REPORT SNO. 6045-2010

How can climate change be incorporated in river basin management plans under the WFD?

Report from the EurAqua conference 2008

Photos:
Glacier: NVE (Norwegian Water Resources and Energy Directorate)
Lake with algal bloom: Sigrid Haande, NIVA
Flood: Bjørn Faafeng, NIVA
Drought: Maggie Kossida, NTUA

Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

Main Office
Gaustadalléen 21
NO-0349 Oslo, Norway
Phone (47) 22 18 51 00
Telefax (47) 22 18 52 00
Internet: www.niva.no

Regional Office, Sørlandet
Jon Lilletuns vei 3
NO-4879 Grimstad, Norway
Phone (47) 22 18 51 00
Telefax (47) 37 04 45 13

Regional Office, Østlandet
Sandvikaveien 59
NO-2312 Ottestad, Norway
Phone (47) 22 18 51 00
Telefax (47) 62 57 66 53

Regional Office, Vestlandet
Thormøhlens gate 53 D
NO-5006 Bergen Norway
Phone (47) 22 18 51 00
Telefax (47) 55 31 22 14

Regional Office Central
Pirsenteret, Havnegata 9
P.O.Box 1266
NO-7462 Trondheim
Phone (47) 22 18 51 00
Telefax (47) 73 54 63 87

Title How can climate change be incorporated in river basin management plans under the WFD? Report from the EurAqua conference 2008	Report No.. 6045-2010 Project No. 40009	Date 30.10.2010 Pages Price 27
Author(s) S. Jannicke Moe, Line J. Barkved, Michael Blind, Christos Makropoulos, Michele Vurro, Sam Ekstrand, João Rocha, Maria Mimikou, Merete. J. Ulstein	Topic group Climate and Environmental modelling Geographical area Europe	Distribution Open Printed NIVA

Client(s) NIVA	Client ref.

Abstract

This report is based on the EurAqua conference 2008: "How can climate change be incorporated in river basin management plans under the WFD?". The conference focused on recent development in relevant EU policy, on challenges for WFD-based water management, and on the science-to-policy interface regarding adaptations to climate change impacts. This report provides recommendations for incorporating climate change considerations into river basin management plans, and identifies relevant research needs with emphasis on ecology, modelling and uncertainty.

4 keywords, Norwegian	4 keywords, English
1. Vanndirektivet	1. Water Framework Directive
2. Vannforvaltningsplaner	2. River Basin Management Plans
3. Økologisk status for vannforekomster	3. Ecological status of water bodies
4. Tilpasning til klimaendringer	4. Adaptation to climate change

Jannicke Moe

Jannicke Moe
Project manager

Øyvind Kaste
Research manager

Bjørn Faafeng
Senior advicer

ISBN 978-82-577-5780-9

How can climate change be incorporated in river basin management plans under the WFD?

Report from the EurAqua conference 2008

Preface

The EurAqua Conference 2008 was a scientific conference on the topic climate change and river basin management, organised 23-24 October 2008 at NIVA in Oslo. The conference focussed on the science-to-application interface related to river basin management, climate change and implementation of the Water Framework Directive (WFD).

The organising committee consisted of Jannicke Moe, Line J. Barkved and Merete J. Ulstein (NIVA, Norway), Michiel Blind (Deltares, the Netherlands), Neil Runnalls (CEH, United Kingdom), Maria Mimikou and Christos Makropoulos (NTUA, Greece), and Willy Bauwens (VUB, Belgium).

We thank the presenters of the EurAqua Conference 2008 for their contributions: Peter Kristensen (EEA activities), Peeter Nõges (EC activities; biodiversity), Anne Lyche Solheim (freshwater quality and ecology), Didier Pont (biological indicators), Tuomo Saloranta (modelling), Øyvind Kaste (modelling), Juha Kämäri (scenarios), Rick Battarbee (reference conditions), Daniel Conley (coastal ecosystems), Joost Icke (WFD explorer), Luc Feyen (floods), Romano Pagnotta (water scarcity and droughts), Robbert Biesbroek (national adaptation strategies), Lidija Globevnik (transnational challenges), Alan Jenkins (policy demands). We also thank Maggie Kossida for valuable comments to the report.

The conference received support from the Research Council of Norway and from the Norwegian Institute for Water Research.

Oslo, 30.10.2010

Jannicke Moe

Contents

Summary **5**

Sammendrag **6**

1. Introduction **7**

2. Relevant EU policy for climate change and river basin management **10**

3. Climate change and management of freshwater quality **11**

4. Climate change and adaptation to freshwater quantity **15**

4.1 Floods 15
4.2 Water scarcity and drought 17

5. From science to policy: how can climate change information be incorporated into water management? **20**

6. Conclusions and recommendations for river basin management and for research **23**

7. References **25**

Summary

This report is based on the conference: "How can climate change be incorporated in river basin management plans under the WFD?", which was arranged by EurAqua at NIVA in October 2008. Climate change is expected to impact freshwater quality and quantity throughout Europe, and is therefore an important issue for water management. River basin management plans are the main instrument of the Water Framework Directive (WFD), which governs water policy and management in the European Union and Norway. Consideration of climate change was not required for river basin management plans in the first 6-year cycle of water management under the WFD (2009-2015), but it will be required for the next two management cycles (2015-2027). However, there are still large knowledge gaps regarding consequences of climate change for freshwater management. Moreover, climate change projections will always be associated with uncertainty. This report focuses on recent development in relevant EU policy, on challenges for WFD-based water management, and on the science-to-policy interface regarding adaptations to climate change impacts (i.e., to increased floods and water scarcity and droughts). The report provides recommendations for incorporating climate change considerations into river basin management plans, and identifies relevant research needs with emphasis on ecology, modelling and uncertainty.

Sammendrag

Denne rapporten er basert på konferansen "How can climate change be incorporated in river basin management plans under the WFD?", arrangert på NIVA av EurAqua i oktober 2008. Klimaendringer forventes å påvirke ferskvannskvalitet og -kvantitet for hele Europa, og er derfor et viktig tema for vannforvaltning. Vannforvaltningsplaner er det viktigste instrumentet for Vanndirektivet (WFD), som styrer vannforvaltningen i EU og Norge. Hensynet til klimaendringer var ikke et krav for vannforvaltningspleanene i den første 6-års syklusen av vannforvaltning under Vanndirektivet (2009-2015), men det vil bli et krav for de to neste forvaltningssyklene (2015-2027). Det er imidlertid fremdeles stor mangel på kunnskap når det gjelder konsekvenser av klimaendringer og forvaltning av ferskvann. Prediksjoner om klimaendringer vil dessuten alltid være tilknyttet usikkerhet. Denne rapporten fokuserer på utvikling i relevant EU-politikk, på utfordringer for Vanndirektiv-basert vannforvaltning, og på skjæringspunktet mellom vitenskap og forvaltning i forbindelse med tilpasninger til effekter av klimaendringer (dvs. økt forekomst av flommer og vannmangel og tørke). Rapporten gir anbefalinger for hvordan hensynet til klimaendringer kan inkluderes i vannforvaltningsplaner og identifiserer relevante forskningsbehov, med spesiell vekt på økologi, modellering og usikkerhet.

1. Introduction

The Water Framework Directive (WFD; European Commission, 2000) is at the centre of the European Union's water policy and management, covering both freshwater and coastal waters. The overall objective of the WFD is good ecological and chemical status of water bodies. Although the issue of climate change is not explicitly included in the WFD, changes in climatic conditions are clearly a significant factor for future water management (Wilby et al., 2006) (see examples in **Figure 1**). A wide range of climate change impacts have been identified as relevant by the Common Implementation Strategy (CIS) for the WFD (CIS, 2009). Among the most relevant physical and chemical factors are changes in water temperature, river flow and groundwater recharge, water availability, frequency and intensity of extreme events such as floods and droughts, change in pollution load and water quality, sea level rise and salt water intrusion. Potential impacts on freshwater ecosystems may include loss of vulnerable species and protected areas, and invasion of non-indigenous species. Moreover, several economic sectors would be affected by climate change impacts on freshwater, including but not restricted to hydropower, navigation, water supply, hydro-infrastructure and land use (Bates et al., 2008).

