to analyze, as they depend in a complex way on management practices, in particular irrigation. Changing climate will affect both the supply of water resources and the demand for water of the different cultivated crops. Adaptation involves a mix of changes in the crop patterns, seasonality, and irrigation techniques.

To analyze impacts on the tourism industry, climate scenarios obtained from selected RCM models are used to estimate future values for the Tourism Climate Index (TCI). This index measures the suitability of climate for general outdoor activities, which are relevant for summer tourism (the most important type of tourism in the area). Early results indicate that, contrary to some previous findings, climate suitability and attractiveness of Mediterranean destinations is not going to worsen, at least in the medium term (around 2050). However, impacts are differentiated among the different Mediterranean regions and changes in the seasonal distribution of tourists' arrivals are expected. The macroeconomic analysis carried out in the WASSERMed project deals with the generation of future economic scenarios, for use in the case studies, an assessment of the effects of changing agricultural productivity, as a consequence of varying water availability, and a study of the system-wide implications of changing tourism attractiveness. The whole analysis is based on a Computable General Equilibrium (CGE) model of the world economy, especially developed for WASSERMed. A CGE model is a very large non-linear system, including market clearing conditions and accounting identities, tracing the circular flow of income inside an economic system. The model is typically calibrated using national accounting data, and simulation exercises are performed by shocking exogenous variables and parameters.

Simulation exercises are being conducted to analyze what changes in the economic structure, competitiveness and trade flows are triggered by variations of water available for agriculture production. When water gets scarce, water intensive goods become more expensive to produce and the economy compensates through higher water imports (virtual water flows). Early results suggest that virtual trade may curb the negative effect of water scarcity, yet the consequences in terms of income and welfare remain quite significant, especially

[9] http://www.wassermed.eu.

[10] http://www.cliwasec.eu.

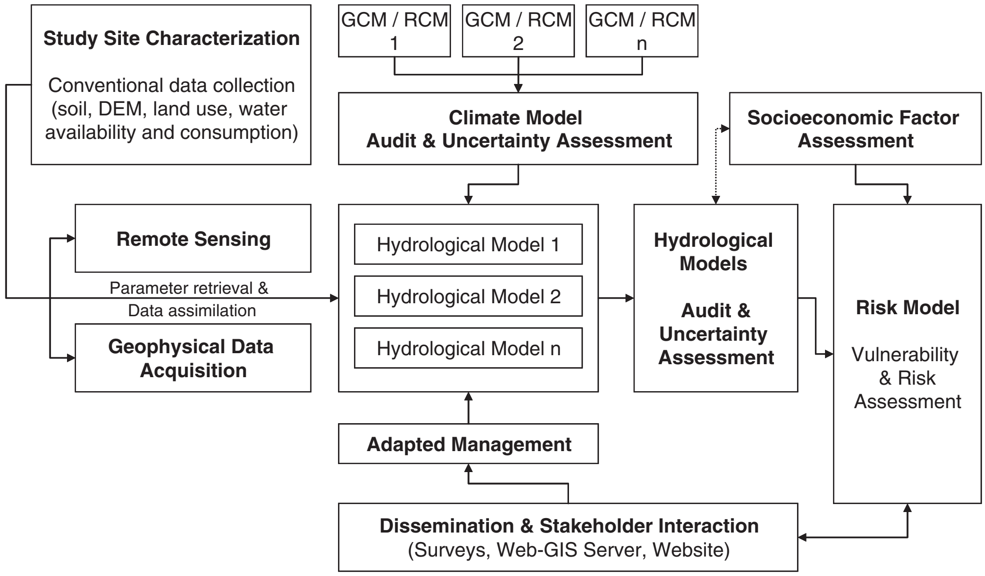

Fig. 2. Workflow of uncertainty quantification and adaptive management in the CLIMB project.

for some regions (e.g., Spain and Greece). The macroeconomic analysis of impacts of climate change and water for the tourism sector is based on estimates of the TCI index. Early results indicate that more incoming tourists will increase income and welfare, but this phenomenon will also induce a change in the productive structure, with a decline in agriculture and manufacturing, partially compensated by an expansion of service industries. In most countries, the decline in agriculture entails a lower demand for water, counteracting the additional demand coming from tourists and bringing about a lower water consumption overall.

