A snapshot of policy and research considerations about water and climate change

Philippe Quevauviller

Abstract: Climate change impacts on the hydrological cycle (e.g. effects on atmospheric water vapour content, changes of precipitation patterns) have been linked to observed warming over several decades. Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution with possible negative impacts on ecosystems and human health, as well as water system reliability and operating costs. In addition, sea-level rise is projected to extend areas of salinisation of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas. Besides this, changes in water quantity and quality due to climate change are expected to affect food availability, water access and utilisation, especially in arid and semi-arid areas, as well as the operation of water infrastructure (e.g. hydropower, flood defences, irrigation systems). This chapter discusses how climate change might impact the reliability of current water management systems on the basis of expert reports prepared at global or EU level, namely reports of the Intergovernmental Panel on Climate Change (IPCC) and guidance documents of the Water Framework Directive Common Implementation Strategy. Examples of international research trends are described to illustrate on-going efforts to improve understanding and modelling of climate changes related to the hydrological cycles at scales that are relevant to decision making (possibly linked to policy).

Keywords: water policies, climate change, river basin management, adaptation, research

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Riassunto: *L'impatto del cambiamento climatico sul ciclo idrologico (come ad esempio l'effetto sul tenore di vapore acqueo nell'atmosfera ed i cambiamenti nei modelli delle precipitazioni) è stato collegato all'osservazione del riscaldamento globale da parecchi decenni. L'innalzamento della temperatura dell'acqua ed i cambiamenti estremi, che includono alluvioni e siccità, sono destinati in futuro a influenzarne la qualità ed a inasprire molte forme di inquinamento delle acque stesse, con possibili effetti negativi sugli ecosistemi e la salute delle popolazioni, così come ad influenzare l'affidabilità del sistema idrico ed i suoi costi di gestione. In aggiunta, l'innalzamento del livello del mare è destinato ad estendere le aree di salinizzazione delle acque sotterranee e degli estuari, con il risultato di una diminuzione della disponibilità dell'acqua potabile per le persone e per l'ecosistema nelle aree costiere. Oltre a questo, variazioni nella quantità e qualità delle acque dovuti a cambiamenti climatici si prevede che incidano sulla disponibilità di cibo, su l'accesso e l'utilizzo delle acque, specialmente nelle aree aride e semiaride, così come sul funzionamento di infrastrutture idriche (ad esempio energia idroelettrica, protezione dalle inondazioni, sistemi di irrigazione). In questo lavoro si tratta di come i cambiamenti climatici possono avere un impatto sull'affidabilità degli attuali sistemi di gestione delle acque sulla base di rapporti preparati a livello mondiale o europeo, cioè rapporti del Intergovernmental Panel on Climate Change (IPCC) e documenti guida o di orientamento del Water Framework Directive Common Implementation Strategy. Esempi delle tendenze della ricerca internazionale sono descritti per illustrare le intese in corso per migliorare la comprensione e la modellazione dei cambiamenti climatici relativi ai cicli idrologici alla scala che risulta rilevante per la gestione e le politiche di attuazione.*

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has published a technical report on water and climate change (Bates et al., 2008), which provide ample evidence that freshwater resources are vulnerable toward climate change. According to the report, climate change impacts on water may have wide-ranging consequences for human societies and ecosystems in Europe and worldwide. In particular, impacts of observed warming over several decades are reflected in changes in the large-scale hydrological cycle (e.g. effects on atmospheric water vapour content, changes of precipitation patterns etc.). Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution from e.g. sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, with possible negative impacts on ecosystems, human health, and water system reliability and operating costs. Furthermore, sea-level rise is projected to lead to increased salinisation of groundwater and estuaries, with a resulting decrease of freshwater availability for humans and ecosystems in coastal areas. Other impacts are also highlighted, such as on food safety/availability and water infrastructure (e.g. hydropower, flood defences, irrigation systems).

