Vulnerability

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Important note to reviewers

- The Executive Summary is missing from this draft report
- List of figures, List of maps, List of tables, List of boxes, List of Abbreviations and Acknowledgements are missing in this draft report
- Cross-references to tables, figures and maps may be incorrect in some cases
- The formatting of text, tables, figures and maps as well as their captions has not been harmonized
- References may be incomplete in some cases and the format of references has not been harmonized
- High-lighted text indicates cross-references to other parts of the text or other EEA reports that need to be verified (generally in green) and areas of further work (generally in yellow)

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To be added later

Abbreviations used

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1. Executive Summary / Key Messages

To be written later

2. Introduction

Water resource management in Europe is complex owing to the diverse geo-physical, climatic, socio-economic, and political realities that exist across member states. Water is generally abundant in much of the region, but it is also unevenly distributed in both time and space, with large areas experiencing increasing levels of water scarcity and drought (EEA 2010a), and particular locations are more at risk of flooding. Climate change is predicted to further exacerbate this in certain areas (IPCC 2012), however the exact changes and impacts are uncertain and are difficult to isolate from the more direct anthropogenic stressors. At the European level a multitude of freshwater assessments have been made available, driven by the State of the Environment Reporting (SoER), and supported by the EU and other international organisations. These assessments have primarily focused on the states and pressures of European waters, but recent assessment (EEA 2011b) has showed their scope to be too narrow, requiring a shift in focus towards management and measures.

Within the EU there has been a gradual shift in water policy from simply addressing human health and economic damage concerns towards a more holistic understanding the environmental impacts of water users and addressing the needs of the environment. This is epitomized in the adoption of the Water Framework Directive (WFD) (EC 2000) and its emphasis on 'good ecological status' or 'good ecological potential' (GES/GEP). However, while the legislative framework is deemed adequate, fundamental weaknesses in implementation and conflicts that exist between water and other existing EU policies outside of the environmental sphere have been identified in the Blueprint to safeguard Europe's water resources consultation document (EC 2012). There have also been few attempts to assess the vulnerability of European waters to future change when assessing the potential impacts of climate change on freshwater resources. This has been a key focus of the IPCC Climate Change and Water Technical Paper (IPCC, Bates, et al. 2008) and more recently the IPCC special report on managing the risk of extreme events (IPCC 2012).

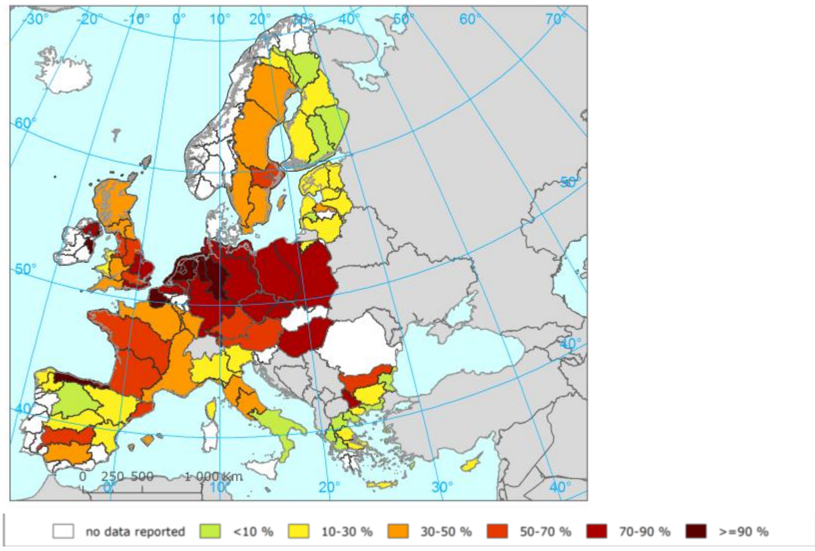
Environmental flows as an indicator of achieving GES/GEP, and how this concept relates to the provision of and sustainability of ecological services, is a particular area where policy increasingly has to acknowledge the complexity of natural systems and inadequacy of exiting legislation at defining the concept. Understanding and accounting for the direct and indirect benefits provided by Europe's freshwater ecosystems are increasingly becoming understood as essential elements in ensuring holistic policy decisions and identifying policy trade-offs such as between the WFD and the Floods Directive (EC 2007c). Identifying the vulnerability and susceptibility of freshwater ecosystem receptors to anthropogenic and climate pressures is critical in assessing such water management policy trade-offs. Ensuring sustainable management of European waters, reducing the vulnerability of society to water related hazards, and achieving GES/GEP requires a greater understanding of how mankind is connected to these complex systems and planning for an uncertain future. Incorporating the connectivity that exists between society and ecosystems with the uncertainty surrounding climate change, will require policy decisions that incorporate a greater role for risk and vulnerability assessment in planning activities.

2.1. Why a thematic assessment on Vulnerability

There exist numerous challenges in attaining the Water Framework Directive (WFD) objectives (EC 2000, art. 4) and the EU response is to provide a range of policy options to be embedded in the "Blueprint to Safeguard Europe's Water". The proposed aim of the Blueprint is to outline a strategy that will ensure good quality water in sufficient quantities for all legitimate uses by 2020. It will also present a future vision towards 2050 in order to influence long-term policy development. The Blueprint will synthesise policy recommendations resulting from the assessment of River Basin Management Plans (RBMPs), the vulnerability of water resources to climate change and other pressures, the review of the EU action on Water scarcity and drought, and a comprehensive fitness check of the overall EU water policy to achieve this ambitious objective.

Europe's waters have been identified as being vulnerable to a diverse set of anthropogenic pressures (EEA (report under preparation) 2012a). Surface freshwaters are affected by major modifications - such as water flow regulation (e.g. dams, weirs, sluices or locks) water abstractions and morphological alterations, straightening and canalisations. These hydro-morphological pressures comprise all physical alterations of water bodies that modify their shores, riparian and littoral zones, water level and flow. They are the most commonly occurring pressure and impact on rivers, lakes and transitional waters in Europe; affecting half of river and transitional water bodies and 30 % of the lake water bodies (Figure 2.1).

Figure 2.1 Proportion of classified water bodies (rivers and lakes) in River Basin Districts affected by hydro-morphological pressures

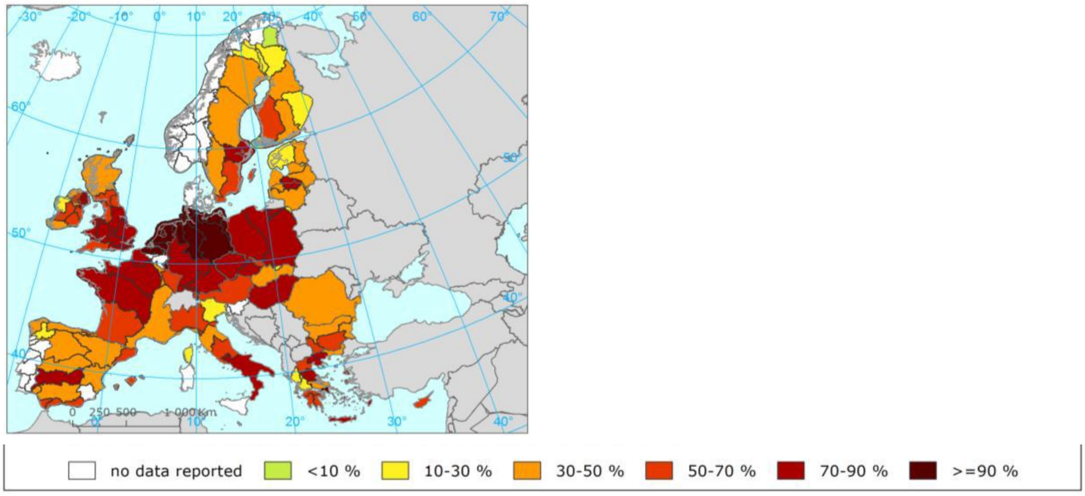


Source: (EEA (report under preparation) 2012a)

In addition to hydro-morphological changes, more than half the surface water bodies in Europe are reported in the 1st cycle RBPMs as not meeting GES or GEP, requiring mitigation measures in order to meet WFD objectives (Figure 2.2). The main pressure responsible for this is diffuse pollution causing nutrient enrichment. An in depth analysis of the pressures, status and impact can be found in the 'European Waters: Assessment of Status and Pressures' report (EEA (report under preparation) 2012a).