2.3.2. Reducing uncertainty and quantifying risk through an integrated monitoring and modelling system

There are a number of major obstacles to the implementation of adaptation measures designed to achieve sustainable management of water resources in southern Europe, North Africa and the Middle East under conditions of climate change. Effective adaptation measures need to be prepared in a multi-disciplinary approach. While there is a scientific consensus that climate induced changes on the hydrology of Mediterranean regions are presently occurring and are projected to amplify in the future, very little knowledge is available about the quantification of these changes, which is hampered by lack of suitable and cost effective hydrological monitoring and modelling systems. To the extent that adaptation initiatives are being proposed and adopted, they are primarily by perceptions of individual stakeholders and are rarely based on a multi-disciplinary assessment covering both natural and associated social and economic changes. In its 4-year design, the FP7 Collaborative project CLIMB (www.climb-fp7.eu) improves modelling capabilities and develops appropriate tools to advance the capacity to assess climate effects on water resources and uses. The project consortium employs a combination of novel field monitoring concepts, remote sensing techniques, integrated hydrological modelling and socioeconomic factor analyses to reduce existing uncertainties in climate change impact analysis and to create an integrated quantitative risk and vulnerability assessment tool (see Fig. 2). Together, these provide the necessary information to design appropriate adaptive water resource management instruments and select suitable agricultural practices under climate change conditions. The integrated risk and vulnerability analysis tool also enables the assessment of risks for conflict-inducing actions, e.g. migration. The improved models, new assessment tools, and their results are evaluated against current methodologies. Improvements are communicated to stakeholders and decision makers in a transparent, easy-to-understand form, enabling them to utilize the new findings in regional water resource and agricultural management initiatives as well as in the design of mechanisms to reduce potential for conflict.

An analysis of climate change impacts on available water resources is undertaken in study sites located in Sardinia, northern Italy, Southern France, Turkey, Tunisia, Egypt and the Palestinian-administered area Gaza. The work plan is targeted to selected meso-scale river or aquifer catchments, with areas in the order of up to a few thousand square kilometres in the above mentioned partner and SICA countries, representing water management units for regional water authorities. Small-scale experimental sites within the watersheds in northern Italy and Sardinia are evaluated in depth for the extension and adaptation of existing and novel hydrological modelling tools. The site specific analysis enables an improved assessment and quantification of region-specific vulnerability and risk factors for agricultural, drinking, residential and industrial water. Advanced climate scenario analysis techniques are employed and dynamical and statistical downscaling of available ensembles of regional climate model simulations is performed to provide the drivers for an ensemble of hydro(−geo)logical models with different degrees of complexity in terms of process description and level of integration. The outputs of the climate-hydrological modelling chain are focused to deliver estimates of changes in hydrological components such as timing and frequency of extreme and effective precipitation, run-off, in-stream mean flow, soil moisture or groundwater balance.

Field monitoring and measurement strategies for surface and subsurface hydrological processes are tested and adjusted to the specific requirements in the study sites. Synergistic radar and optical remote sensing techniques are extensively employed to provide steady state parameters (e.g. land use, land cover, soil hydraulic properties), to retrieve dynamic model parameters (e.g. soil moisture and roughness, vegetation structures), to monitor process variables (e.g. infiltration, water stress) and to validate model results. Data assimilation procedures are crucial to incorporate relevant data and process understanding into existing modelling concepts, thereby significantly reduce uncertainty in predicted hydrological quantities. An important output of the research in the individual study sites is to develop a set of recommendations for an improved monitoring and modelling strategy for climate change impact assessment. Once the model concepts are optimized to adequately represent the current-state hydrology in the study sites, they will be tested over a range of selected