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The reliability of water management systems might be affected by consequences of climate change, in particular regarding possible impacts on hydrological characteristics (Bates et al., 2008). Adaptation and mitigation options are currently discussed and designed to either ensure water supply during average and drought conditions or to reduce the magnitude of impacts of global warming on water resources (in turn reducing adaptation needs) while considering possible negative side effects such as, for example, increased water requirements for bio-energy crops, reforestation etc.. These options are closely linked to a range of policies covering different sectors, e.g. energy, health, food security, water and nature conservation, requiring that adaptation and mitigation measures are evaluated across multiple water-dependent sectors. This paper will focus on the relevant EU water policies and say few words about international developments about water and climate change policy and research.

Climate change impacts on water

With the general consensus among scientists that climate change is at least to a certain extent caused by human activities, we have to realise that, according to the terminology of the EU Water Framework Directive (2000/60/EC) or WFD (discussed in section 3), direct climate change impacts on water resources are not classified as an "anthropogenic pressure" in the narrow sense. The reason is that these impacts cannot be mitigated by programmes of measures undertaken by water managers. It is, however, recognised that climate change impacts may interact with and potentially aggravate other anthropogenic pressures, which would then classify them as an anthropogenic pressure. For example, both the availability of water and the demand for water for uses such as agriculture may be affected by changes in precipitation and hotter/drier summer periods. Pollution patterns may also be altered as a result of lowered water levels (less dilution). Also, climate change mitigation efforts may result in pressures on water resources (Wilby et al., 2006).

Changes in precipitation patterns (seasonal and spatial) influence the quantity and quality of water resources and impacts on their uses, e.g. abstraction of both surface and ground waters (Wilby et al., 2006). Management of water resources is hence closely related to various drivers, including climate change, land cover and increasing water consumption (Figure 1).

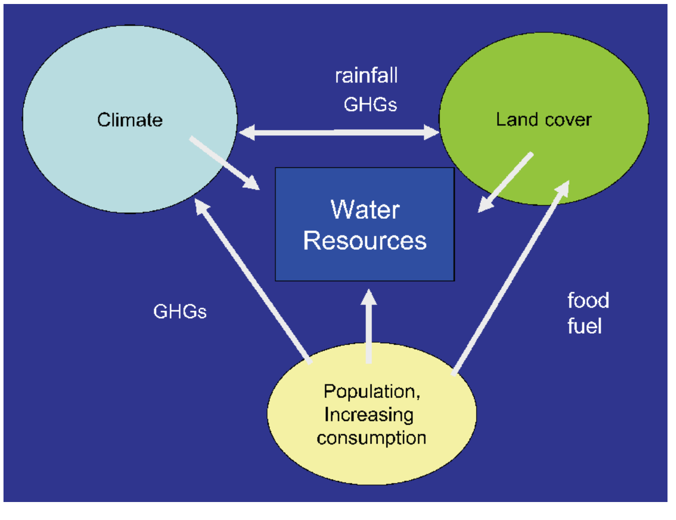

Fig. 1: *Sustainable water management in the context of global drivers of change (courtesy of R. Harding, WATCH project 'Water and Global Change').*

Intense rainfalls may lead to long-term threats to groundwater resources, resulting in surface flooding rather than infiltration to groundwater. Water quality may also be affected by nutrients and pesticides run-off takes from agricultural land into rivers and lakes. From the 'lesser availability' viewpoint, droughts may have an impact on river ecology, in particular extremes may have adverse effects on aquatic ecosystems. Other possible impacts concern water demand (increased demand and/or differing patterns) and infrastructures (e.g. effects on water treatment etc.), sewer network operations etc.