Water scarcity and extreme hydrological events in the form of droughts and floods are also contributing factors to not meeting GES and GEP. These water resource issues are discussed in detail in chapters 4 and 5. Too little or too much water impacts almost all economic sectors; including agriculture, energy supply, drinking water supply, industry and tourism. But managing water resources sustainably also means ensuring that ecosystems have the quality and quantity of water required to function and maintain natural processes.

Figure 2.2 Proportion of classified water bodies (rivers and lakes) in River Basin Districts found to be in less than good ecological status or potential



Source: (EEA (report under preparation) 2012a)

More about resource-efficiency technologies, economic instruments and the water-energy-food nexus can be found in the 'Towards efficient use of water resources in Europe' report (EEA 2012b). This report focuses on the drivers of climate change and land use changes and more specific how they effect on floods and water scarcity. This report builds on earlier EEA reports describing the state of Europe's water resources and the pressures they face (EEA 2009; EEA 2010a; EEA 2011a).

2.2. Water quantity policies

EU water policy as formulated in the Water Framework Directive (WFD) is based on the objective of achieving good status of all EU waters by 2015 and looks in detail to chemical and biological status, as well as changes in hydro-morphology - expressed as ecological status. Except for groundwater the WFD is not directly designed to address quantitative water issues, although its goal includes mitigation of drought effects and its environmental objectives include finding a balance between abstraction and recharge of groundwater. Thus water quantity is only implicitly taken into account by requiring environmental flow boundaries to sustain freshwater ecosystems.

In 2007, with the Floods Directive (EC 2007c), legislation came into force to reduce the risk of adverse consequences from flooding, especially for human health and life, the environment, cultural heritage, economic activity and infrastructure. The Floods Directive refers explicitly to the WFD for its contribution to mitigate the effects of floods. However, reducing the risk of floods is not one of the principal objectives of the WFD, nor does it take into account the future changes in the risk of flooding as a result of climate change.

Development of river basin management plans under the WFD and of flood risk management plans under the Floods Directive are elements of integrated river basin management. The two processes should therefore use the mutual potential for common synergies and benefits, having regard to the environmental objectives of the WFD. To make coordination in between both directives feasible, reporting time lines are brought in line with each other.

In 2007 the European Commission published a communication on water scarcity and droughts (EC 2007b) that addressed the main challenges together with recommendations. Several of the economic issues mentioned are dealt with in a recent EEA report 'Towards efficient use of water resources in Europe' (EEA 2012b).These include putting the right price tag on water, considering additional water supply infrastructures, fostering water efficient technologies and practices, and fostering the emergence of a water-saving culture in Europe Other aspects are assessed in more detail within this publication. A particularly important aspect is land use planning, which together with climate change is considered one of the main drivers of increasing droughts and water scarcity. As a result of knowledge improvement water accounts and an advanced Water Exploitation Index (WEI+) for Europe are presented in chapter 4.

2.3. Structure of this report

This report is part of a series of thematic assessments that the EEA is publishing in 2012 ([1]) to support discussion and development of the 'Blueprint to safeguard Europe's Water Resources'.

Chapter 3 outlines a framework for assessing freshwater vulnerability and the resilience of ecosystem services – unpacking the terminology and background science and exploring through examples why they are important. The approach of combining hazards and vulnerabilities in risk management is extended by considering concepts of ecological resilience and vulnerability.

Chapter 4 focuses on the pressures, state and outlook of Europe's freshwater, especially regarding actual situation and changes in floods and droughts. Sustainable water resource management requires knowledge in the form of robust data and indicators that can show the links between water management, social and economic benefits, and ecosystems services. In this chapter, the advanced water exploitation index, the so-called WEI+, is presented.

In chapter 5 the economic, social and ecologic impacts of floods and water scarcity and droughts are discussed. It deals with demand and supply-side management strategies and gives some potential categories of measures for sustainable water quantity management.

[1] An overview of all 2012 publications on water can be found:
http://www.eea.europa.eu/themes/water/publications-2012/publications-2012-on-water.

3. Freshwater ecosystem services and their vulnerability

This section of the report will identify key European freshwater ecosystem services and seek to explain why a thematic assessment of vulnerability is needed for Europe's freshwater ecosystems and how this contributes to the process leading to the 'Blueprint to safeguard Europe's Water Resources'.

With freshwater ecosystem vulnerability we expand the concept of hazard and risk to humans, towards a more holistic view that incorporates ecosystem services and the susceptibility of a whole environment. It will illustrate why a move towards a risk-based management framework, incorporating fundamental concepts of resilience and vulnerability, could contribute towards safeguarding European waters through more effective freshwater ecosystem management and greater water security.

This section will explore why some of the many definitions that exist for vulnerability, resilience and related terms, evolving over time and in different disciplines (e.g. climate change) can be applied in such a framework. This report will not, however, go into detail regarding the diversity of different concepts and applications that can exist across scientific and social science disciplines but will use the core concepts of vulnerability as a framework for outlining more sustainable water resource management in relation to ecosystem services.

The first part of this chapter is about freshwater ecosystem services, followed by a section on the vulnerability of water resources. The last section looks at relevant pressures for water resource management and how this affects the freshwater ecosystem services.

3.1. Freshwater ecosystems and the central role of water

Water plays a central role in the functioning of the biosphere and in supporting life. The freshwater ecosystems that exist are a result of the hydrological cycle, and these systems provide a unique and diverse array of services upon which human society depends upon. This section outlines the key ecosystem services that freshwater systems provide and how these are increasingly under threat.

3.1.1. What are freshwater ecosystem services?

Ecosystems provide valuable goods and services that have a significant, yet often undervalued, contribution towards continued human wellbeing, development, economic security that in many instances cannot be replaced. Attempts at valuing these services at a global level (Costanza et al. 1997) have provided economic valuations in excess of global gross national product. The principal freshwater provisioning, regulating and cultural services on which human development relies are listed below in Table 3.1. Aquatic and terrestrial ecosystems require adequate freshwater resources and flows to maintain the physiochemical processes and functions, species, and communities (Acreman and Ferguson 2010). Human regulation of the water environment and water resource development has affected the ability of many freshwater systems functioning and this pervasive alteration is contributing to significant biodiversity loss and degradation of the goods and services that these systems provide (N. LeRoy Poff et al. 2007). Protection and restoration of these irreplaceable ecosystems is increasingly being recognised as crucial in achieving sustainable development and often provide the most cost-effective options for securing food production and protection from natural hazards (UNEP, Nellemann, and Corcoran 2010).

Table 3.1 Freshwater-related ecosystem services

Provisioning services	Examples
Food	Fish, agriculture,
Fuel and fibre	Wood for fuel and building, peat, fodder
Fresh water	Retention of water for domestic, industrial and agriculture
Biochemical	Medicine and materials from biota
Genetic material	Genes for resistance to plant pathogens
Regulating services	
Hydrological flows	Groundwater recharge,
Natural hazards	Flood control, storm protection
Sediment transport	Distribution of nutrient rich sediments
Marine	Coastal delta maintenance,
Waste	Water purification and assimilation of waste
Cultural services	
Spiritual	Religion, inspiration, health, aesthetic
Recreation	Recreational activities, social events