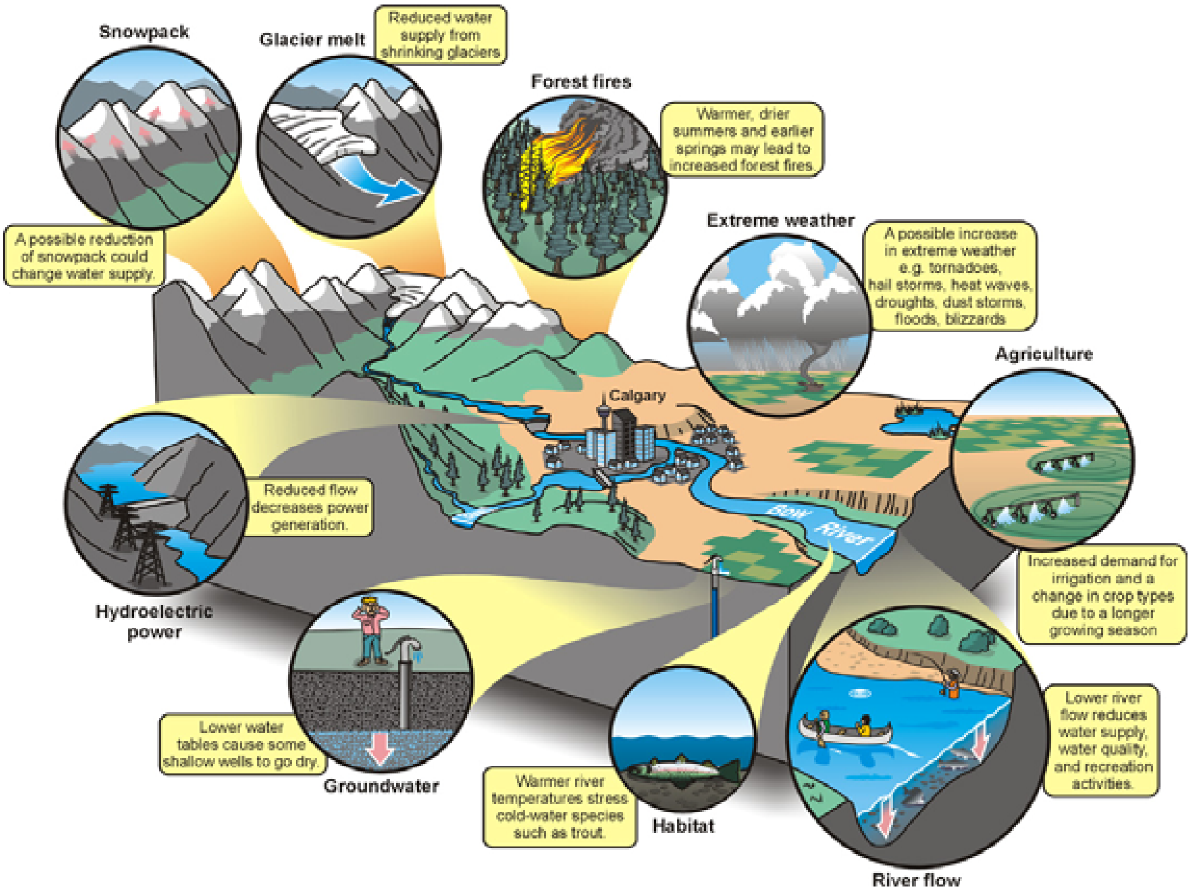


Figure 1. Examples of potential climate change impacts on freshwater. (Source: Natural Resources Canada; http://geoscape.nrcan.gc.ca/h2o/bow/climate_e.php).

Although the WFD does not currently consider impacts of climate change, it can be argued that the flexibility and cyclical approach advocated by the WFD make it well-suited to allow adaptation of water management to climate change-related issues (CIS, 2009). The implementation of the WFD will need to include climate change considerations at several steps, including characterisation of water bodies, identification of pressures and impacts, design of monitoring schemes, and economic analysis of measures (Figure 2). Moreover, the concept of enhanced ecosystem resilience, which the WFD supports, may be the best suited way to deal with the inherent uncertainty associated with climate change projections. We therefore support the view that the WFD provides an adequate framework for considering the impacts of climate change for adaptive water resource management. However, a common procedure for including climate change first needs to be identified (European Commission, 2006).

The instruments for water management according to the WFD are the river basin management plans (RBMPs), which all EU member states are required to develop (WFD Article 13; Annex VII). The river basin is a suitable level for integrating water management considerations while adopting a cross-sectoral approach, bringing together aspects of agriculture, land use, water supply and sanitation, urban planning and energy production. Climate change considerations should therefore be incorporated into RBMPs, to ensure that the eventual programme of measures is sufficient to achieve the WFD objectives under potential future climatic changes. However, the available knowledge on climate change impacts on ecological and chemical status of water bodies has so far not been sufficient for providing the required scientific support. Acknowledging this knowledge gap, climate change consideration has not been required in the first river basin management cycle (2009-2015). Nevertheless, for the second (2015-2021) and third (2015-2021) cycles of river basin management, it is expected that the EU member states demonstrate how climate change projections have informed assessments of WFD pressures and impacts, how monitoring programmes are aligned to detect climate change impacts, and how choices of measures are as far as possible robust to future projected climate conditions (CIS, 2009) (**Figure 2**).

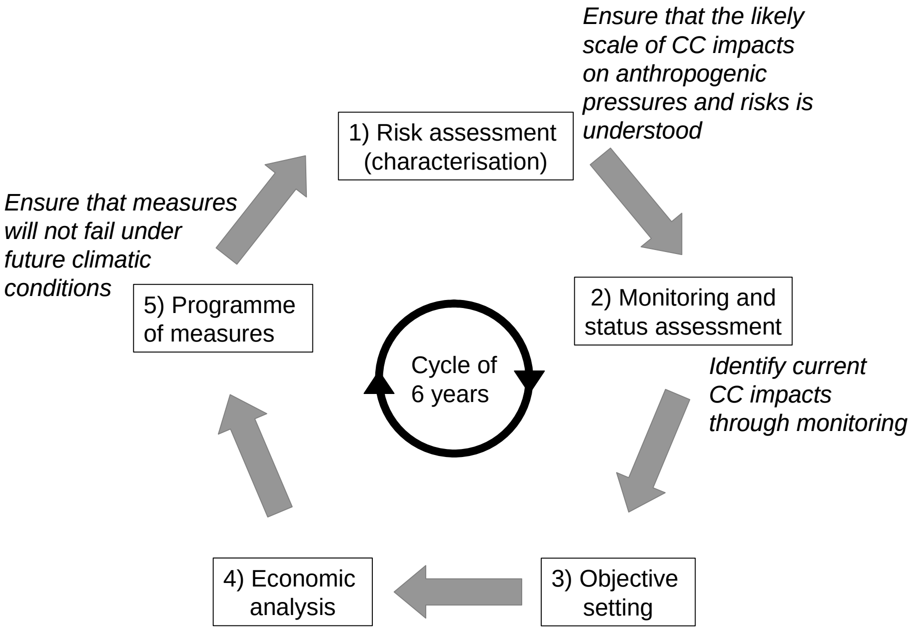


Figure 2. Main steps in the cycle of WFD-based river basin management, and essential components for planning for climate change (in italics). 1) Risk assessment - the summary of significant pressures and impacts of human activity on the status of water bodies (Article 5); 2) Monitoring and assessment of the status of water bodies (Article 8 and Annex V); 3) Setting of environmental objectives for management (Article 4); 4) Economic analysis of water use (Article 5 and Annex III); 5) Programme of measures to achieve the environmental objectives (Article 11).

The European Network of Freshwater Research Organisations (EurAqua; http://www.euraqua.org) focus on the development of European freshwater science and its dissemination on a European scale, and aim at contributing to the development of the scientific basis of European water management. Within this context EurAqua organised a conference in October 2008 to address the question: "**How can climate change be incorporated into river basin management plans under the WFD?**". The conference was organised in three sessions:

1. **Climate change and WFD - current status and uncertainties**
2. **Modelling, tools and technology - uncertainties and future challenges**
3. **Adaptation to climate change - bringing science into policy**

This report summarises the main issues addressed during the first and third session regarding recent developments in relevant EU policy, on the current state-of-art and research needs, and on science-to-policy interfaces that are required for specific issue of adaptations to climate change – with an emphasis on extreme events (floods as well as water scarcity and droughts). In particular, the report focuses on guidelines for river basin management and on research needs for providing the required scientific support.

The following section of the report identifies key EU policy documents relevant to the climate change discussion to provide the legislative and policy context. Next we present current knowledge and research needs regarding management of freshwater quality and adaptation to quantity, respectively. The report then proceeds to address challenges and opportunities in the science-policy interface, and concludes by summarising recommendations for incorporating climate change into river basin management plans.