A good knowledge of the global/regional distribution of water resources is essential for assessing climate change impacts on them. This includes the identification of the most sensitive hydrological systems at the scale of river basins, including a better understanding of climate-induced changes in hydrological systems and processes (e.g. variables such as river flows, groundwater and lake levels, soil moisture, evapotranspiration, snow cover, glacier extent, permafrost etc.), as well as impacts on biodiversity (Wilby et al., 2006). The evaluation of climate change impacts on sectoral water uses is also essential, e.g. on agriculture (rain-fed and irrigated), forestry (including forest fires and deforestation), hydropower, navigation and water supply (domestic, agricultural and industrial). Finally, possible impacts on infrastructure, health, transport, financial services (e.g. insurance sector), energy and tourism should also be assessed. In doing so, an integrated approach is recommended in order to tackle multi-risk evaluations at the river basin scale, distinguishing land-use changes due to human activities from climate-induced changes, taking into account uncertainties of the evaluations and of future climate change projections (including the increased occurrence of extreme flood and droughts, socio-economic developments, model resolution etc.). At the present stage, attributing hydrometeorological extremes to climate change is still uncertain because of a lack of accurate data and full scientific understanding of the functioning of the climate system.

Policy background

Introduction

Climate change impacts in the light of freshwater resource management and policies are extensively discussed in the IPCC Technical Paper on Water (Bates et al., 2008). In particular, the document evaluates the impacts of climate change on hydrological processes and regimes, and of freshwater resources (availability, quality, uses and management), at a worldwide scale, and highlights their implications for policy, looking at different sectors. Recommendations are also formulated regarding adaptation measures in regions prone to climate change related extremes concerning water resource management, ecosystems, agriculture and forestry, coastal systems, sanitation and human health. This shows that awareness for policy actions is growing worldwide. However, no legal framework is currently in place to tackle climate change impacts on water at a global scale. The next section examines the current policy trends.

EU policies

With the Water Framework Directive (WFD), the European Union is developing a robust integrated water resources management system, with legal instruments being in place or in development (Chave, 2007; Quevauviller et al., 2008). Let us recall that the WFD is built upon the principles of river basin management planning (Figure 2), and this implies that all types of waters and pressures that may affect them are considered, and that programmes of measures (supported by extensive monitoring) to achieve 'good status' objectives by 2015 are designed. In this context, the 'good status' is based upon chemical and ecological status for surface waters, and chemical and quantitative status for groundwater. Ongoing discussions pinpoint that climate change might influence all steps of WFD implementation, and thus on the status objectives (Wilby et al., 2006; Ludwig et al., 2009). Recently, a guidance document has been issued by the WFD Common Implementation Strategy (chaired by the European Commission), which examines river basin management in a changing climate (European Commission, 2009a).

Possible risks posed by climate change to the achievement of environmental ('good status') objectives are not specifically addressed in the WFD. However, several articles of the directive provide a framework to include climate change impacts into the planning process. In particular, the requirement of the directive to collect information on the type and magnitude of 'significant pressures' affecting surface waters could be considered as including climate change with the consensus that it is at least to a certain extent caused by human activities (Wilby et al., 2006). It may be argued that climate change impacts cannot be classified *sensu stricto* as anthropogenic pressure in the context of the WFD since they cannot be mitigated by water manager's actions. However, climate change might potentially exacerbate existing or future anthropogenic pressures and should hence be considered within the policy framework.

Some WFD milestones that might be impacted by climate change have been examined in depth (Wilby et al., 2006; Ludwig et al., 2009), and the main conclusions are as follows:

- **Characterisation of water bodies and pressures**. Based on a review of the impact of human activities (and related pressures) on the status of surface and groundwaters, this step considers water system typologies which may be sensitive to climate (hence to climate change). In this context, climate change might have impacts on, for instance, river flow patterns, precipitations, water level fluctuations etc., with indirect impacts on pollution patterns (affecting both point and diffuse sources) and effects on the status of water bodies.
- **Risk assessment**. Similarly, the assessment of risks, which is an essential part of the WFD (in particular for the design of programmes of measures, see below), might be affected by climate change interferences with potential impacts on good status achievements. Examples of impacts are changes of water temperature, decreased dilution capacity of receiving waters, exceedence of water quality standards, changing metabolic rates of organisms, fish migration patterns, increased eutrophication, changes of river flows, etc.
- **Prevention of status deterioration**. Modifications of flow regimes and physico-chemistry of rivers could have significant impacts on key species and hence on ecological status achievements, in particular in protected water bodies (Limbrick et al., 2000), e.g. effects on spawning conditions for salmons, climate-driven shifts in species and community composition etc.
- **Achievement of good status**. In the light of the above considerations, it is obvious that possible climate change-related shifts in surface water body's characteristics might have effects on WFD status achievements. This includes impacts on the compliance to environmental water quality standards (chemical status), impacts on fish mortality and biota composition (ecological status), etc. Extreme flood and drought events might also impact on status objectives, leading e.g. to increased sediment loads and mobilisation of contaminated sediments.
- **Programmes of measures** of the WFD objectives depend upon the above operational steps and hence may also be affected by climate change impacts. Their success will depend upon the accurate characterisation of water bodies and pressures in the first place, and upon flexibility to future changes in climate.
- **Monitoring** is essential for providing data that will be used to check compliance to WFD objectives. Considering possible climate change-related shifts in water body characteristics, monitoring strategies might need to be reviewed at regular intervals (this is actually foreseen under the WFD framework), taking into account the climate change component.