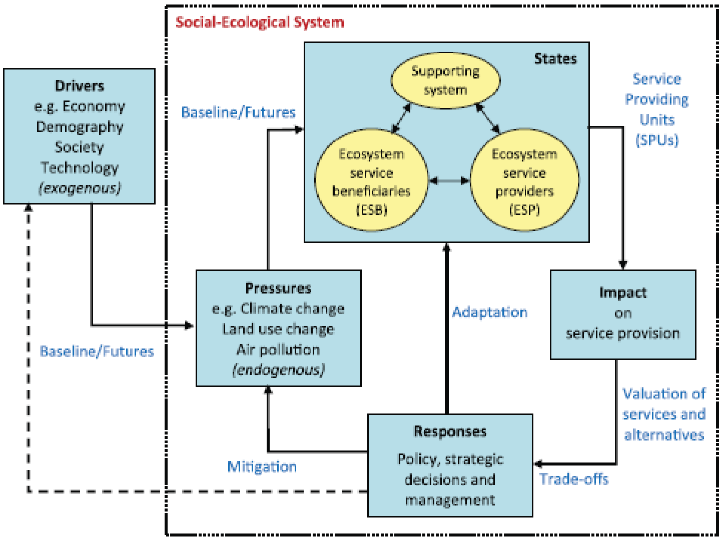
Source: adapted from Millennium Ecosystem Assessment et al. (2005)

The ecosystem provisioning, regulating and cultural services identified represent the flow of natural capital and stock of materials that humanity relies upon to drive economic growth (Costanza et al. 1997). Identifying and valuing such services represents a step towards what has been termed a 'green economy'. This represents an economy based upon a realization that maintaining the natural systems that provide humanity with diverse and valuable services is central to sustainable development. The European Union view a green economy as generating growth, creating jobs, and eradicating poverty through investment and preservation of the natural capital upon which long-term sustainable development depends (EC 2011). Maintaining this flow of natural capital is only as sustainable as the ability of ecosystems to regenerate following the extraction of natural capital or recover following natural or anthropogenic disturbance. This ability to recover is the resilience of the system, and it is clear that many global ecosystems have been managed in such an unsustainable manner that once resilient systems are now facing collapse, with particular concern surrounding wild fisheries and freshwater systems (Millennium Ecosystem Assessment et al. 2005). As access to ecosystem services is overexploited there is a resulting degradation and loss of capacity to maintain that service in the future. This ultimately puts the ecosystem and the services it can provide at real threat to profound changes in its form and functioning. Improving the efficiency of resource use and maintaining the resilience of ecosystems are core challenges in moving towards a greener economy that values ecosystem services.

The Framework for Ecosystem Service Provision (FESP) assesses environmental change driver impacts on ecosystem services and to subsequently identify the most relevant mitigation or adaptation strategies (see figure 3.1). The approach is based upon the DPSIR (Drivers-Pressures-States-Impacts-Response) framework (Stanners et al. 2007) and incorporates the concept of the social-ecological system, whereby human society and natural systems are directly linked. Population and associated economic growth act as driving forces for pressure upon the environment, and society can monitor and evaluate intervention measures. The resulting states and impacts upon the environment have direct implications for human health, development and well-being. Yet providing robust assessments of such potential environmental states and impacts is, however, not a simple process due to the complexity of the interactions in between ecosystem (natural capital), economy (produced capital) and human well-being (social and human capital). The intrinsically link in between these 3 types of capital are central in most interpretations of what Green Economy is and at the core of these links is a dual challenge of (EEA 2012d):

- ensuring ecosystem resilience of the natural systems that sustain us (and limiting pressure on natural systems so that their ability to function is not lessened);
- improving resource efficiency (and reducing the environmental impacts of our actions).

Figure 3.1 Framework for Ecosystem Service Provision (FESP)



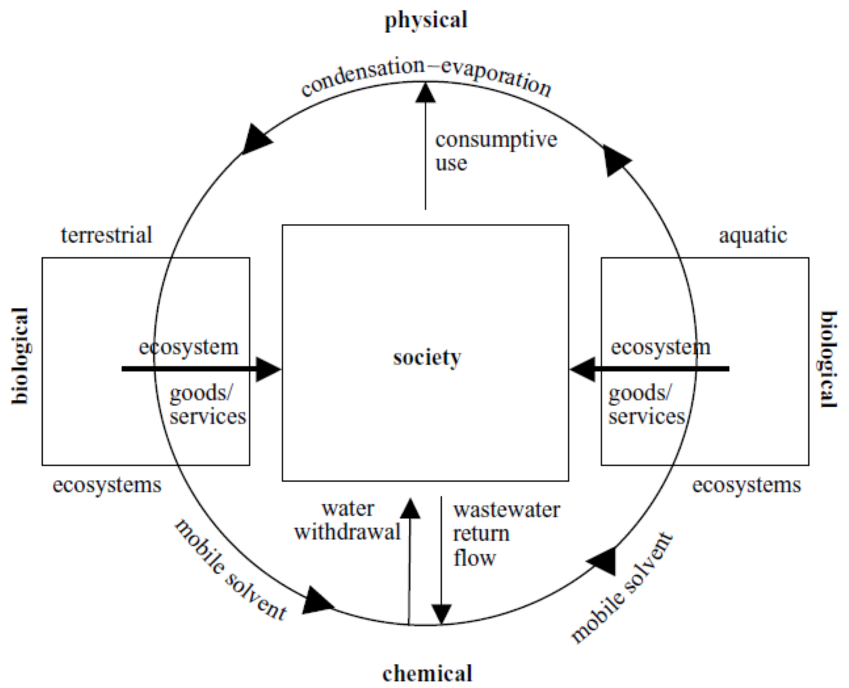
Source: Harrison and Rubicode Consortium 2012

Several of the reports EEA in 2012 will deal with the resilience of freshwater dependent ecosystems. While water quality aspects and hydro-morphology are the main aspects defining the status of water bodies as defined by the water framework directive (EEA (report under preparation) 2012a) this report focusses on the quantitative volumes available for the environment. In detail the more extreme situations in terms of water quantity – water scarcity and drought and floods – are assessed in current situation and in relation to the climate change and land use pressures. More about improving water resource efficiency can be found in other EEA reports (most recent: EEA 2012a).

3.1.2. Freshwater as the lifeblood of natural and human systems

Freshwater can be considered the bloodstream of the biosphere, providing pathways for physical, chemical and biological processes that maintain ecosystems (Falkenmark 2003), Humans are reliant on the biological systems and processes this biosphere and associated ecosystems provide, which are essentially life-support systems that provide the bulk of renewable resources and regulating services upon which the continued development of human society is based. In this regard, the water resource flow acts as a global conveyor of physical and chemical services between the atmosphere, terrestrial and aquatic environment, as illustrated in Figure 3.2. These systems are both dynamic and interacting but there are the increasing impacts of human development (see section 3.1.3) on the quantity and quality of freshwater available. The fluxes cannot be maintained and are changing in volume and quality which is increasingly having negative impacts upon the natural environment and the ecosystem services society depends upon (N. LeRoy Poff et al. 2007).

Figure 3.2 Schematic illustration of water as the bloodstream of the biosphere



Source: Falkenmark 2003

3.1.3. Human development and freshwater ecosystem services

Water has always been essential to human development and remains central as the link between food, energy, climate, and economic growth – a nexus of issues that is increasingly being identified as a threat to human security due to over exploitation and poor management of freshwater resources. Water resources as natural capital and providing ecosystem services is influenced by and influences environment policy priority areas like climate change, nature and biodiversity, natural resources and waste and health and quality of life (EEA 2010b; EEA 2010d). The international nature of trade places particular vulnerability on the areas that suffer low water availability or extreme hydrological variability yet exploit a high proportion of their water resources for production of agricultural and industrial products. This in turn increases the vulnerability of economies that depend upon resources from these water stressed regions. Economic, social, political, technological and environmental trends on a global scale (EEA 2010b; EEA 2010d) are driving forces with effect on climate, land use, and demographic changes; identified as key pressures on water availability and hydrological variability. The recently published European Environmental Indicator Report (EEA 2012d) outlines that while progress in ensuring greater resource efficiency is clear the evidence for improvements to ecosystem resilience is lacking. The report identifies that human demand directly competes with ecological systems' demands.