2. Relevant EU policy for climate change and river basin management

The implications of climate change for water management have been addressed by the European Commisson (EC) and the European Environment Agency (EEA) through several recent publications (see also http://ec.europa.eu/environment/climat/adaptation/index_en.htm). These include:

- The report to the Water Directors: *Climate Change and the European Water Dimension* (JRC, 2005).
- The workshop report *Climate change impacts on the water cycle, resources and quality* by the EC's Joint Research Centre, Directorate General for Environment and Directorate General for Research (European Commission, 2006).
- The Floods Directive (European Commission, 2007a).
- Communication on Water scarcity and drought (European Commission, 2007b).
- The report *Climate change and water adaptation issues* (EEA, 2007). This report aims to evaluate the implications of the need to adapt to climate change for water resource policy and regulation across Europe, to assess the strengths and weaknesses of current policies and regulations, and to describe progress and activities in European countries.
- The document *Impacts of Europe's changing climate - 2008 indicator-based assessment*, produced by the European Environment Agency, Joint Research Centre and World Health Organisation (EEA, 2008). This document focuses on past trends and projections based on various indicators.
- The Common Implementation Strategy for the WFD policy paper *Climate change and water* (CIS, 2008). This paper focuses on the resilience of aquatic ecosystems, the limitations due to uncertainties, the flexibility needed to include new knowledge, and integration of other sectoral policies.
- The "white paper" *Adapting to climate change: Towards a European framework for action* (European Commission, 2009).
- The EEA report "Water resources across Europe - confronting water scarcity and drought" (EEA, 2009).

Finally, the guidance document *River basin management in a changing climate* (CIS, 2009) was published by the EC in November 2009, as the first result of numerous actions listed in the "white paper" (European Commission, 2009). Guiding principles from this document will be addressed towards the end of this report.

3. Climate change and management of freshwater quality

Impacts on climate change are reported for a large set of variables related to freshwater quality, which can broadly be categorised as physical, chemical and biological indicators (EEA, 2008). Since the WFD requires that so-called biological quality elements are used for status assessment of surface waters, it is important to consider potential climate change impacts on biological indicators. However, biological processes are inherently more complex and variable than physical and chemical processes, and the probability of detecting a significant climate change signal in biological indicators is therefore much less than for physical and chemical indicators (CIS, 2009). It is therefore also important to assess climate change impacts on physical and chemical factors, and consider how these in turn may affect biological processes.

Physical factors that indicate climate change include higher water temperature, less ice cover, increased water flows (North-Central Europe), increased droughts (South Europe), elevated erosion, more stable stratification of water masses in lakes, and altered water discharge including water level and retention time. A rise in water temperature and other physical changes will affect the rate of biogeochemical processes that influence chemical water quality. Expected climate change-induced changes in water chemistry include (EEA, 2008):

- Higher water turbidity due to increased erosion.
- Discoloration in surface waters due to increased dissolved organic carbon contributed by the catchment.
- Reduced oxygen content due to both higher water temperature and longer summer stratification periods (in lakes).
- Increased nutrient concentrations (eutrophication) due to several factors: increased external loading from more erosion and sewer overflows, internal loading caused by longer summer stratification, lower water levels in the summer.
- Increased salinity of groundwater due to sea level rise, salt water intrusion (caused mostly from increased agricultural abstractions) and increased evaporation (particularly in Southern Europe).
- Possibly increased concentrations of toxic substances due to several factors: increased transport of persistent organic pollutants to colder areas, increased uptake in fish and other biota, and increased use of pesticides.

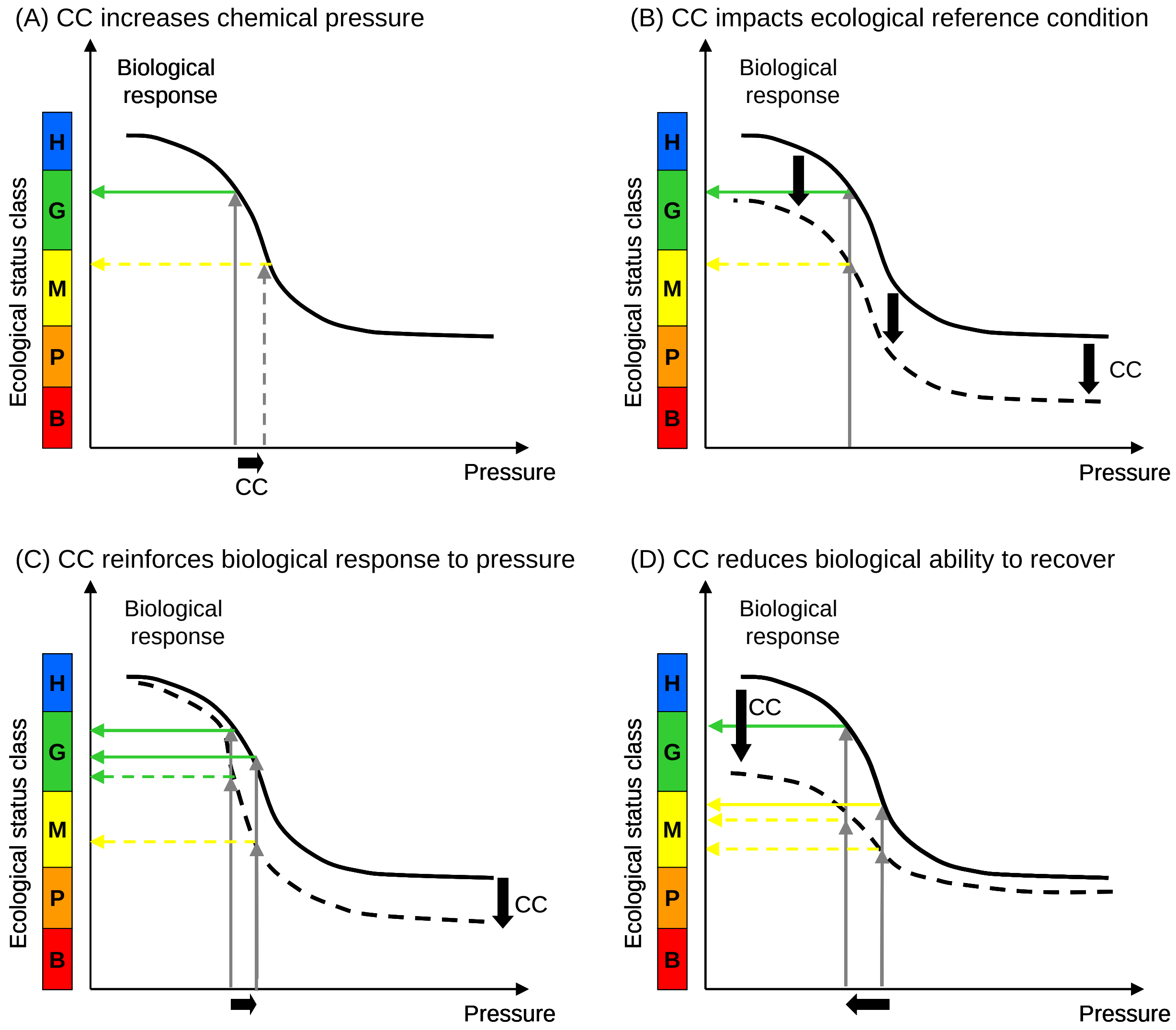
Although some general trends can be described for whole regions of Europe (EEA, 2008, UNECE, 2009), the climate change impact on freshwater quality is complex and dependent on the nature of the river basin in question. Conclusions of the most obvious impacts such as changes in turbidity or coloration can be made with reasonable certainty, but other impacts are still highly uncertain. For example, it is widely assumed that climate change will cause increased nutrient transport. In regions with pronounced winter seasons, however, nutrient transport may decrease due to changed snow melt and freeze-thaw conditions as well as better uptake of nutrients in plants (Ekstrand and Wallenberg, 2010).

The WFD-based status assessment for water bodies evaluates several aspects of ecological communities, both in terms of different biological groups (phytoplankton, macrophytes, fish, etc.), and different properties of the community structure within these groups (such as abundance, species richness and sensitive vs. tolerant species). Although climate change impacts on such biological indicators may be difficult to disentangle from other pressures, many relevant examples have been reported recently (Battarbee *et al.*, 2008, EEA, 2008, Jeppesen, 2009), including:

- More harmful algal blooms in lakes, due to i.a. higher nutrients concentrations and higher temperature
- Less macrophytes in lakes, due to less underwater light and more water level fluctuations
- Less salmonids and other predatory fish, due to less oxygen and higher temperature
- Less zooplankton in lakes, due to changes both in algal and fish community composition

Biodiversity is often considered a particularly important aspect of ecosystems, which is recognised by the WFD as well as by the EC Habitats Directive and other European initiatives such as the Natura 2000 network. Climate change can impact aquatic biodiversity through various mechanisms, such as temperature increase, changes in river flow regimes and lake mixing regimes, and change in seasonality of events. Freshwater biodiversity is expected to be more sensitive to climate change than marine biodiversity due to the existence of “captive” ecosystems contained within physical barriers, smaller populations more prone to extinction, and more anthropogenic pressure resulting to habitat destruction. Aquatic species with low mobility, such as mussels, are predicted to be particularly at risk because of low ability to keep pace with the rate of change in freshwater habitats (Gitay et al., 2001). Ecosystems with a low variety of functional "roles" are expected be particularly sensitive to climate change (Barrett et al., 2008). The biodiversity component most commonly used in WFD-based assessment is species richness, although other biodiversity aspects can also be identified. Prediction of particular species changes will be possible only in a minority of cases, but prediction of trends in general structure and operation of certain generic freshwater ecosystems in broad zones of Europe may still be practicable (Moss et al., 2009).