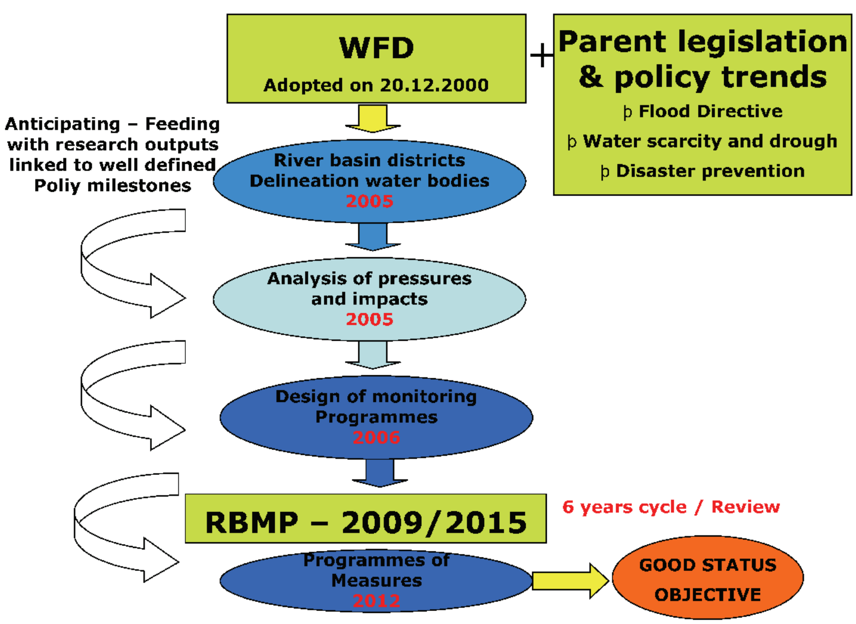

Fig. 2: *EU water policy milestones.*

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The above referred guidance document (European Commission, 2009a) elaborated under the Common Implementation Strategy (CIS) has been built upon principles of the European Commission's White Paper on 'Adapting to climate change (European Commission, 2009b). One of the features of this White Paper 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 above policy framework, the Floods Directive (European Commission, 2007a) 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. This directive is 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 increased risks of flooding due to climate change and for developing appropriate adaptation approaches.

The increased frequency of droughts due to climate change are also considered in the policy context, which is illustrated by the EC Communication on water scarcity and droughts (European Commission, 2007b) setting out a number of policy options. An annual European assessment of water scarcity and droughts is conducted by the European Commission to monitor changes across Europe and to identify where further action is needed in response to climate change. In addition, a review of the strategy for water scarcity and droughts is planned for 2012.

As noted in the 2009 Guidance document (European Commission, 2009a), the successive steps of the WFD River Basin Management Planning (RBMP) process provide a convenient structure for incorporating adaptation to climate change through risk assessment, monitoring, environmental objective setting, economic analysis and action programmes to achieve well defined environmental objectives.