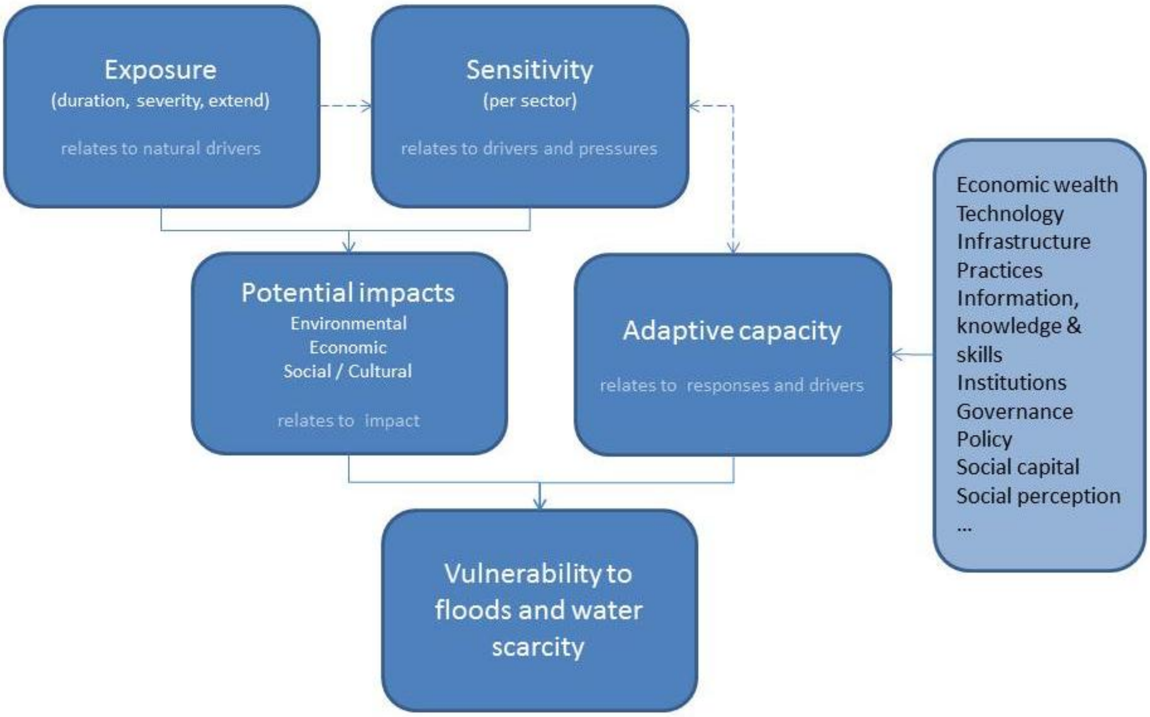
Water has increasingly become an international concern, as shocks such as droughts and floods in one country can have international repercussions. Such dependency and potential disruption will increase with growing population and resource requirements and is predicted to be further exacerbated by climate change (Vörösmarty et al. 2000). These shocks will cause more indirect impacts upon the natural services and capital lost through disturbance to ecosystems. This could result in a potential chain-reaction of events across globalized systems of trade, driving increased vulnerability for those dependent on affected services. As the true value of ecosystem services has only recently been recognised it may yet be a long time before they are properly accounted for in more sustainable management decisions and incorporated into international trade within ecosystem services. Various accounting tools and methodologies have been proposed that can assist our understanding of how to value water in an international trading environment, such as the Water Footprint concept (Hoekstra and Chapagain 2006; Hoekstra and Mekonnen 2012), which is essentially a conceptual way to communicate water use. While this approach provides a useful tool with which to raise awareness of how water is utilized and traded at the international level it should not provide any indication of how water footprints affect water supply or requirements of ecosystems (EEA 2010a). Freshwater and the ecosystem services it provides are therefore an international concern, for agricultural and energy sectors as well as domestic consumption, and this global dimension and nexus of issues surrounding water vulnerability will increasingly need to be considered in any policy trade-offs.

3.2. Vulnerability, Resilience and adaptive capacity – managing for variability

The preceding section has introduced the concept that anthropogenic disturbance of natural ecosystems can significantly affect the ability and vulnerability of such systems to sustain their functioning and to recover following disturbance. This section seeks to ‘un-package’ what these terms imply for the management of freshwater ecosystems, particularly considering the high level of natural hydrological variability that can occur. Freshwater ecosystems and the services they provide society are constantly affected by natural changes in the environment such as seasonal changes in flow or extreme hydrological events such as floods and droughts. This variability in quantity, timing and quality is a central part of what drives the unique ecosystems that can exist (N. Poff 2009), renewing and sustaining higher ecological functioning. These systems are also increasingly under threat from anthropogenic disturbance of such natural variability, particularly where more static environmental conditions are created in order to maintain more dependable water supplies (e.g. abstraction for agriculture, reservoirs) or provide flow regulation (e.g. dams, weirs). While such intervention might serve to reduce the vulnerability of human populations to extreme hydrological events, the vulnerability of the natural environment to such shocks can be increased - with repercussive impacts upon parts of society that depend on the services these affected ecosystems provide. The aim of this section is to outline the fundamental concepts relating to ecological and social vulnerability and how these relate to the growing awareness that managing for hydrological variability is a central part of sustainable water management.

A variety of definitions exist for *Vulnerability* according to the specific context. The United Nations International Strategy for Disaster Reduction (UNISDR 2009), for example, defines vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. The Intergovernmental Panel on Climate Change defines vulnerability to climate change as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, Bernstein, et al. 2008). While being aware of the different definitions and concepts of vulnerability, we do not use a specific definition or concept stringently in this report but rather use the term in a more generic way (EEA 2012c; EEA (report under preparation) 2012b) (see also Figure 3.3).

Figure 3.3 Conceptual schemes of the components of vulnerability in relation to water scarcity and floods



Source: adapted from Füssel and Klein 2006; Metzger et al. 2006; Uyttendaele et al. 2011

In the same way, *Resilience* - in a more generic way - is described as the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation and the capacity to adapt to stress and change (EEA 2012c).

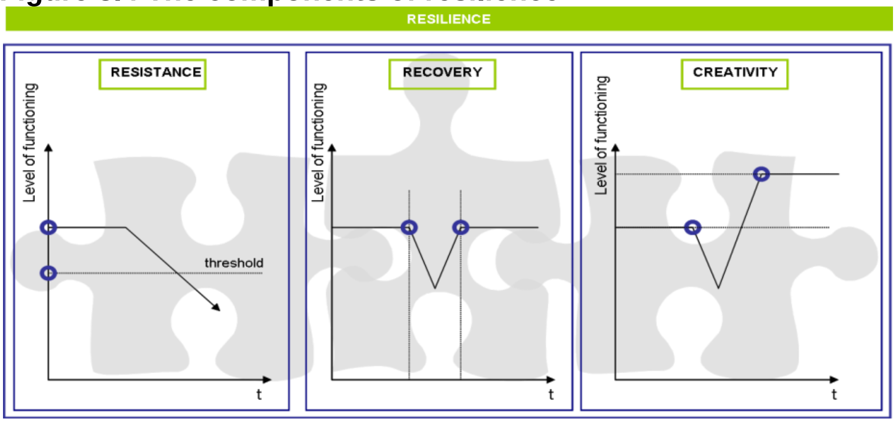
3.2.1. Social vulnerability and resilience

The transformation of natural systems in order to improve socio-economic development often results in a wide range of detrimental impacts upon natural systems (Rapport and Singh 2006). Efforts to reduce these negative impacts require conceptual frameworks that acknowledge coupled human-environment systems and the complex linkages that exist between them (Turner et al. 2003). The social-ecological system, is the proposed analytical unit that comprises societal (human) and ecological subsystems in recursive feedback (Gallopín 2006; Alessa et al. 2008). Fundamentally the social-ecological system acknowledges that ecological and social vulnerability are inextricably interdependant, and building resilience in either system requires management that accounts for both components.

The concepts of social vulnerability and resilience have evolved from integrated considerations of ecological resilience and human vulnerability to natural hazards and climate change. Social vulnerability can be defined as focusing on the demographic and socio-economic factors that act to mitigate or augment the impacts of natural hazards (Uyttendaele et al. 2011). Thus, social vulnerability represents the susceptibility of community to harm from exposure to hazard, and is a function of the sensitivity and adaptive capacity of society. It implies that while such interlinked social-environmental systems are characterised by non-linear relationships, thresholds and uncertainty, the resilience of a group is the ability to respond to, and recover from, hazards and represents an opportunity for innovation and development (Folke 2006). Therefore, considerations of social vulnerability imply a move away from control of stable systems, towards managing the capacity of social-ecological system to adapt to and even shape change (Walker et al. 2004).