Ecological reference conditions and pressure-response relationships are the basis for all WFD-compliant national assessment systems used for the classification of water body status.
Ecological reference conditions are determined from the values of the biological quality elements found in reference sites, for a given water body type. Reference sites are in turn defined as water bodies with minimal anthropogenic impact, but this definition does not include climate change impacts. However, climate change may affect the ecological communities in reference sites, as well as other components involved in assessment of ecological status (**Figure 3**). National classification systems will therefore need to take into account climate change impacts on reference conditions (Wilby, 2004), ecological class boundaries and water body typology (Frisk and George, 2010). For example, a slight increase in temperature in French rivers is predicted to reduce the abundance of salmonid fish, regardless of (local) anthropogenic pressures (Pont et al., 2006). This implies that the current definition of reference conditions as well as the boundary between good and moderate status classes for salmonid fish will need to be reconsidered. Larger shifts in temperature may for example reduce species richness, and thereby impact the resilience or "buffer capacity" of ecosystems (Suding et al., 2004). Studies on ecosystem recovery following restoration attempts show that ecosystems do not necessarily follow the same "trajectory" back to their previous state (Jeppesen et al., 2005, Duarte et al., 2009), and this "recovery trajectory" may be further confounded by climate change.



(A) CC increases chemical pressure

(B) CC impacts ecological reference condition

(C) CC reinforces biological response to pressure

(D) CC reduces biological ability to recover

Figure 3. Potential impacts of climate change on components of ecological status classification, for a hypothetical biological indicator (e.g. species richness of benthic macroinvertebrates) which responds to a local physical/chemical pressure (e.g. organic pollution). Ecological status classes: H = high, G = good, M = moderate, P = poor, B = bad. Solid curves: present situation; stippled curves: impact of climate change (CC). (**A**) CC affects the level of local pressures. (**B**) CC affects the reference condition of the biological element (i.e. the baseline or condition found in sites with minimal impact of other anthropogenic pressures). (**C**) CC affects the biological element's response to increased local pressures, including thresholds used for defining boundaries between ecological status classes. (**D**) CC affects the biological element's ability to recover when local pressures are decreased due to measures.

When considering impacts of climate change for aquatic systems, it can be helpful to distinguish conceptually between primary and secondary impacts. Primary impacts can be described as direct links between climate drivers and ecological response (e.g., increased metabolic rates due to higher water temperatures), while secondary impacts can be seen as indirect impacts on ecosystems due to societal responses to climate change (e.g., elevated water abstractions for irrigated agriculture or construction of new flood defence infrastructure). Models used to assess climate change impacts therefore need to take account of not only changes in temperature, hydrology etc. but also changes in human behaviour and management practices, although this will be difficult in practice. There is much evidence of ecological (primary) responses to climate change, but the inherent variability of ecological communities makes it difficult to distinguish a direct climate change "signal" from background "noise" with statistical significance (Pont et al., 2007). Therefore, it is generally not expected that the biological indicators used for status assessment will be able to distinguish a direct effect of climate change from effects other human pressures, at a level requiring reclassification of sites within the timeframe of the WFD implementation (CIS, 2009). Instead, it is expected that indirect pressures arising from human activities in response to climate change - both mitigation and adaptation - will have a greater impact on aquatic ecology (CIS, 2009).

Based on the arguments above, the following key research needs and challenges regarding freshwater quality and ecology need to be addressed:

- Analysis of long-term ecological time series from both reference sites (i.e. with low impact from local pressures) and impacted sites are required to allow for a separation of climate effects from other pressures.
- A better spatial resolution of monitoring and assessment is required to identify qualitative changes on different types of individual water bodies within RBDs.
- More insight is needed on evolutionary adaptations and migration of species to improve predictions of impacts on ecosystems.
- Quantitative predictions are needed for regional climate change impacts on e.g. external and internal nutrient loading, salinity, bacterial contamination and harmful algal blooms.
- Climate change effects on community composition and diversity remain highly unpredictable. However, development of standardised biodiversity indicators could enable the monitoring of biodiversity changes within the WFD monitoring networks.
- More knowledge is also required regarding how changes in freshwater quality and ecology could affect major water users and other ecosystem goods and services, and to quantify potential economic consequences.

4. Climate change and adaptation to freshwater quantity

Climate change is expected to reinforce extreme variations in freshwater quantity, in terms of increased risk of floods as well as increased risk of water scarcity and droughts. Such extreme events may pose risks to human health and economic activity. Adaptation to climate-induced changes in freshwater quantity has therefore been addressed more in-depth in two separate policy documents in addition to the WFD: the EU Floods Directive (European Commission, 2007a) and the EU Water Scarcity and Droughts strategy (European Commission, 2007b), respectively.

4.1 Floods

Recent climate change predictions state that regions of Northern Europe will experience more precipitation and thus increased river flow, while Southern Europe will receive less precipitation (Dankers and Feyen, 2008, 2009). Moreover, intense precipitation events are expected to increase in magnitude and frequency throughout most of Europe, even in regions where mean precipitation decreases. Other climatic factors may contribute to increased floods as well, especially in snow-dominated river basins. The current estimate of annual damage due to floods in EU is € 6.5 billion, while the estimated annual damage for the 2080s is projected to rise to at least twice this figure (Feyen et al., 2009).

Climate change adaptation will be considered in the first implementation cycle of the Floods Directive, starting in 2011 with the preliminary flood risk assessment. In addition to this directive, flood risk has also been addressed in other WFD-related policy documents (European Commission, 2006, CIS, 2008, European Commission, 2009) and in connection to other policies such as agriculture, spatial planning and nature conservation. "Flood risk" according to Floods Directive is the potential losses caused by flooding, and is determined by three components (**Figure 4**): flood hazard - probability and magnitude of the flood event; exposure - capital, population and ecological assets exposed; and vulnerability - susceptibility to the hazard. Both climate and land use are hence major drivers of flood risk, in terms of their influence on flood hazard and flood exposure, respectively.

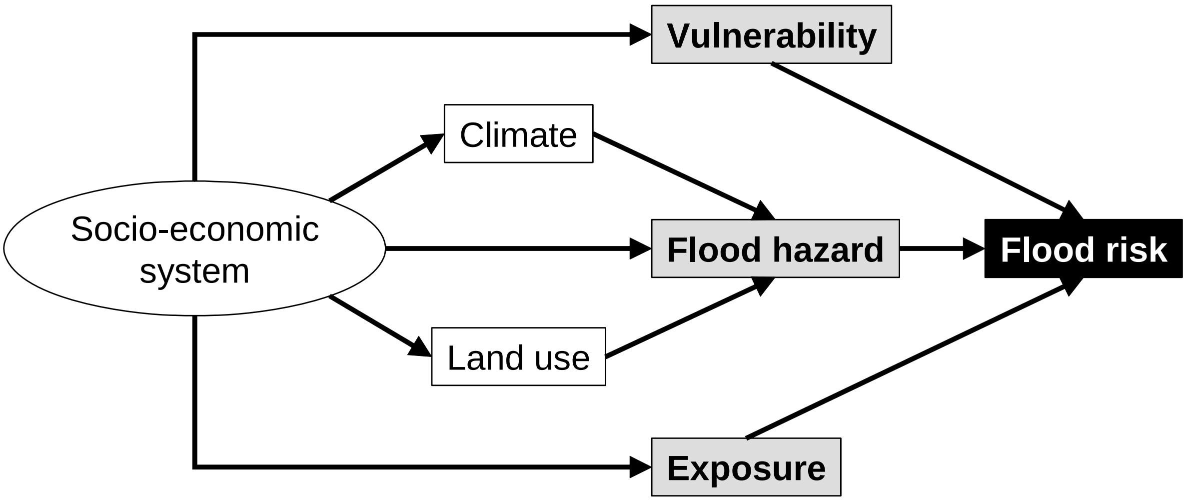


Figure 4. Components of flood risk which are affected by socio-economic systems. After Feyen et al. (2009).