International policies

While climate change impacts on water resources and the need for management efforts are recognised worldwide, there is not yet a 'global policy' which deals with adaptation measures to climate change as regard water resources. This need is, however, highlighted by the UN Economic Commission for Europe (UNECE) in a recently published guidance document (United Nations, 2009). The key messages follow the same lines as IPCC recommendations (Bates et al., 2008). In particular, the guidance states that implementing integrated water resources management will support adaptation to climate change (which goes along the conclusions of the EC guidance document; European Commission, 2009a), including planning at river basin level, strong intersectoral cooperation, public participation and ensuring best use of water resources. UNECE insists on the fact that legislation should not present barriers for adaptation and should be flexible enough to accommodate continuing environmental and socio-economic changes. Finally, the UNECE guidance stresses that uncertainty should not be a reason for inaction, and highlights that action, knowledge and experience sharing, and research on adaptation should be pursued simultaneously and in a flexible way.

Another key policy trends at international level is the Hyogo Framework for Action 2005-2015 (HFA), which has been adopted by the United Nations in January 2005. Its scope clearly goes beyond water-related disasters (including e.g. earthquakes, tsunamis, volcanic eruptions, storms), but extreme floods and droughts are being considered. The HFA is under the responsibility of the United Nations International Strategy for Disaster Reduction (UN-ISDR). More information about the UN-ISDR objectives can be found in the 2010-2011 Biennial Work Programme (United Nations, 2010).

CURRENT RESEARCH

Introduction

The implementation of the WFD and its operational features, including those linked to climate change adaptation and mitigation, represents huge scientific challenges and research needs. A recent paper published by the author (Quevauviller, 2010b) discusses research orientations of projects undertaken within the EU Framework Programme for Research and Technological Development. The section below provides a brief summary of these discussions (the reader is invited to consult the above referred paper for further details). It should be noted that gaps in climate change research and water and related recommendations are also discussed in UN Reports (United Nations, 2009a, 2009b) and IPCC (Bates et al., 2008). The European Environment Agency has also identified research needs regarding policy support in a technical report (European Environment Agency, 2007). From these reports, it clearly appears that scientifically sound data and other information are essential for making climate projections, while reducing their uncertainties, in particular for vulnerable groups and regions, and this includes issues encompassing all aspects of the hydrological cycle (taking into consideration the needs of end users and including social and economic information). Research on climate change is often closely linked to policy developments at EU level, as highlighted in the White Paper on adaptation to climate change (European Commission, 2009b), and on-going discussions about integration of adaptation and mitigation measures in the river basin management planning of the Water Framework Directive (European Commission, 2009a). The sections below provides a non-exhaustive snapshot of projects funded under the 6th Framework Programme (2002-2006)[a] and the on-going 7th Framework Programme (2007-2013)[b], highlighting their potential to be linked to policy developments. A more comprehensive list of projects is available in catalogues published by the European Commission (2009c).

Research into climate change impacts on the water environment and cycle

EU-funded Research to understand and quantify the impact of climate change on freshwater ecosystems at the catchment scale has been active through the EURO-LIMPACS[c] project, which examined climate change interactions with other key drivers and pressures related to aquatic systems at multiple time scales. Scientific outputs included analyses of long-term data sets, the reconstruction of past trajectories from sediment archives, experimental approaches in the laboratory and in mesoscosms, model and scenario developments, and the development and test of Decision Support Systems (DSS). At a global scale, specific research on climate change impacts on the global water cycle is carried out under the WATCH[d] project which

[a] *In particular projects funded under the 'Global Change and Ecosystems' sub-priority*

[b] *In particular projects funded under the 'Environment (including climate change)' theme*

[c] *European project to evaluate impacts of global change on freshwater ecosystems - http://www.eurolimpacs.ucl.ac.uk*

[d] *Global change and water - www.eu-watch.org*

unites different expertises (hydrologists, climatologists, water use experts) to examine the components of the current and future global water cycles, evaluate their uncertainties and clarify the overall vulnerability of global water resources to climate change, in relation to the main societal and economic sectors. WATCH aims to increase our understanding of drought and large-scale flood development for the past and future climates through studies at different scales (global, regional, river basin).