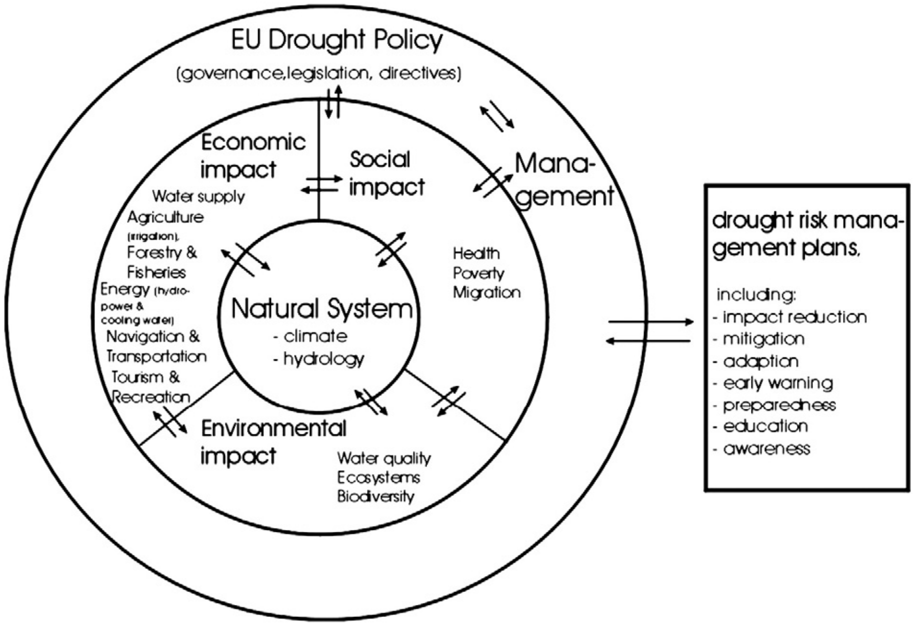

Fig. 3. Integration of relevant aspects towards a future EU Drought Policy.

climate change scenarios to project future hydrological budgets and extremes.

2.4. Climate change impacts on droughts

2.4.1. Identification of research gaps

The FP7 Support Action XEROCHORE (*An Exercise to Assess Research Needs and Policy Choices in Areas of Drought*[11]) synthesized the knowledge base on past, current and future drought. The analysis included hydro-climatic drivers of the natural hazard, environmental and socio-economic impacts, management and policy responses. The project provides a vision on research needs and steps forward towards incorporating drought risks within the WFD development. It describes a monitoring–modelling framework that combines observed and simulated data from the hydro-climatic, economic and environmental systems to assess (future) impacts of natural and human influences on drought frequency and severity. The framework includes: (i) detection of changes (e.g. trends) in time series of observed and modelled hydro-meteorological and impact data, (ii) attribution of changes (natural and/or anthropogenic) in historical drought frequency and severity, (iii) assessment of future changes, which require linking and coupling of climate, hydrological and impact models at the appropriate spatial scales, and (iv) analysis of uncertainty in detection, attribution and projections. The research vision also addresses the required paradigm shift from crisis to risk management, which currently gains more ground as a means of reducing Europe's risk at drought through a lower societal vulnerability. It underpins the importance of engaging into risk assessment and management practices and identifies policy gaps and requirements for further improvement of the drought management policy framework across scales: from the pan-EU to the river basin level (Kampragou et al., 2011). The policy-relevant outcome from XEROCHORE has been communicated through a set of Science Policy Briefs (see below) (Fig. 3).

Besides the overall vulnerability of global water resources to climate change, the above mentioned WATCH project also investigated spatio-temporal characteristics of past and future drought. An important outcome is the Drought Catalogue (Hannaford et al., 2011; Hannah et al., 2010) that proved to be a good basis for: (i) the spatio-temporal analysis of observed hydrological drought, (ii) comparison with large-scale climate drivers, to examine the causes behind major European events, and (ii) a benchmark against which historic drought of global hydrological models could be tested. Time series of observed river flow revealed a regionally coherent picture of mean annual flow trends and a pronounced gradient between positive (wetter) trends in the Northwest and negative (drier) trends in the Mediterranean and in the Southeast. The observations also revealed that summer low flows show drier trends over a larger area than the annual flow (Stahl et al., 2010). A multi-model ensemble mean obtained from 8 to 10 global hydrological models represents observed trends in river flow and average drought characteristics better than any single model (Stahl et al., 2012). Trend estimates are particularly reliable for annual runoff, winter runoff, and high flows. Multi-model experiments of global hydrological models and three GCMs (A2 emission scenario) revealed significant changes in runoff variability across Europe with a decrease in the north and an increase in the Mediterranean, which likely might be associated with a change in snow and evaporation conditions (Gudmundsson et al., 2011).