The problem of increased flood risk in regions of Europe should be addressed by each of its three components (hazard, exposure and vulnerability). Flood hazard can be reduced by traditional structural measures, which must however be adjusted to projected changes and uncertainty (Hennegriff, 2007). Other relevant factors are changes in land-use management within the "room for the river" concept, as well as other practices aiming to restore the natural catchment response to rainfall (for example re-forestation, sustainable drainage systems and water-sensitive urban design) (Makropoulos et al., 2001). Flood exposure is strongly related to land use and urbanisation. As an example, the expected annual damage for the greater Madrid region is projected to increase from €13 million to €23-110 million, depending on projected land-use changes. It is therefore paramount to discourage development in flood-prone areas (Feyen et al., 2009). Finally, flood vulnerability can be reduced at local level, e.g. by flood-proofing of buildings, as well as at larger scales through preparedness (such as early warning, information, education and insurance).

Climate and socio-economic changes will likely increase flood risk in large parts of Europe, and it is necessary to design flood risk management strategies that are robust and/or adaptable to climate changes. This requires that knowledge, data and methods are iteratively integrated across scientific disciplines and socio-economic sectors. Several key research and development challenges can be identified:

- The role of uncertainty in relevant sciences, such as climatology, hydrology, land-use planning, socio-economic sciences and decision-making needs to be upgraded, recognising the intrinsic unpredictability of these systems. In particular, the uncertainty due to statistical analysis of extremes can be considerable.
- Long term, high-quality observations and data sets need to be obtained, supported by long-term funding.
- The mechanisms that trigger extreme events such as flash-floods must be better described, in order to improve early-warning systems.
- Interactions and feedbacks between climate, land use and hydrological cycle need to be better understood, with emphasis on feedback loops.
- Downscaling from global to regional climate models must be improved to be able to represent and assess variability and extremes at regional and local scale. Moreover, techniques to downscale or translate regional climate simulations to extreme river flows (i.e. hydrological modelling) are needed.
- Damages and cost/benefits of adaptation measures must be quantified more precisely.
- Formal treatment of uncertainty in the chain "emissions - climate - extreme flows - inundation - damage" is required to explore the reliability of climate change predictions and assess the impact of this uncertainty on potential adaptation activities.
- Flood risk mapping and management needs to take into account these uncertainties and communicate them both to decision makers and to the general public.

4.2 Water scarcity and drought

Europe is becoming increasingly affected by droughts: the proportion the EU population affected has increased from 6 % in the period 1976-1990 to 13 % in the period 1991-2006 (DG Environment, 2007). The total estimated economic impacts over the past 30 years are € 100 billion at EU level, while the annual average impact doubled between the 1976-1990 and the following period 1991-2006 (up to 6.2 billion €/year in the most recent years). Different types of droughts can be identified: e.g. precipitation droughts, soil moisture droughts, agricultural droughts and streamflow droughts (see Feyen and Dankers 2009). Water scarcity and drought has been traditionally regarded as a threat mostly for Southern Europe. However, the pattern of droughts over time reveals that all of Europe - from northern to southern regions - may potentially be faced with such events (European Commission, 2007b, 2007c).

Climate change is expected to increase the frequency and severity of droughts across Europe, with potentially significant impacts on water quantity and quality (Lehner *et al.*, 2006, IPCC, 2007). Drought events can be observed at both local and river basin scale, although the characteristics of droughts vary significantly among regions, in terms of their extent, duration, frequency and severity. This regional variability is not necessarily captured when drought onset and offset are declared at the national level, since national average drought indicator values often hide a more dire local or regional situation (**Figure 5**).

In Italy, for example, water resources are unevenly distributed from north to south due to climatological and geomorphologic features. Overall water stress conditions are on average high, but locally water stress can be more or less severe, for example in the Apulia region in South-East Italy. In fact, even the sub-alpine Po valley region has experienced repeated drought events in the last decade. In 2003, for example, snow deficit triggered a general water shortage. This prompted managing authorities, including water regulation, civil protection, irrigation districts and stakeholders to collaborate to resolve the crisis. Timely information exchange among all actors allowed effective decision making, and effective communication with the population facilitated the acceptance of water restrictions in a large area. Important lessons were learned from this incident, and the policy is now moving from a re-active crisis management approach to a pro-active risk management approach (Iglesias et al., 2009).

A recent initiative for bringing science closer to policy is the on-going development of a European Water Scarcity & Drought Information System (WSDIS) (European Commission, 2007b). The objective is to provide a reliable information base at the appropriate temporal and spatial resolution required for decision-making. It is expected that the information system will present an annual EU assessment, based on agreed indicators and data provided by EU member states and stakeholders on a yearly basis. The WSDIS will be available through the web portal of water-related information for EU, the Water Information System for Europe (WISE; http://water.europa.eu). However, water scarcity is a complex phenomenon, and cannot be described properly with a single indicator. A central part of the WSDIS is therefore the development of a coherent indicator system. On-going steps in this process are the development of adequate indicators to capture all aspects of water scarcity using a Driver-Pressure-State-Impact-Response framework approach (Kossida et al., 2009). Again, the temporal and spatial scale of the information needs is an important issue. The main indicator in use today - the Water Exploitation Index - is currently reported annually at the national scale. Thus, only one value is reported to represent the complex situation for a whole country and year, while regional and temporal variations are not depicted (**Figure 5**). It is thus apparent that such an indicator would be more useful if downscaled to individual river basins (Kossida et al., 2009).