Based on the work of Adger (2000) the variable components that define the resilience concept are illustrated in figure 3.4. Early definitions employed the measure of resistance to denote the degree of disruption the system can tolerate before a significant change past a threshold takes place. The inclusion of the social-ecological interactions incorporates societies potential response when exposed to a hazard - recovery indicates the preservation and restoration of fundamental structures and functions, while creativity is the ability of resilient communities to improve their capacity for response. A resilient system can also return to a state of higher functioning that is less vulnerable, and this is a function of the creativity or adaptive capacity of the system.

Figure 3.4 The components of resilience



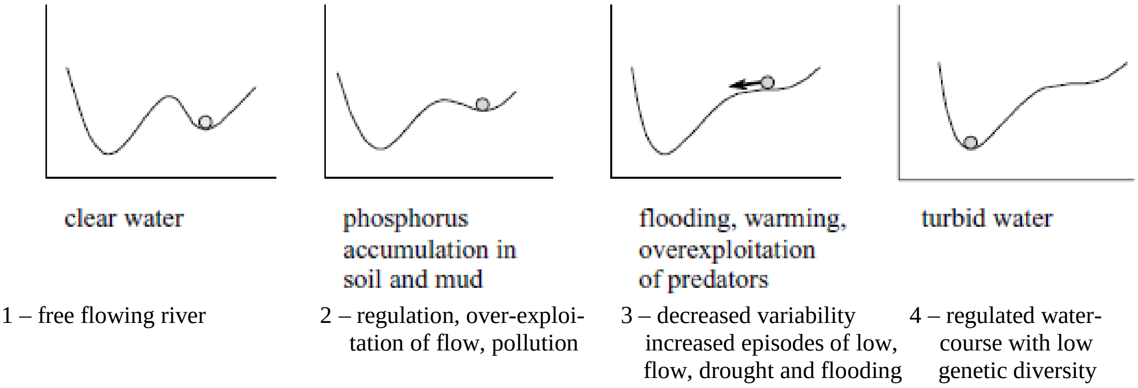
Source: FREEMAN project / Uyttendaele et al. 2011; CRUE, Thieken, and Beurton 2012

3.2.2. Introducing ecological resilience and vulnerability

It has long been understood that ecological systems are not stable assemblages of species in a static environment; rather they are dynamic systems able to withstand stress and shocks yet still maintain function and remain within a general state. Ecological resilience denotes the capacity of an ecosystem to withstand disturbance without changing self-organized processes (Gunderson 2000). The terms resilience, vulnerability and adaptive capacity of ecological systems to both natural and anthropogenic stressors were introduced into the ecological literature by Holling (1973) to explain how a natural system functions and changes over time in response to such disturbance and naturally fluctuating environmental processes.

A fundamental concept in considering ecological resilience is that while stability is defined as a system near to an equilibrium state that we might consider the reference condition, resilience is most often thought of as the amount of disturbance a system can be subjected to before a change in state occurs (Gunderson 2000). A certain amount of caution should be exercised in not interpreting this equilibrium state as good ecological status (GES), as the environment could already have been significantly affected and thus already be in an altered stability domain. Folke (2003) illustrates in figure 3.5 how humans can drive a decrease in resilience that ultimately leads the ecosystem into a different state, termed ‘stability domain’. As phosphorus accumulates in the soil and mud of the lake system the stability domain is reduced and the subsequent pressure of flooding or over exploitation of predators causes the system to shift into a turbid eutrophied water state.

Figure 3.5 Shifts between states in lakes from human-induced reduction of resilience



Source: ETC/ICM, Based on Folke 2003

Note: The figure is an illustration using the ball and cup view of stability. Valleys are stability domains and balls the system, with arrows indicating disturbance. Engineering resilience is defined by the slopes, while ecological resilience is the width of the stability domain (Gunderson 2000).

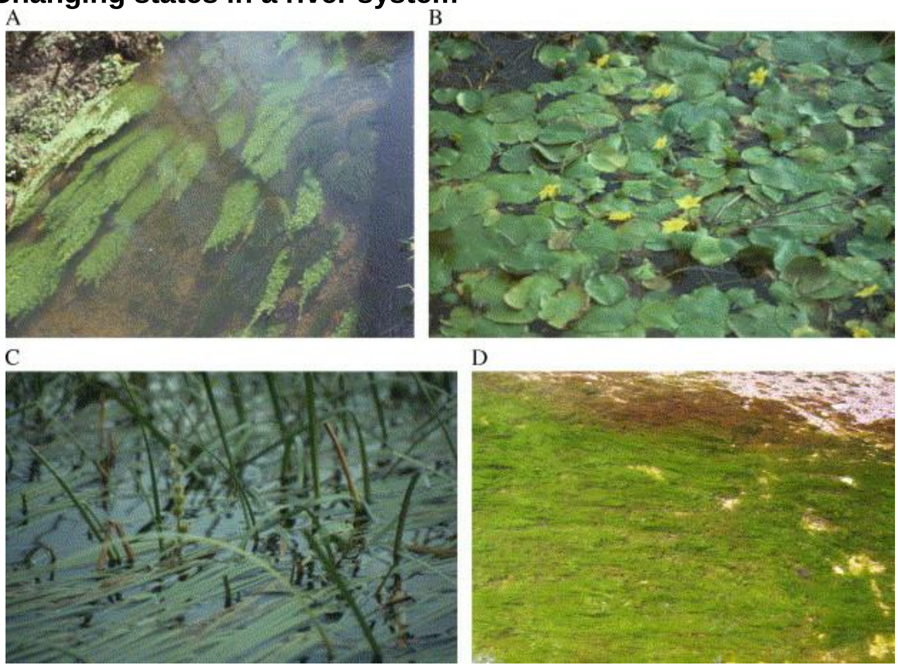
In terms of how the concept of resilience applies to a European freshwater river, we can consider the different stages and states that exist as a free flowing and naturally variable system gradually becomes a more regulated and exploited river - and the associated impacts due to such anthropogenic regulation. As the freshwater system becomes over exploited and regulated to meet anthropogenic demands the natural variability is removed, flow is reduced, and pollution events become more regular and less diluted. Such changes erode the systems resilience to further disturbance and ecological research has shown that faced with a sudden event, such as a flood or prolonged drought, a threshold can be reached causing the system to slide into a reduced state of functioning (Scheffer et al. 2001) – reflected in reduced species diversity and loss of habitat.

Box 3.1: Change in ecological state - eutrophication of rivers

The increases in the primary production (eutrophication) of water bodies, such as algae and rooted plants, due to significant nutrient inputs is a serious consequence of increased pollution loads in many water bodies. Eutrophication can have significant economic impacts on society and communities that depends on freshwater from affected sources. From the current understanding of lake systems the predominant cause of shift from a macrophyte to phytoplankton dominated system has been identified as the development of algal growths on macrophytes which effectively reduce the available light. There are, however, multiple stable states that can exist between these two extremes, representing interaction between phytoplankton biomass, turbidity, light availability, grazing macroinvertebtates and the feedback effects that exist.

A conceptual model of how eutrophic conditions develop in short-retention-time river systems has been developed by Hilton et al. (2006), based upon the literature available. While there is agreement that nutrient increases are required to develop eutrophic conditions to develop, there is in fact a lack of evidence in short-retention-time rivers and that in fact the interaction of hydraulic drag with light limitation is the most significant factor. The impacts of this interaction and the types of macrophytes that exist through these changing states are shown below in figure 3.6, from a clear flowing river containing tall submerged plants (A) towards dominance of floating leaved plants (B) and emergent plants (C) and finally a river with high nutrient loading dominated by filamentous algae (D). Thus while the lower reaches of long slow flowing or impounded rivers tend towards phytoplankton domination under nutrient-enriched conditions, these short-retention-time rivers should tend towards a dominance of benthic algae driven primarily by the development of epiphytic algal communities reducing light availability. What is also clear from this research is that there are multiple interacting processes involved in the gradual eutrophication of short-retention-time rivers, highlighting the complexity of the system and the difficulty in pinpointing how exactly such a system will respond to anthropogenic disturbance and what essentially constitutes a loss of resilience.