2.4.2. Current developments of research supporting drought policies

The recently started FP7 project DROUGHT-R&SPI (*Fostering European Drought Research and Science–Policy Interfacing*[12]) will reduce future Europe's vulnerability and risk to drought by investigating drought in six case study areas in water-stressed regions (e.g. Mediterranean, The Netherlands) with drought analyses at the pan-European scale. Databases with knowledge and experiences on past droughts at different scales are being developed. A drought typology (Van Loon and Van Lanen, 2011), including a better assessment of the role of groundwater (Van Lanen et al., submitted for publication) and an improved early drought warning at the pan-European scale based upon soil moisture are being developed, which will improve forecasting of a suite of interlinked physical and impact indicators. The collated state-of-the-art drought information will be used as a basis for an intercalibration experiment with

[11] http://www.feem-project.net/xerochore/.

[12] http://www.eu-drought.org/.

national, EU and other international projects. The study will create a better understanding of past droughts (e.g. underlying processes, occurrences, environmental and socio-economic impacts, past responses), which then will contribute to the exploration of assessment of drought hazards, impacts, potential vulnerabilities and promising management and policy options in the 21st Century. It will support the development or further improvement of drought management planning in the framework of the 2nd cycle of WFD River Basin Management Plans (2015). The policy options identified in the Blueprint to safeguard Europe's water (2012) will be important guidance. DROUGHT-R&SPI has been establishing a dialogue at different scales with actors in the water field right from the start of the project (see below). The work will be embedded in the expert network of the European Drought Centre (EDC) and linked with the European Drought Observatory (EDO) ensuring that the outcome will be consolidated beyond the project' lifetime.

In the final phase, the XEROCHORE project has contributed to the communication of research output in a readily-usable format for policy-makers through five Science–Policy Briefs (SPBs). Each SPB is linked to a particular WFD article, and identifies: (i) policy focus, (ii) purpose, (iii) policy milestones and relevant XEROCHORE key outputs, (iv) limitations identified by XEROCHORE, and (v) main recommendations (Fig. 4). In the DROUGHT-R&SPI project, science–policy interfacing has been taken on board directly from the beginning of the project. A dialogue is being searched with actors in the water field at different scales. A Case Study Dialogue Forum (CS-DDF) is being established in each of the six case study areas. In steps, the wide-ranging aspects of drought are being discussed, i.e.: (i) analysis of past natural hazards, socio-economic and environmental impacts, mapping underlying causes, and identification of responses by decision-makers and local users to mitigate drought impacts and enhance local resilience, (ii) exploration of future scenarios (future drought occurrences, socio-economic, environmental and policy factors that could affect drought vulnerability), and policies on potential options for long term risk mitigation, and (iii) assessment of options for long-term drought risk mitigation (effectiveness, cost, benefits and potential trade-offs, incorporating uncertainty). Parallel and interlinked with the CS-DDFs, pan-European Drought Dialogue Fora (pan-EU DDF) will be organised with policy-makers, stakeholders, water managers, NGOs and scientists to ensure that the design and review of EU water-related (incl. drought) policy-making is fine-tuned to policy implementation at the national and the river basin scale (standard operation procedures). Science–policy interfacing across these scales is paramount because vulnerability is context-specific (e.g. physical, environmental, socio-economic, cultural, legal, institutional), which requires analyses on detailed scales, whereas international policies and drought-generating climate drivers and land surface processes are operating on (sub-)continental scale.

2.4.3. Improving drought early warning and forecasting to strengthen preparedness and adaptation to droughts in Africa

DEWFORA is a three year FP7 project, launched in early 2011. Together with several other (in many cases related) FP7 projects, DEWFORA forms a part of the Africa call, where the focus is on collaborative research in the African continent. The main aim of DEWFORA is the development of an improved framework for drought forecasting, warning and response across Africa. Such a framework will contribute to the reduction of vulnerability to droughts across Africa. In WMO (2006) the importance of early warning within drought management is underlined; through provision of forecasts predicting the onset, duration and severity of forthcoming droughts, the impacts can be reduced by implementing mitigation measures.

To forecast droughts at a lead time sufficient to effectively implement mitigation measures is, however, challenging. Within the project the predictability of droughts, expressed through relevant drought indicators obtained from state-of-the art seasonal forecasting systems is assessed. Several methods for seasonal forecasting are considered, including the current seasonal forecasting system operated at the European Centre for Medium Range Weather Conditions (ECMWF), System 4 (Molteni et al., 2011), and the seasonal forecasting system of the Centre for Scientific and Industrial Research (CSIR) in South Africa (Landman et al., 2012).