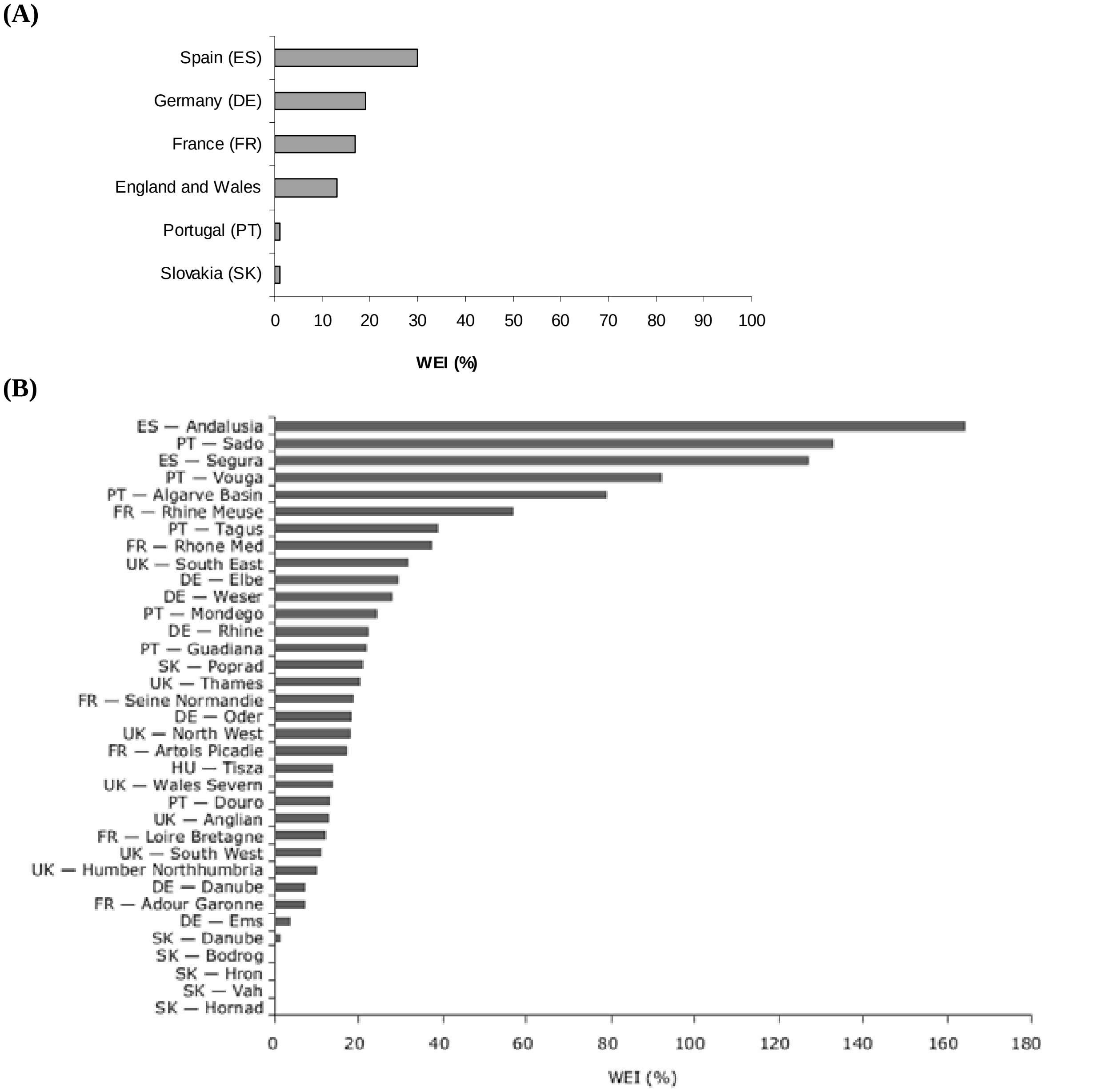


Figure 5. The Water Exploitation Index (WEI) for selected EU countries: results aggregated to national level (A) and to river basin level (B). The WEI is calculated as the ratio of total freshwater abstraction to the total renewable resource. A WEI above 20 % implies that a water resource is under stress and values above 40 % indicate severe water stress and clearly unsustainable use of the water resource. A comparison of the two aggregation levels show e.g. that while Spain appears to have an overall WEI of 30 %, certain Spanish river basins such as Andalusia and Segura have a WEI above 100 %. Source: (A) EEA based on data submitted to the Eurostat, 2007; (B): EEA, 2009.

EurAqua has already stressed the need for a specific European drought policy within the context of long-term sustainable use of water resources in Europe (EurAqua, 2004), including the need to integrate drought into a wide range of other EU policies and the need for specific drought mitigation measures at a European level (forecasting, monitoring, research and knowledge sharing). Furthermore, we highlight the following research and development needs for improving the management of water scarcity and drought in Europe:

- Climate scenarios must be downscaled and adapted to more detailed local scenarios for impact analysis. The general objective is to fill the gap between the resolution of state-of-the-art global climate models (GCMs) and the resolution required for impact studies. In fact, even the spatial resolution of regional climate models (RCMs) is still unsuitable for local scale studies of eco-hydrological processes, mainly due to land use and topography approximation. Local biases require additional post-processing before RCM output can be adopted as a forcing in process models for local impact predictions (Portoghese et al., 2009).
- Better modelling tools are needed for impact assessment of climate change, including: water resource availability and variability, water demand scenarios, complex environmental feedbacks affecting availability of and demand for water resources, and societal feedbacks due to land use and migration. These tools need to be able to integrate knowledge from different domain-specific models and investigate interactions between domains, under high levels of uncertainty. An example of a suitable tool is the OpenMI interface, which facilitates the modelling of process interactions (Gregersen et al., 2007, Makropoulos et al., 2009).
- Adaptation initiatives are needed to reduce the vulnerability of natural and human systems against actual or expected climate change impacts. Examples are water demand management, water-aware land-use planning which takes into consideration water availability (Makropoulos, 2006) and increased efficiency of infrastructures (Savic et al., 2008).
- Timely and shared information on drought evolution and water scarcity occurrence must be enhanced and improved, and coordinated at the European level. Such information need to include changes in water resources, socio-economic impacts and actions undertaken at meaningful scale, closer to hydrologic units such as river basins. A common indicator system should be built upon this common information platform to improve response mechanisms and the potential for transferable lessons.
- Since climatic changes including droughts do not respect national boundaries, there is a need for effective transboundary monitoring, which should employ recent technology including remote sensing data sources (Fotopoulos et al., 2010).

5. From science to policy: how can climate change information be incorporated into water management?

Several EU policies on climate change strive towards mitigation, and attempt to maintain global warming at +2 °C compared to pre-industrial times. Synergistic actions for mitigation of climate change require integrated policies to effectively reduce greenhouse gas emissions and enhance sinks. Nevertheless, stopping climatic changes is unlikely at least in the near future, because of the complexity, inertia and inherent unpredictability of the global climate system (EEA, 2008). A more realistic approach for the near future is therefore adaptation: efforts to cope with climate change impacts at present and to anticipate changes in the future.

Such considerations of climate change in river basin management plans are expected to be a challenge for the EU member states and require an effective mechanism to incorporate the best available scientific knowledge and understanding into both policy and implementation.

Research prioritisation is required, which in turn requires an improved interaction between policy and science, addressing on questions such as: What are the most important upcoming policy documents? What science is required to underpin policy? What are the most uncertain scientific aspects? Science-policy interfaces are expected to play an important role at a number of levels within the WFD context, including national, regional and local policy and implementation. EU is actively trying to improve the uptake of science into water policy through various mechanisms:

- EU has funded research project focusing on the science-policy interface, for example Harmoni-CA (http://www.harmoni-ca.info), which aimed at harmonising catchment modelling in support to the WFD and to enhance the uptake of modelling results to policy.
- The European Research Agency networks (ERA-nets) have projects run by research funding agencies of the EU Member States, aiming to exchange information on research programmes, exchange research results, identify common issues for research and jointly tender common research issues. Examples of relevant projects are IWRM-NET (focus on WFD), CRUE (focus on flood risk management) and CIRCLE (focus on climate change research). Water management institutes are closely involved in these projects, which contributes to improving the science-policy interface.
- The Water Information System of Europe has recently launched a portal for research, technology and development (http://www.wise-rtd.info), where data and knowledge are made available to policy makers, scientists and water managers. In particular, the WISE-RTD portal forwards best tools, practices and guidelines in support of integrated river basin management.
- An expert group on climate change and water has been settled within the work programme[1] 2010-2012 of the WFD Common Implementation Strategy, which includes an activity on science-policy interface.

The identification and implementation of effective management measures require high political capabilities and public awareness. For example, the involvement of local stakeholders in the process for the definition of a drought management plan can have several benefits. Firstly, the public awareness about the negative impacts of irresponsible water use during drought periods may be promoted. Secondly, eliciting and taking into account the main stakeholders' interests and concerns

---

[1] Available from http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_documents/final_2010-2012/_EN_1.0_&a=d

related to water management during drought periods may help avoiding potential conflicts and to identify highly consensual measures. These, in turn, may result in an easier implementation of selected measures (Vurro et al., 2009).

Still, many challenges remain for meeting climate change-related policy demand with relevant and updated science. For example, development of new infrastructure for increasing water supply, such as desalination or reservoir construction, could result in increased greenhouse gas emissions. EU member States are therefore required to perform a "climate check" on their WFD programme of measures. The climate check should consider both how the measure will function under future climate conditions and whether the measure will have negative climate effects (**Figure 6**, Arrows 1 and 2). On the basis of their impact on climate change mitigation and/or adaptation, measures to improve water quality can be either classified as “counter-productive" (e.g. desalination plants using electricity from coal power plants, thereby contributing to green-house emission), "win-win" (e.g. water-aware land-use management which both improves water quality and prevents flooding), or "no-regret" (e.g. control of point source pollution with no impact on climate change mitigation or adaptation). Measures for adaptation to floods or droughts can correspondingly be classified as counter-productive, win-win and no-regret with regard to other measures.