Figure 3.6 Changing states in a river system



Source: Hilton et al. 2006 (text and photos)

3.2.3. Environmental flows and natural variability

Ecologists now better understand how flow regime and natural variability, especially the extremes in form of floods and droughts, can be important determinants for ecosystem structure and resilience. A more holistic understanding of ecosystem health has led to a paradigm shift in ecosystem management that considers whole ecosystems containing diverse species with variable flow preferences, sustained by a dynamic flow regime (N. Poff 2009). The variation in flows can act to rejuvenate and maintain aquatic habitats, and changes to the timing of flows can have some of the most significant impacts on freshwater ecosystems (N. Leroy Poff and Zimmerman 2010). Extreme events can exert a selective pressure on ecological populations, renewing biodiversity and building resilience in the system. A shift in thinking is required that moves management interventions away from hard-engineered control in all situations, to accepting change is inevitable (Folke 2003), and to accept that variability can be beneficial. This variability must however be balanced against the requirements for society to be protected against the most extreme events, something that will not always be possible through more 'soft' interventions. Reducing human vulnerability to floods through 'hard-engineering' options like dams, dikes or channelization could, for example, lead to a reduction of ecosystem functioning (e.g. flow regulation, loss of floodplain connectivity). More examples can be found in chapter 5.2 on flood risk management.

Maintaining the environmental flows that provide freshwater ecosystem services is an essential element in preserving the biodiversity and ensuring resilience to uncertain futures and system shocks. The term environmental flows emerged to emphasise that a share of the water moving through an environment should be allocated to natures requirements if the goal of integrated water resource management is to be realized (Bernhardt et al. 2006). Such requirements are central to the Water Framework Directive (WFD) goal of Good Ecological Status, despite not explicitly using the term (EC 2000). A key issue however in actually achieving such ecologically acceptable flows depends on how they are defined and implemented. Incorporating elements of natural variability and resilience provides a more realistic and perhaps achievable way of assessing how vulnerable freshwater ecosystems are and what would be the most appropriate improvement interventions.

3.2.4. *The role of vulnerability assessments*

In considering climate change and its impacts on society and the environment it became clear in the climate change debate that the severity of impacts depended not only on the event extremity but also on the exposure and sensitivity of the affected systems (see also figure 3.3). Vulnerability was thus raised as a central concept in climate change policy through article 4.4 of the United Nations Framework Convention on Climate Change (UNFCCC) and adaptation for vulnerable countries (UN 1992), and became a central theme in the 'Climate Change 2007 – Impacts, Adaptation and Vulnerability report' (IPCC 2007). These documents evaluate key vulnerabilities to climate change and highlight the role of stresses. Vulnerability assessments and the indicators they provide are widely perceived as providing the preferred bridge between academic work and policy need - synthesising complex data into a single index that can be applied by policy makers and managers (Hinkel 2011). The recent IPCC special report on managing the risks of extreme events and disasters (IPCC 2012) exemplifies the standardised use of vulnerability assessments to a particular topic of risk, namely climate change. It moves beyond merely considering the direct risk to society from increased hazards towards considering how such events can affect vulnerability to future extremes by modifying the resilience and adaptive capacity of affected societal or ecological systems.

There is considerable scope for developing vulnerability assessments to assess policy trade-offs and particular need to represent the interactions between society and ecological systems. A range of vulnerability assessment models exist, with the requirement that such assessments be enlarged and revised to include the capacity to consider coupled human-environment systems. A revised assessment architecture is proposed, that incorporates: i) links with broad human and biophysical conditions; ii) perturbations and stressors that emerge from these processes and condition; and iii) the coupled system in which vulnerability rests (Turner et al. 2003). Although comprehensive, such a methodology clearly illustrates is the complexity of managing water in a coupled human-environment system, and the need for freshwater policy to consider vulnerability if sustainable management and informed policy trade-offs are to be achieved.

3.3. Environmental pressures and environmental change

3.3.1. *Natural variability, pressures and perturbations*

The natural environment is highly variable in time and space, and can change slowly over time as a result of a continuously increasing pressure (stressor) or during major events (perturbation) outside the normal range in which the system exists (Turner et al. 2003). While perturbations such as major floods and droughts clearly exist outside of the local social-economic-ecological system, these events could be considered internal phenomena for the global level (Gallopín 2006). These perturbations represent direct hazards to human settlements and typically require engineering solutions to reduce the sensitivity and exposure of population and infrastructure; such is their potential for human and economic loss. More gradual changes, such as decreased groundwater availability, are typically a function of how the social-economic-ecological system operates and represent over-exploitation and mismanagement of natural resources.

Large scale changes in ecosystem service supply are expected across Europe as a result of changes in climate and land use, leading in most cases to increased vulnerability to reduced services provided (Metzger et al. 2006), especially in the Mediterranean region (Schröter et al. 2005). A multitude of human activities denoted direct drivers by Postel and Richter (2003), can have adverse impact on the freshwater environment and the resulting ecosystem services (see table 3.2). These activities generally represent the replacement of naturally functioning systems characterised by high levels of variability and resilience with more regulated systems engineered solely for human requirements (Millennium Ecosystem Assessment et al. 2005). Such regulations reduce the amount of freshwater available for ecosystems and the remaining water is subject to a highly unnatural regime. These activities reduce the resilience of naturally functioning systems to perturbation events, and in some cases this causes greater vulnerability to the society that depends upon those services that would act to mitigate and attenuate such events.

Table 3.2 Summary of direct drivers

Human Activity (Direct Driver)	Impact on Ecosystems	Services at Risk
Dam construction	alters timing and quantity of river flows. Water temperature, nutrient and sediment transport, delta replenishment, blocks fish migrations	provision of habitat for native species, recreational and commercial fisheries, maintenance of deltas and their economies, productivity of estuarine fisheries
Dike and levee construction	destroys hydrologic connection between river and floodplain habitat	habitat, sport and commercial fisheries, natural floodplain fertility, natural flood control
Diversions	depletes stream flow	habitat, sport and commercial fisheries, recreation, pollution dilution, hydropower, transportation
Draining of wetlands	eliminates key component of aquatic ecosystem	natural flood control, habitat for fish and waterfowl, recreation, natural water purification
Deforestation/land use	alters runoff patterns, inhibits natural recharge, fills water bodies with silt	water supply quality and quantity, fish and wildlife habitat, transportation, flood control
Release of polluted water effluents	diminishes water quality	water supply, habitat, commercial fisheries, recreation
Overharvesting	depletes species populations	sport and commercial fisheries, waterfowl, other biotic populations
Introduction of exotic species	eliminates native species, alters production and nutrient cycling	sport and commercial fisheries, waterfowl, water quality, fish and wildlife habitat, transportation
Release of metals and acid forming pollutants into the atmosphere	alters chemistry of rivers and lakes	habitat, fisheries, recreation, water quality
Emission of climate altering air pollutants	potential for changes in runoff patterns from increase in temperature and changes in rainfall	water supply, hydropower, transportation, fish and wildlife habitat, pollution dilution, recreation, fisheries, flood control

Source: Postel and Richter 2003

Box 3.2: Long-term studies of Lake Windermere, Cumbria, United Kingdom

Lakes provide essential ecosystem goods and services on which humans depend, and are integral to many global biogeochemical cycles, yet are sensitive to environmental perturbation operating at global, regional and local scales, many resulting from human influence. Such pressures from human activity and long-term background changes can degrade ecological status, a loss that arisen in part due to the underestimation of ecosystem goods and services that are not fully accounted for. The complex web of external pressures and internal interactions that control the biological structure and ecological function of lakes requires a ‘systems approach’, where different trophic levels are studied and different approaches including long-term monitoring are taken (Maberly and Elliott 2012). This complexity can result in dramatic shifts in the functioning and structure of such systems. Long term monitoring is key to understanding and developing insights into how systems react to change in the environment and external stressors.