At a regional level, climate change impacts on water resources are studied in the Mediterranean area through the CIRCE[e] project, which investigates how strongly climate variations induce significant changes in the hydrological cycle and develops a regional climate model able to analyze the conditions in the Mediterranean area (investigations concern surface water, groundwater, coastal aquifers and the interactions between them). A more focused research is undertaken by the on-going ACQWA[f] Project, studying the consequences of climate change in mountain regions where snow and ice is currently an important part of the hydrological cycle. Numerical models are used to predict shifts in water amount by 2050, and how these changes will impact upon socio-economic sectors such as energy, tourism and agriculture. A related project is: the HighNoon[g] project which assesses the impact of Himalayan glacier retreat, explore possible changes of the Indian summer monsoon on water resources in Northern India and recommend appropriate and efficient response strategies for adapting to hydrological extreme events such as floods and droughts. This project illustrates international cooperation efforts in climate change research which are also illustrated by other projects, e.g. a recently launched cluster on 'Climate change impacts on water and security' which builds up cooperation among EU countries and neighbouring Mediterranean countries (Roson et al., 2010).

Research into mitigation / adaptation options and costs

Research on climate change mitigation / adaptation options has been carried out in the framework of the AquaStress project, with particular emphasis given to methods, tools and guidelines e.g. for groundwater modeling, groundwater recharge, improved crop policies etc. Adaptation and mitigation strategies have also been investigated within the ADAM[i] project which made significant contributions to climate change policy developments through regular policy briefs, highlighting that Green House Gas emissions could be technically reduced in Europe by up to 80% by 2050. This has only an indirect link to river basin management developments but it is relevant to integrated water resource management. Besides these research initiatives, the NeWater[j] project studied challenges such as climate change, flood-plain management and endangered ecosystems to move from the current regimes of river basin water management to more adaptive regimes in the future. The project has developed a book on Climate Change Adaptation in the Water Sector and publicly available synthesis products which are available on the project webpage.

Research on the economic valuation of mitigation/adaptation measures has been developed within the AQUAMONEY[k] project, and is continued by the recently launched ClimateCost[l] project which further develops climate change and socio-economic scenarios with quantification of related costs, including an assessment of physical effects and economic damages of major catastrophic events. Finally, gaps related to adaptation strategies developed in Europe in combating climate impacts on water (preventing, eliminating, combating, mitigating) are being studied by the ClimateWater[m] project.

Research on droughts and water scarcity

Research specifically addressing water scarcity and droughts are discussed by the XEROCHORE[n] Support Action which has established the state of the art of drought-related policies and identified research gaps on various drought aspects (climate, hydrology, impacts, management, policy) and steps to take in order to fill them. Networking is developed with close links to on-going initiatives, e.g. the European Drought Centre and relevant research projects which include drought components such as. WATCH, CIRCE and the recently launched MIRAGE[o] project on Intermittent River Management.

Research on floods

Flood research has been carried out at EU level since 2004, an example of which is the FLOODsite[p] Project, which integrated expertise from across the environmental and social sciences, as well as technology, spatial planning and management, and developed robust methods of flood risk assessment and management and decision support systems which have been largely tested in pilot sites. The project has directly supported the EU Flood Directive 2007/60/EC. More than 100 research reports are available for public upload on the project website. Climate change-related extreme events such as flash floods have also been studied by the FLASH[p] project, and predictive scenarios were developed on the basis of the collection and analysis of lightning data and precipitation observations. Parallel research is aiming to improve the preparedness and the operational risk management for flash floods and debris flow generating events (IMPRINTS[r] project). Finally, the recently launched project CORFU[s] will look at advanced and novel strategies and provide adequate measures for improved flood management in cities, focusing on Europe-Asia cooperation.