Preliminary results of the seasonal forecasts across the Horn of Africa for the severe 2010 drought show that the precipitation anomalies in October–December that contributed to the drought were predicted from July onwards. This shows that there is a skill in the seasonal forecast predictions. However, results also show that the skill of these predictions varies spatially across the different African climates, and also depends on the season. Predicting meaningful indicators of hydrological and agricultural drought as a consequence of the seasonal meteorological predictions is even more challenging, particularly at the scale of river basins, and even more so at a spatial scale that is meaningful to for example farming communities. One of the challenges of the research in hydrological predictions is linking between the regional/continental scale and skilful predictions at

Fig. 4. Example of the head of a XEROCHORE Science Policy Brief addressing the WFD Characterisation of water bodies (Art. 5).

these more local scales. Link these different hydrological scales requires the resolving of emergent process as these become apparent at smaller scales (Trambauer et al., submitted for publication).

Similar to other natural hazards managing drought risk requires not only drought hazard but also the vulnerability to drought to be well understood (Birkmann, 2007). Measuring vulnerability is, however, complex and several approaches are described in the literature (Birkmann, 2007). Within DEWFORA, a white paper has been developed presenting an approach to developing relevant indicators that measure both drought hazard and vulnerability. Vulnerability is expressed as a combination of exposure, susceptibility and coping capacity. The combination of these and the drought hazard provides an understanding of drought risk. This can then be mapped at different scales, allowing policy makers to better target drought mitigation. At longer time scales, the project also considers changes to the drought risk as a consequence of the changing climate, and the framework developed considers adaptation strategies to reduce drought risk and increase resilience.

Within DEWFORA, research is concentrated in six case studies. Four of these are basins that have been selected to represent the diverse climate systems found across Africa. This includes the Eastern Nile basin (Egypt, Sudan, Ethiopia), the Oum-er-Rbia basin (Morocco), the Niger Basin (focusing mainly on the Inner Niger Delta in Mali), and the Limpopo basin (South Africa, Botswana, Zimbabwe, Mozambique). A fifth case study focuses on meteorological and hydrological drought forecasting at the regional scale (concentrating on the Horn of Africa), and the African continental scale. This case study will develop a pre-operational drought forecasting system, which is closely linked with the European Drought Observatory (EDO). The work in this case study will also contribute to ongoing initiatives developing a global drought information system (Pozzi et al., submitted for publication).

Embedding of the project within the current practices of drought monitoring and warning is a prerequisite to help improve these. An in-depth review of current practices across Africa at the continental and regional scale has been carried out. Related efforts at the global scale have also been reviewed. Current practices reviewed include the continental scale FEWS-NET (Verdin et al., 2005), the regional climate outlook forums such as SARCOF (Garanganga, 2007; Johnston et al., 2004), as well as many other regional and local approaches. An interesting result from this review found that although there are many organisations involved in drought management across Africa, most of these have a focus on the response to (drought) emergencies. There are significantly less organisations with a focus on adaptation and longer term sustainable solutions. To support the development of more sustainable approaches, the project includes several dissemination efforts, including stakeholder workshops at the regional and Pan-African scale, capacity building and training workshops, as well as a YouTube film to allow outputs from the project reach a wider public. Additionally, the sixth case-study in DEWFORA will provide an inter-comparison of drought monitoring and warning in Europe and Africa. It is expected that this case study will allow research in Africa to benefit from advances made in Europe. Additionally it will allow the experience gained in the case studies, as well as from existing drought monitoring and early warning practice in Africa to feed back to drought science and policy in Europe.

2.5. Research on floods

Following up of a large-scale research project in support of the EU Flood Directive (the FLOODsite Project – Integrated Flood Risk Analysis and Management Methodologies – www.floodsite.net) which terminated in 2009, other projects were funded within the FP7 among which.