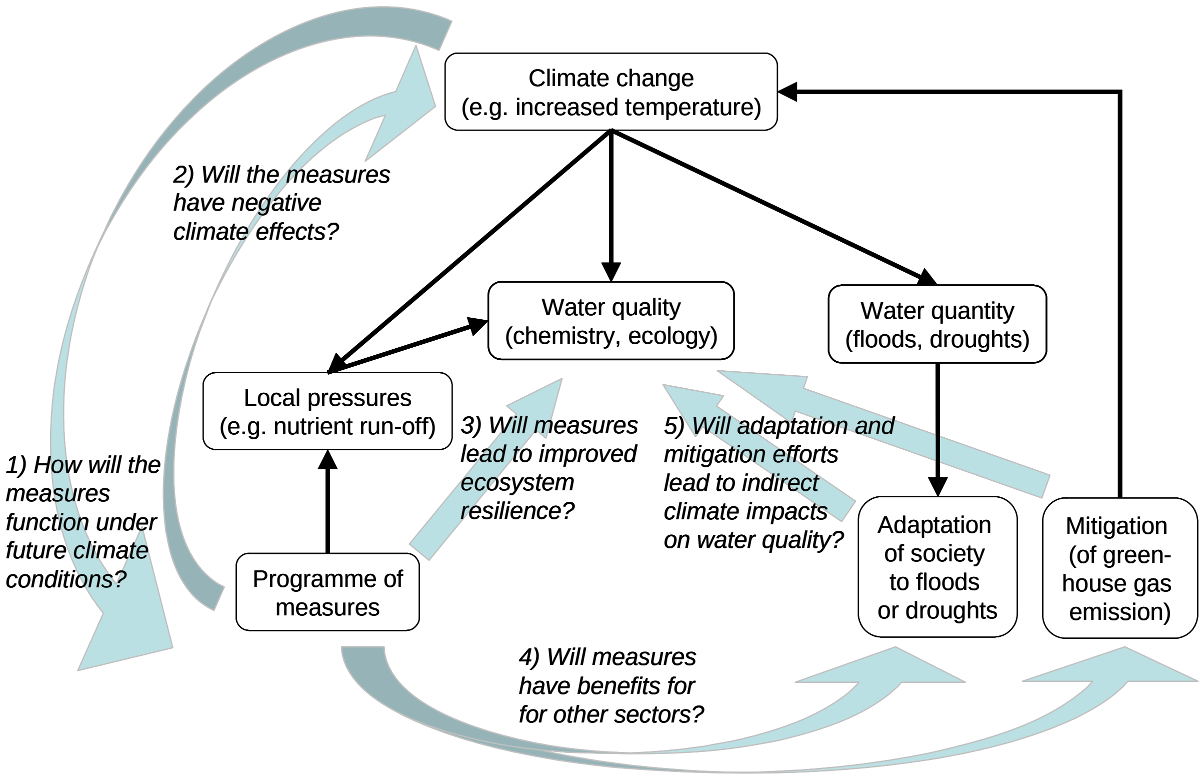


Figure 6. Summary of key relationships between river basin management, climate change and adaptation, as presented in this report. River basin management plans should include a "climate check" for the programme of measures (arrows 1 and 2; see also Figure 2). In additon to reducing local pressures, favoured measures should ideally improve the ecosystem's resilience and robustness towards climate change (arrow 3) and work in synergy with other sectors (arrow 4). Finally, river basin management plans should consider how society's activities for adaptation to and mitigation of climate change impacts might in turn impact water quality, and thus potentially counteract the success of the measures. (For simplification, the relationship between programme of measures and water quantity is omitted here).

An additional problem for providing scientific support to water managment policy under climate change is that some process-based models traditionally used for supporting water management may no longer be reliable. Many models are based on assumptions of stationarity, by assuming that certain model parameters (such as long-term average precipitation) can be regarded as constant and can be estimated from historical data records. However, some climatic "constants" may now be changing and assumptions of stationarity may no longer valid in such cases (Milly et al., 2008). The CLIME project concluded that scientific methods used to support the WFD will need to be revised at regular intervals to accommodate both the direct and indirect effects of climate change (Frisk and George, 2010). They identified several climate-related issues that need consideration, including methods used to downscale results from climate models to a catchment scale, the modelling techniques used to assess the climatic sensitivity of lakes, and even the conceptual model used to support the WFD.

In conclusion, there is currently a risk that science is not able to meet the policy demands regarding freshwater management and climate change adaptation. A survey of the EU member states' national adaptation strategies - a general plan of action for addressing the impacts of climate change - concluded that scientific knowledge needs to "speed up", in order to meet the demands of climate adaptation policies (PEER, 2009). This is due to, inter alia, policy interactions at the larger scale, lack of scientific evidence on the long-term effectiveness of impacts and measures, as well as to the inherent uncertainty related to climate change. Current policy ambitions and legislation seem to be running ahead of scientific understanding, which might lead to a "wait and see" approach of water managers (Frisk and George, 2010).

6. Conclusions and recommendations for river basin management and for research

Many of the topics discussed in this report have since the EurAuqa 2008 conference been incorporated in the EC guidance document "River basin management in a changing climate" (CIS, 2009). Here we present a summary of the guiding principles that are most relevant to the focus of this report (Figure 6).

Given the large uncertainty regarding regional climate change projections and realised impacts on aquatic ecosystems, river basin management plans should incorporate management strategies that deliver benefits regardless of the climate outlook. Robust and adaptive river basin management measures are low-regret or reversible, incorporate safety margins, employ "soft" solutions, are flexible, and are mindful of the actions being taken by others to mitigate or adapt to climate change.

Projections and scenarios based on climate models should be used for improving river basin management planning, and it is crucial to have a clear understanding of the assumptions made and of the uncertainties related to these assumptions. Uncertainty in models should not be used as a justification for "doing nothing". Instead, river basin managers should use a range of climate projections or scenarios in the analyses for river basin management planning in order to accept and work within the context of an uncertain future. Through sensitivity testing it should then be possible to establish which individual or combinations of measures are most effective at achieving water management objectives.

A review of the impact of human activities on the status of water bodies must be carried out by the EU member states. However, climate change have similar impacts as local anthropogenic pressures, for quality elements used for status assessments in a river basin. River basin management plans should consider primary (direct) impacts of climate change for water bodies as well as secondary impacts (indirect impacts of climate change due to society's adaptation and mitigation activities). Risk assessments that are too narrowly focused on existing pressures within river basins may overlook important but physically remote, indirect or longer-term drivers of water body status.

Monitoring of surface water bodies is important both for assessing current ecological status and effects of abatement measures, as well as for detecting potential effects of climate change (Figure 2). The first priority should be to establish or safeguard monitoring programmes that will help benchmark and track long-term climate change impacts as they materialise. Robust information on changes at reference sites is the primary means of isolating climate change impacts from local pressure impacts. Long consistent series of monitoring data are needed for this purpose, to account for natural variation as well as climate-induced trends. It is important to assess how best use can be made of available data from existing networks, and that sites with relevant long data records are sustained over coming years as part of wider surveillance efforts. Knowledge of when and where climate change might be first detected can help target investigative monitoring and reporting of effects in "hot spots" (the most vulnerable water bodies). Climate change indicators can be deployed that improve the chance of early detection, and hence the lead-time for invoking adaptive measures. Likewise, long-term consistent monitoring data are important for improving prediction of flood risks and for forecasting water scarcity and drought.

Programmes of measures for river basin management should undergo a "climate check" (Figure 6), especially for measures that are costly and will have a long lifespan. This check should involve a sensitivity analysis of the proposed measures to evaluate long-term effectiveness and cost-efficiency under changing climate conditions. The preferred option should be measures that will be able to cope with a range of climate conditions or are sufficiently flexible to be adapted to changing conditions. Where feasible, "no-regret", or "win-win" measures should be adopted as these yield beneficial outcomes regardless of the eventual outcomes of climate change. Ideally these measures should also work with natural processes and realise multiple benefits, e.g., for flood risk management, drought management and nature conservation as well as for other sectors.

An overall guiding principle for flood risk management as well as for drought management is to follow the guiding principles set out for the WFD, and to use the basic methodological framework to achieve climate change adaptation. Again it is stressed that full certainty in forecasts of climate change will be never be obtained, but adapting management to potential climate change should nevertheless be started as soon as possible. Favoured measures should be able to reduce the vulnerability of natural and human system against actual and expected climate change effects, advancing the policy from a re-active crisis management approach to a pro-active risk management approach.

To conclude, EurAqua emphasises research needs in the following areas regarding climate change and WFD-based river basin management (EurAqua, 2009):

- **Ecology**. More knowledge is needed on both direct and indirect impacts of climate change on ecological processes - in combination with other pressures, abatement measures and climate change adaptation strategies. Particularly important for WFD implementation are impacts on ecological reference conditions and on ecosystem resilience and recovery.
- **Modelling**. Hydrological modelling and other relevant process modelling needs downscaling of climate change scenarios to appropriate geographical scales such as river basins, to support water management at relevant scales. Statistical modelling and analysis needs long-term consistent data from monitoring networks, in order to distinguish between climate change effects, other anthropogenic pressures and natural variation.
- **Uncertainty**. The inherent uncertainty of climate change processes and impacts must be recognised and handled in all types of models and predictions. The role of uncertainty must be better communicated to managers and to the public.

7. References

Bates, B. C., Kundzewicz, Z. W., Wu, S. & Palutikof, J. P. (Eds.). (2008) *Climate change and water. Technical Paper of the IPCC.*, IPCC Secretariat, Geneve.

Battarbee, R. W., Kernan, M., Livingstone, D., Nickus, U., Verdonschot, P., Hering, D., Moss, B., Wright, R., Evans, C., Grimalt, J., Johnson, R., Maltby, E., Linstead, L. & Skeffington, R. (2008). Freshwater ecosystem responses to climate change: the Euro-limpacs project. In *The Water Framework Directive - Ecological and Chemical Status Monitoring.* (P. Quevauviller, U. B., C. Thompson & T. Simonart (ed.)). Wiley, Chichester, UK.

CIS (2008). Climate Change and Water. IN European Communities (Ed.).

CIS (2009). River basin management in a changing climate. IN European Communities (Ed.).