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[e] *Climate change and impact research: the Mediterranean environment – http://www.circeproject.eu*
[f] *Assessing Climate change impacts on the Quantity and quality of Water – www.acqwa.ch*
[g] *Adaptation to changing water resources availability in Northern India with respect to Himalayan glacier retreat and changing monsoon pattern – http://www.eu-highnoon.org*
[h] *Mitigation of water stress through new approaches to integrating management, technical, economic and institutional instruments – http://www.aquastress.net*
[i] *Assessing adaptation and mitigation policies – www.adamproject.eu*
[j] *Adaptive integrated water resources management – www.newater.info*
[k] *Assessment of the environmental and resource costs and benefits of Water services – http://www.aquamoney.ecologic-events.de/*
[l] *Full costs of climate change*
[m] *Bridging the gaps between adaptation strategies of climate change impacts and European water policies – http://www.climatewater.org/*
[n] *An Exercise to Assess Research Needs and Policy Choices in Areas of Drought – http://www.feem-project.net/xerochore/*
[o] *Mediterranean intermittent river management – http://www.mirage-project.eu/index.php*
[p] *Integrated Flood Risk Analysis and Management Methodologies – www.floodsite.net*
[q] *Observations, Analysis and Modeling of Lightning Activity in Thunderstorms, for use in Short Term Forecasting of Flash Floods – www.flashproject.org*
[r] *Improving Preparedness and Risk Management for Flash Floods and Debris Flow Events – http://www.imprints-fp7.eu/*
[s] *Collaborative research on flood resilience in urban areas*

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Conclusions

Integrated water resources management (IWRM) principles are now increasingly used as a basis to effectively manage water resources at river basin and transboundary levels. Policy-wise, this principle is operational in Europe through the Water Framework Directive but much remains to be done to tackle climate change adaption at river basin scale and supporting research is deemed essential in this respect. Let's indeed recall that policy orientations rely on scientific evidence. In other words, the need to improve the role that science plays in environmental policy-making is pivotal to the successful implementation and review of international water and climate change policies. This issue has been discussed in depth in the water sector at European Union level within the last few years, highlighting the need to develop a conceptual framework for an effective science-policy interface. This is discussed in length in recent books (Quevauviller, 2010a; Gooch and Stålnacke, 2010). Figure 3 illustrates the necessary links between research recommendations or tools and "users" (policy-makers, stakeholders, water managers), and the need to ensure a "memory" of scientific information (facilitated by various dedicated websites), demonstration of the applicability of the research and dissemination through appropriate communication and "translation" of the scientific information (adapted from Quevauviller, 2010b), and this concludes this paper.

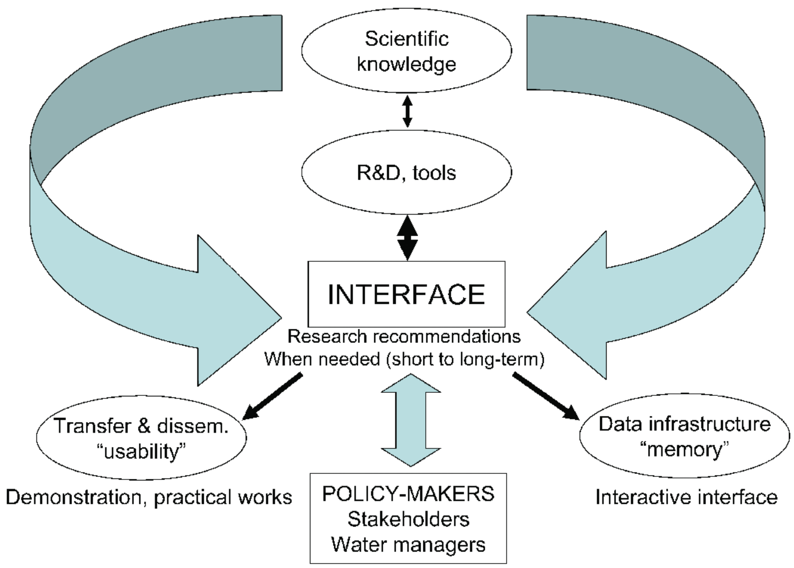

Fig. 3: *Needs of interface between science and policy (adapted from Quevauviller, 2010b).*

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