2.5.1. Improving preparedness and risk management for flash floods and debris flow events[13]

Nowadays, it is widely recognised that the changes in climate, land-use and socio-economy are becoming the drivers that are putting most pressure to the entire water cycle. In the particular case of the pressures induced by climate change, the most important effects are related to the increase of extreme event frequencies, that have a direct impact on the natural hazards triggered by heavy rains. Thus, the projected increase of the occurrence frequencies of heavy rainfall events would directly contribute to increases in flash floods and associated effects as debris flow events and landslides. Although the present agreement that the cause of the flash flood risk increase detected over last decades (as well as of the damages associated with these extreme events) is more related to the growth of exposure and vulnerability than to the direct effects of climate change (Bates et al., 2008), it is also true that the expected modification of the occurrence frequencies of these events in the next decades will change the present perception leading to future changes in these trends.

In this framework, recent flash flood events have shown that the existing strategies and defence systems should be revised for coping with the current and future flood risk situations. Especially in the changing environment we are facing, in which uncertainties associated to all the processes related to flood risk play a significant role, the traditional approach of flood management is no longer valid. The "flood fighting" concept relying on structural solutions for flood defence should be, at least, partially replaced by new strategies that target to a more holistic approach of flood risk management and consider the uncertainties induced by the global change. This will imply the application of adaptive management tools allowing our society to move towards the new paradigm of "living with floods".

Furthermore, the European Union has implemented a set of instruments to address various aspects of disaster management, and specifically floods. Among these instruments we can note the Community Mechanism for Civil Protection or the European Union Solidarity Fund, created after the severe floods that hit central Europe in the summer of 2002. Specific flood prevention policies exist in many European countries. However, concerted and coordinated action at the level of the EU would considerably add value and improve the overall level of flood protection. The Flood Directive (European Commission, 2007a) is an excellent example of such an action. This Flood Directive introduces the need of developing Flood Risk Management Plans (FRMP) at a basin level, plans that should include measures to reduce the risk of flooding in an integrated framework.

> "… *Flood risk management plans shall address all aspects of flood risk management focusing on prevention, protection, preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basin*" (Chapter IV, Article 7.3).

Thus, the policies for flood risk reduction and management have also shifted from a defence-based (mostly structural measures) to a more comprehensive, integrated flood risk management approach. In this new integrated approach, the full flood disaster cycle, i.e. prevention, preparedness, response and recovery, is taken into consideration. From this point of view two new directions appear to be of high priority: on one hand, it is essential to further reduce exposure and vulnerability to floods in order to reduce the risks associated with them, for instance promoting active policies allowing us to avoid new developments in flood-prone areas, adapting future infrastructures to the risk of flooding, improving not just protection measures but also promoting appropriate land-use, agricultural and forestry practices. On the other hand it is also urgent to transform the

[13] http://www.imprints-fp7.eu/.

advances on the knowledge of the physical phenomena triggering these events into operational methodologies able to support decision makers both in the planning activities and especially in the real-time risk management actions and plans.

In this context, and specifically thinking in flash floods (the most devastating floods) and in its associated effects, the development of operational early warning systems becomes a key element. Is in this framework in which the project IMPRINTS represents an outstanding step ahead in the development of active measures for flash flood risk management. The project has been focused into producing improved methods and tools to be used by practitioners of the emergency agencies and utility companies responsible for the management of flash flood risks and associated effects. These tools are seen as the most effective way to improve the preparedness and the operational risk management of flash flood generating events, as well as to contribute to the reduction of loss of life and economic damage, and to sustainable development through reducing damages to the environment.

One of the major results of the project has been the development of an operational platform, which integrates the different advances in increasing the anticipation time of the forecasts of these flash flood events. This platform has been designed as a full Decision Support System integrating hydrometeorological forecasts going from 5 days ahead to few hours ahead, able to adapt the resolution of the warnings to the forecasting uncertainties both in space and time.

The system have been validated during the project life, being able to show outstanding predictability capacities in the several real flash flood events occurred, provide warnings between 24 h to 36 h in advance. The advanced techniques for high resolution hydrometeorological forecasts included in it have also been proved as effective operational support tools to the risk management few hours ahead of the emergency occurrences.

Finally the project has also developed a methodological approach to explore the climate change, and other associated changes affecting flood occurrences as forest fires and land-use changes (Cabello et al., 2011). The research highlighted the importance of including the consequences of these potential changes in the future planning at basin scales and in the development of flood reduction management plans, and thus supporting the implementation the EU Flood Directive.