Figure 3.7 Views over the Windermere lake system and catchment

Copyright photos: CEH

Long term monitoring of Windermere since 1945 has revealed that eutrophication of the lake started before monitoring and was driven by nutrient enrichment from population increases, sewage disposal and agricultural intensification. Since then nutrient enrichment has enhanced the lake response to meteorological change (McGowan et al. 2012). Climate change impacts have been picked up in Blelham Tarn (Foley et al. 2012) showing that over 40 years the duration of stratification had increased by nearly 40 days, as had the hypolimnetic anoxia period. Another study of *Daphnia galeata* (Thackeray et al. 2012) data collected over 80 years indicated change in nine of ten phonological metrics, primarily driven by phytoplankton phenology and spring water temperature, both linked to climate change.

3.3.2. Tipping point or gradual change?

Ecosystems can change gradually over time or may have a tipping point that can be triggered by an extreme event or meeting a certain threshold value for an important system component. The external drivers discussed in section 3.3.1 can change gradually over time (e.g. habitat fragmentation, overharvesting) or represent a catastrophic change to the system (e.g. dam installation, significant pollution event). Natural perturbations' such as floods and droughts can cause a significant shift in the timing, quantity and quality of flows in river systems. However change is caused or manifests it will to differing degrees upset the functioning state of the ecosystem in some way and cause a reduction in resilience. Ecological research has shown that with reduced resilience from human alteration of the freshwater system a sudden event may trigger a critical threshold to be reached from which the system will move into a less desirable state with reduced ecosystem service provision (Scheffer et al. 2001). Much of this can be explained by considering the pathways in which the system is able to return to a previous state and how particular species can re-colonize. Any disturbance in a natural system will act like a selective force, moulding traits so that species can persist. This can be expressed in traits such as resistance to high flow and capacity to recover following a flood, or resistance to high temperatures and low oxygen during droughts (Lake 2007). Also important are the availability of refugia that bolster resilience after disturbance by providing sources for decolonization after the disturbance. Any reduction in the natural flow regime will thus render a less adaptive set of species to flood events or low flow conditions. Also by un-coupling the river form the floodplain in order to provide flood defence structures there is a reduction in the availability of refugia and re-colonization pathways for biota following either a gradual change or extreme event.

3.3.3. Climate change

Any change in climate will lead to changes in regional weather and have range of associated impacts upon society and the environment. There is considerable evidence that the world's climate and weather are continually changing as a result of naturally fluctuating climatic systems and due to the anthropogenic emission of carbon dioxide driving a global trend in temperature increases. The complexity of what drives these changes leads to significant uncertainty when attempting to predict future patterns of change. This uncertainty is amplified when considering the impacts upon the hydrological cycle and the associated impacts upon society and freshwater ecosystems. The IPCC Fourth Assessment Report on impacts, adaptation and vulnerability (IPCC 2007) chapter on Freshwater resources and their management identified vulnerabilities of freshwater to climate variability from changing precipitation patterns and greater year-to-year hydrological variability. While this is most apparent in semi-arid and low-income countries, the fact that water infrastructure is generally designed for stationary conditions means there exists a high degree of sensitivity and vulnerability to uncertain non-stationary future conditions driven by climate change. Changes to hydrology identified include (IPCC 2007):

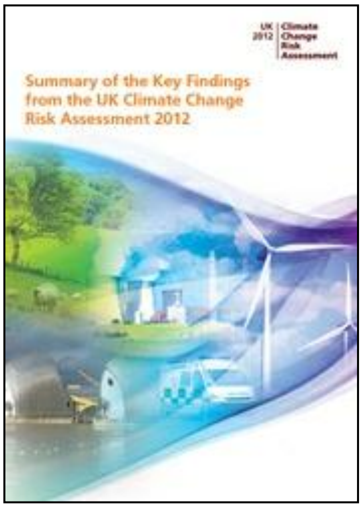
i. Changes in volume, intensity, type and timing of precipitation will alter river flows and resultant wetland and lake levels;
ii. Temperature, radiation, humidity and wind speed changes will affect the hydrological cycle and further exaggerate impacts of decreased precipitation;
iii. Groundwater is less directly affected but can become more strongly relied upon to provide secure access to freshwater;
iv. Increased variability and intensity of precipitation is projected to increase flood risk and drought;
v. Water quality will be significantly affected by multiple stressors such as higher temperatures, increased low flows, more intense rainfall all exacerbating many forms of water pollution.

Significant progress has been made since the release of the IPCC fourth assessment reports (AR4) (IPCC, Bernstein, et al. 2008) that outlined the physical basis and the impacts, adaptation and vulnerability in ascribing confidence to the direction of change and associated impacts. Both the data sets and climate models have progressed, as has the terminology used to ascribe confidence in the available evidence. A recent IPCC document (Mastrandrea et al. 2010) provides guidance for the treatment of uncertainties for the AR5 authors, whereby the evidence type, quality and consistency are combined with an assessment of agreement between evidence. There are also more rigorous statements to indicate the likelihood of a potential outcome using probability criteria. While the AR5 is still in development a special report on the risks of extreme events and disaster (IPCC 2012) updates the global assessment, with more rigorous terminology and consideration of the role of vulnerability and exposure in determining risk and impact. The salient points concerning water vulnerability in Europe are listed below;

i. Exposure and vulnerability are key factors determining risk to hazards and associated impacts;
ii. Extreme and non-extreme weather or climate events affect vulnerability to future extremes by modifying resilience, adaptive capacity and coping capacity;
iii. The severity if climate extremes impacts depends on the level exposure and vulnerability to extremes;
iv. Attention to temporal and spatial dynamics of exposure are particularly important when designing risk management policies that may reduce risk in the short-term, but increase long-term vulnerability (e.g. dike systems reduce flood exposure, but encourage settlement patterns that could lead to an increase in flood risk);
v. Climate change leads to changes in the frequency, intensity, extent, duration and timing of extreme weather and climate events, and can result in unprecedented extremes;
vi. Exposure and vulnerability are dynamic, varying across spatial and temporal scales;
vii. There is limited to medium evidence of climate-driven changes in magnitude or frequency of floods at regional scales – however, there is medium confidence that projected rainfall increases will lead to increases in certain catchments;
viii. There is medium confidence that droughts will intensify in the 21st century, particularly in southern Europe, the Mediterranean and central Europe;
ix. Extreme events will have the greatest impacts on sectors with close links to climate, such as water, agriculture and food security;

x. There is high confidence that changes in climate have the potential to seriously affect water management systems, however this is not necessarily the most important driver of change at the local scale.

Box 3.3 The United Kingdom Climate Change Act 2008 – Climate Change Risk Assessment 2012



The United Kingdom has undertaken an extensive climate risk assessment (Department for Environment Food and Rural Affairs 2012) that assess the potential impacts and opportunities of climate change to key themes that affect future UK development and security. The need to embrace long-term planning and better understand risks is viewed as critical in ensuring a resilient society and environment. This will be achieved using a risk-based approach, with the government leading a National Adaptation Programme to be published in 2013. The key risks to water and freshwater systems identified within the themes considered for the UK include:

Natural Environment - the direct and indirect impacts of climate change on the natural environment could be significant by the 2050s, potentially further exacerbating existing pressures on ecosystems and contributing to the further decline of some species. Key impacts include i) low water levels and reduced river flows leading to increased concentration of pollutants from agriculture, sewage and air pollution damaging freshwater habitats and other ecosystem services; ii) warmer rivers, lakes and seas impacting on biodiversity and the productivity and functioning of aquatic and marine ecosystems; iii) possibility of algal blooms, ocean acidification and species range shifts impacting on marine habitats, species and ecosystem services; iv) changes in timing of seasonal events and migration patterns can result in mismatches between species such as predator-prey/host relationships.

Agriculture & Forestry – could be affected by both extreme weather events and gradual climate change, particularly beyond 2050. Key impacts include i) higher summer soil moisture deficits, increasing demand for irrigation to maintain crop yields and quality; ii) crop losses and other impacts on high quality agricultural land due to flooding and agricultural land lost to coastal erosion; iii) increased competition for water resources in the summer owing to reduced summer rainfall and the need to address unsustainable abstraction; Drier conditions and any increase in the frequency of drought will reduce agriculture and timber yield and affect woodland condition.