Dankers, R. & Feyen, L. (2008). Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations. *Journal of Geophysical Research,* **113**, D19105.

Dankers, R. & Feyen, L. (2009). Flood hazard in Europe in an ensemble of regional climate scenarios. *Journal of Geophysical Research,* **114**, D17116.

DG Environment (2007). Water Scarcity and Droughts Second Interim report. European Commission.

Duarte, C., Conley, D., Carstensen, J. & Sánchez-Camacho, M. (2009). Return to Neverland: shifting baselines affect eutrophication restoration targets. *Estuaries and Coasts,* **32**, 1, 29-36.

EEA (2007). Climate change and water adaptation issues. *EEA Technical report No 2.*

EEA (2008). Impacts of Europe's changing climate - 2008 indicator-based assessment. European Environment Agency.

EEA (2009). Water resources across Europe - confronting water scarcity and drought.

Ekstrand, S. & Wallenberg, P. 2010. Climate change impact on nutrient loss in regions with pronounced winter seasons. *Journal of Water and Climate Change* (in press).

EurAqua (2004). Towards a European drought policy. http://www.euraqua.org/download/18.4a4d22a41128e56161b800015566/Drought_brochure_992kb.pdf

European Commission (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

European Commission (2006). Climate Change Impacts on the Water Cycle, Resources and Quality. Scientific and Policy Report. *Climate Change and Natural Hazards series 8* EUR 22422. Climate Change Impacts on the Water Cycle, Resources and Quality, Brussels, Belgium.

European Commission (2007a). Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

European Commission (2007b). Addressing the challenge of water scarcity and droughts in the European Union.

European Commission (2007c). Mediterranean water scarcity and drought report.

European Commission (2009). Adapting to climate change: Towards a European framework for action.

Feyen, L., Dankers, R. & Bódis, K. (2009). Evaluating the benefits of adapting to changing flood hazard in Europe. *IOP Conference Series: Earth and Environmental Science* 6. Climate Change: Global Risks, Challenges and Decisions, Copenhagen, Denmark.

Fotopoulos, F., Makropoulos, C. & Mimikou, M. (2010). Flood Forecasting in transboundary catchments using the Open Modeling Interface. *Environmental Modelling and Software* **25**(12): 1640-1649.

Frisk, T. & George, G. (2010). Climate change and the water framework directive. In *The Impact of Climate Change on European Lakes.* (George, D. G. (ed.)) Aquatic Ecology Series 4. Springer Science+Business Media B.V.

Gitay, H., Brown, S., Easterling, W. & Jallow, B. (2001). Ecosystems and Their Goods and Services. In *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* (McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J. & White, K. S. (ed.)). Cambridge University Press, Cambridge.

Gregersen, J. P., Gijsbers, P. J. A. & Westen, S. J. P. (2007). OpenMI: Open modeling interface. *Journal of Hydroinformatics,* **9**, 3, 175-191.

Hennegriff, W. (2007). Climate change and floods - findings and adaptation strategies for flood protection in Baden-Württemberg. *Water Science & Technology*, **56**, 4, 35-44.

Iglesias, A., Garrote, L., Cancelliere, A., Cubillo, F. & Wilhite, D. A. (2009). *Coping with Drought Risk in Agriculture and Water Supply Systems,* Dordrecht, Springer.

IPCC (2007). IPCC Fourth Assessment Report. Working Group I Report "The Physical Science Basis".

Jeppesen, E., Søndergaard, M., Jensen, J. P., Havens, K. E., Anneville, O., Carvalho, L., Coveney, M. F., Deneke, R., Dokulil, M. T., Foy, B., Gerdeaux, D., Hampton, S. E., Hilt, S., Kangur, K., Köhler, J., Lammens, E. H. H. R., Lauridsen, T. L., Manca, M., Miracle, M. R., Moss, B., Nöges, P., Persson, G., Phillips, G., Portielje, R., Romo, S., Schelske, C. L., Straile, D., Tatrai, I., Willén, E. & Winder, M. (2005). Lake responses to reduced nutrient loading; an analysis of contemporary long-term data from 35 case studies. *Freshwater Biology,* **50**, 10, 1747-1771.

Jeppesen, E. B. e. a. (2009). Chapter 5: Interaction of climate and eutrophication. In *Changing climate and changing freshwaters: a European perspective.* (Kernan, M., Battarbee, R. W. & Moss, B. (ed.)). Blackwell.

JRC (2005). Climate Change and the European Water Dimension. IN Eisenreich, S. J. (Ed.), European Commission - Joint Research Centre.

Kossida, M., Koutiva, I., Makropoulos, C., Monokrousou, K. & Mimikou, M. (2009). Water Scarcity and Drought: towards a European Water Scarcity and Drought Network (WSDN).

Lehner, B., Döll, P., Alcamo, J., Henrichs, T. & Kaspar, F. (2006). Estimating the impact of global change on flood and drought risks in Europe: a continental, integrated analysis. *Climatic Change,* **75**, 3, 273-299.

Makropoulos, C. (2006). Decision support tools for water demand management. In *Water Demand Management.* (Butler, D. & Memon, F. A. (ed.)). IWA Publishing.

Makropoulos, C., Safiolea, E., Efstratiadis, A., Oikonomidou, E., Kaffes, V., Papathanasiou, C. & Mimikou, M. (2009). Multi-reservoir management with Open-MI. A. University of the Aegean. 11th International Conference on Environmental Science and Technology, Chania, Greece.

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P. & Stouffer, R. J. (2008). Stationarity is dead: Whither water management? *Science,* **319**, 573-574.

Moss, B., Hering, D., Green, A. J., Aidoud, A., Becares, E., Beklioglu, M., Bennion, H., Carvalho, L., Declerck, S., Dobson, M., Donk, E. v., Feuchtmayr, H., Friberg, N., Grenouillet, G., Hobaek, A., Irvine, K., Johnson, R., Meerhoff, M., Ormerod, S., Papastergiadou, E., Ptacnik, R., Verdonschot, P., Clement, B., Davidson, T., Dudley, B., Jeppesen, E., Kernan, M., Sandin, L., Simpson, G., Weyhenmeyer, G. A., Box, D., Brucet, S., Hillebrand, H., Jones, I., Manca, M., Olafsson, J., Penning, E., Quintana, X., Seferlis, M., Triga, C. & Verschoor, A. M. (2009). Climate change and the future of freshwater biodiversity in Europe: a primer for policy-makers. *Freshwater Reviews,* **2**, 2.

PEER (2009). Europe Adapts to Climate Change: Comparing National Adaptation Strategies. http://www.peer.eu/publications/europe_adapts_to_climate_change/.

Pont, D., Hugueny, B., Beier, U., Goffaux, D., Melcher, A., Noble, R., Rogers, C., Roset, N. & Schmutz, S. (2006). Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. *Journal of Applied Ecology,* **43**, 70-80.

Pont, D., Hugueny, B. & Rogers, C. (2007). Development of a fish-based index for the assessment of river health in Europe: the European Fish Index. *Fisheries Management and Ecology*, **14**, 6, 427-439.

Portoghese, I., Vurro, M. & Bruno, E. (2009). From regional climate simulations to the hydrological information needed for basin scale impact studies. 11th Plinius Conference On Mediterranean Storms, EGU, Barcelona, Spain.

Savic, D. A., Boxall, J. B., Ulanicki, B., Kapelan, Z., Markropoulos, C., Fenner, R., Soga, K., Marshall, I. W., Maksimovic, C., Postlethwaite, I., Ashley, R. & Graham, N. (2008). Project Neptune: Improved Operation of Water Distribution Networks. Water Distribution Systems Analysis, South Africa.

Suding, K. N., Gross, K. L. & Houseman, G. R. (2004). Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology & Evolution*, **19**, 1, 46-53.

UNECE (2009). Guidance on water and adaptation to climate change. IN Publications, U. N. (Ed.) *Economic Commission for Europe. Convention on the Protection and Use of Transboundary Watercourses and International Lakes.* New York and Geneva.

Vurro, M., Bruno, E., Giordano, R., Portoghese, I., Preziosi, E. & Romano, E. (2009). Climate changes impacts on drought management in Mediterranean area: how to improve the approaches. European and Mediterranean workshop on climate change impact on water-related and marine risks, Murcia, Spain.

Wilby, R. L. (2004). Impacts of climate change on reference sites used for ecohydrological restoration and research. *Ecohydrology and Hydrobiology*, **4**, 243-253.

Wilby, R. L., Orr, H. G., Hedger, M., Forrow, D. & Blackmore, M. (2006). Risks posed by climate change to delivery of Water Framework Directive objectives. *Environment International*, **32**, 1043-1055.