2.5.2. Flood resilience in urban areas

Through a series of case studies in Europe and Asia, the CORFU project[14] (2010–2014) looks at drivers which impact on urban flooding. The objective is to develop a consistent framework for analysis of sustainable long term urban flood management and the development of flood resilient cities (Djordjević et al., 2011). The interactions between urban and economic growth trends and urban structure are important elements. In conjunction with climate change projections, these drivers feed into development scenarios which will be used for prediction of flood impacts. Ultimately, these will enable the assessment of the cost-effectiveness of flood resilience measures and flood management strategies.

The CORFU approach is based on Integrated Urban Water Management (IWRM) applied at city level, with *monitoring* and *modelling* as two strongly interlinked activities. Progress is being made in several related domains. Monitoring of precipitation and flows within a real-time urban flood information system is elaborated beyond the existing state-of-the-art. In the CORFU case study areas, these range from off-line records only, or a small number of on-line rain gauges, to very sophisticated systems where weather radar observations, dense networks of rain gauges and flow monitoring devices are integrated with modelling tools in RT flood management systems (Hénonin et al., submitted for publication). The aim is to define the most effective use of the technology and equipment available in different cities. Second, sampling of pathogens present in drainage systems is under way together with the analysis of their potential effect on humans who are exposed to them during flood events. These results have been linked with new advanced tools for 2D modelling of transport and fate of pathogens during a flood event. The assessment of corresponding health impacts will be built into the CORFU comprehensive methodology for evaluation of tangible and intangible flood damage. This will enable a new, *disease-based* urban flood management. In addition, a modelling tool has been developed for calculation of direct flood damage. This proves to be challenging in megacities with monsoon climates, where one event (out of many scenarios considered) may cause damage on tens of thousands of buildings. Finally, beyond hydrologic/hydraulic analyses, modelling within CORFU includes simulation of urban growth and calculation of indicators which are used to develop methodologies that quantify flood resilience in cities.

In the context of WFD, cities need to be seen as an integral part of river basins because the former affect not only the runoff dynamics but also the water balance. In the CORFU Beijing case study, and in many other locations, limited water resources pose a limit for the growth and development of the city. Hence, the two-way interaction between a city and a wider river basin is rather complex since it involves mutual pressures related to both flooding and water resource management.

3. Needs for science–policy interfacing

It is increasingly recognised that a new paradigm is needed to improve the communication and uptake of research outputs by policy-makers and stakeholders (Quevauviller, 2010b; Quevauviller et al., 2005), which will only be possible through the development of an operational "science–policy interface" for boosting exchanges among policy-makers and the scientist community. The development of such an operational interface will require regular interactions and guidance of a dedicated group mixing policy people, scientists and stakeholders (Quevauviller, 2011). This is currently contemplated within the WFD Common Implementation Strategy (CIS) through a dedicated SPI (science–policy interface) expert group and in some of the ongoing FP7 projects (e.g. DROUGHT-R&SPI), which will hopefully enable to improve science–policy interactions in a sustainable way.

It should be stressed that the projects presented in this paper are not necessarily connected and that there is no "joint communication" addressed to policy-makers and stakeholders. In this respect, a science–policy interfacing platform might result in better sharing of information and communication to the "users of science", providing that efforts are made to gather research information according to themes e.g. those developed under working groups of the CIS.

4. Conclusions

The integration of research advances in modelling and monitoring in WFD river management planning is essential to better identify and design climate change adaption measures that will be needed at river basin scale. This represents, however, a challenge in that an effective integration will be closely linked to our capacity to ensure that scientific knowledge is fit-for-purpose (timely and in an appropriate format) to be considered within the EU water and climate policy cycle. This challenge calls not only for increasing research efforts but also for the development of science–policy interfacing mechanisms (Quevauviller, 2010b, 2011). This ambitious goal involves many different actors, hence its complexity as it considers not only the "human side" with different mentalities but also many different disciplines/sectors with their specific practices (Quevauviller, 2010a). At present, this framework remains to be practically developed and

[14] www.corfu7.eu.

implemented in Europe, and this is a task to be tackled for the forthcoming decade. This paper gives an outline of projects which may appear as a kind of patchwork of on-going research without a clear connection, which frequently reflect a mere reality. A mediation mechanism (science–policy interfacing) might help to improve connections among research carried out in a common theme at international, national or even regional levels.

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