Buildings & Infrastructure - buildings and infrastructure will be affected by both extreme weather events and long-term gradual change in the climate. The challenges arise from higher temperatures and changing rainfall patterns.

Business &Services - main water related risks and opportunities to the Business sector are related to flooding and water resources.

Health & Wellbeing - will be affected by both extreme weather events and long-term gradual change. The main challenges arise from higher temperatures (on land and sea), changing rainfall patterns and rising sea levels

The impacts of climate change on freshwater ecosystems are difficult to discern due to the complexity of the systems and the uncertainty concerning the effect of climate change on the hydrological cycle. What is generally agreed is that increases in temperature and changing precipitation patterns will lead to changes to the quantity, quality and timing of freshwater flows in the environment. These changes can have a range of eco-hydrological impacts upon freshwater systems outlined in table 3.3.

Table 3.3 Key eco-hydrological impacts of climate change

Impacts of climate change	Eco-hydrological impacts	Impacts for ecosystems and species
Changes in volume and timing of precipitation Increased evapotranspiration Shift from snow to rain, and/or earlier snowpack melt Reduced groundwater recharge Increase in the variability and timing of monsoon Increased demand for water in response to higher temperatures and climate mitigation responses	**1. Increased low-flow episodes and water stress**	Reduced habitat availability Increased temperature and pollution levels Impacts on flow-dependent species Impacts on estuarine ecosystems
Shift from snow to rain, and/or earlier snowpack melt Changes in precipitation timing Increase in the variability and timing of annual monsoon	**2. Shifts in timing of floods and freshwater pulses**	Impacts on spawning and emergence cues for critical behaviors Impacts on key hydrology-based life-cycle stages (e.g., migration, wetland and lake flooding)
Increased temperatures Reduced precipitation and runoff	**3. Increased evaporative losses from shallower water bodies**	Permanent water bodies become temporary/ ephemeral, changing mix of species (e.g., from fish-dominated to fairy shrimp–dominated)
Increased precipitation and runoff More intense rainfall events	**4. Higher and more frequent storm flows**	Floods remove riparian and bottom-dwelling organisms Changes in structure of available habitat cause range shifts and wider floodplains Less shading from near-channel vegetation leads to extreme shallow water temperatures
Changes in air temperature and seasonality Changes in the ice breakup dates of lakes	**5. Shifts in the seasonality and frequency of thermal stratification (i.e., normal seasonal mixing of cold and warm layers) in lakes and wetlands**	Species requiring cold-water layers lose habitat Thermal refuges disappear More frequent algal-dominated eutrophic periods from disturbances of sediment; warmer water Species acclimated to historical hydroperiod and stratification cycle are disrupted, may need to shift ranges in response
Reduced precipitation and runoff Higher storm surges from tropical storms Sea-level rise	**6. Saltwater encroachment in coastal, deltaic, and low-lying ecosystems**	Increased mortality of saline-intolerant species and ecosystems Salinity levels will alter coastal habitats for many species in estuaries and up to 100 km inland
Increase in intensity and frequency of extreme precipitation events	**7. More intense runoff, leading to increased sediment and pollution loads**	Increase of algal-dominated eutrophic periods during droughts Raised physiological and genetic threats from old industrial pollutants such as dioxins
Changes in air temperature Increased variability in temperature	**8. Hot or cold-water conditions and shifts in concentration of dissolved oxygen**	Direct physiological thermal stress on species More frequent eutrophic periods during warm seasons Oxygen starvation for gill-breathing organisms Miscues for critical behaviors such as migration and breeding

Source: WWF / Le Quesne et al. 2010

3.3.4. Land use change

Amongst many aspects of global change, land use change has a key human-induced effect on ecosystems ((Lambin et al. 2001)). Changes in climate and land use can result in large changes in ecosystem service supply often going together with an increased vulnerability of these ecosystems. The provision of many ecosystems services relies directly on land use ((Metzger et al. 2006)). When socio-economic scenarios and climate models are combined on the local scale and for the next decades the socio-economic changes often seem dominant in their effect on future land use and land use changes (Schröter et al. 2005). Metzger et al. (2006) made scatter plots for different categories of ecosystem services for different European regions and different socio-economic scenarios. The vulnerability shows a tension around economic growth in southern Europe. Economic growth can indicate more technological developments, infrastructure, equity and power, combined in a higher adaptive capacity (Metzger et al. 2006). At the same time, the socio-economic scenarios with the largest economic growth are the ones with most pronounced land use changes and largest negative potential impact on ecosystem services (Metzger et al. 2006)

Water resources and spatial planning have for a long time been seen as 2 separate management problems (Valenzuela Montes and Matarán Ruiz 2008). A modern view on land-use policy aims at getting a sustainable harmonization of economic, social, cultural and environmental interests in the society at regional to local level (Viglizzo et al. 2012). Integrated water management regards the spatial correlations between water and spatial development and doing so take into account the WFD (EC 2000) as well as the EU Strategic Environmental Assessment Directive (EC 2001). Land use changes can seriously influence both low flows and water availability as floods and inundations, especially when land use changes means sealing of soils and transforming open areas – like agriculture or nature – into urban areas, industrial zones or construction sites often going together with increased soil sealing. Sealing of soils by impervious materials is, normally detrimental to its ecological functions. (Scalenghe and Marsan 2009) as these modifications are fundamental in determining the rate of water intake into the soil. Most soil sealing is anthropogenic covering areas permanently or temporarily. An example of this latest is plastic sealing in agriculture as protective cover to adjust soil temperature, to control erosion or to control weeds. The sealing of surfaces also has evident consequences on neighbouring areas, as they increase the amount and the speed of the runoff water, increasing the risk of ponding and erosion in the unsealed neighbourhoods (Scalenghe and Marsan 2009). In addition the proximity of unsealed areas to pollution sources such as roads exposes them to pollution (Wolf et al. 2007). But an unsealed soil, managed appropriately can buffer (smaller) flooding and mitigate or reduce the transfer of pollutants. When not managed appropriately they can exacerbate problems acting as a source of nutrients, pathogens and sediments polluting groundwater resources. (Haygarth and Ritz 2009)

Changes in size of population (and the resulting size of households and changes in behaviour) as well as changes in the activities of different economic sectors may lead to urban and infrastructure expansion. As there is no precise information on soil sealing, often the evolution of built-up areas is used as a proxy (Scalenghe and Marsan 2009). Intensive *impermeabilisation* of urban areas also put additional pressure on sewage systems – by increased speed and amount of runoff - increasing the risk of urban flooding (Natale and Savi 2007). This can also have consequences for the water quality due to direct runoff and reduced filtering capacity water passing through the soil (Gaffield et al. 2003). In paved areas, impervious areas can be reduced with semi-pervious systems that allow water infiltration (Nehls et al. 2006). Other systems are adopted from agricultural techniques like amendments of gypsum (Singer and Shainberg 2004)or shallow tillage (disrupting the seal and returns infiltration).

In general, forests and afforestation are seen as positive for the water balance and the hydrological cycle. Nevertheless, little is known about the quantitative changes in nutrient and hydrological budgets following changes in land use (Van der Salm et al. 2006). The same can be said for agriculture, where there's a lack of integrated quantitative understanding of how agricultural modifications of the hydrological cycle regulate the prevalence and severity of abrupt changes in ecosystems (Gordon, Peterson, and Bennett 2008). Compaction as a result of intensification of agricultural practices (by livestock or machine wheels) affects water supply regulation (Haygarth and Ritz 2009).

Water plays a major role in sustaining ecosystems services (Gordon, Finlayson, and Falkenmark 2010) and maintaining their resilience to cope with extreme drought or floods (Folke et al. 2002). Maintaining ecosystem services in an agricultural landscape is helpful in managing water resources (Rockström et al. 2010).While a River Basin Management Plan makes an overview of a whole river basin district, independent of administrative internal boundaries, IWRM should also focus on downscaling to smaller areas (generally below 1000 km²) when it comes to measures to identify win-win opportunities between upstream and downstream areas. An example can be upstream green water investments like water harvesting with implications for downstream uses like reduced sedimentation. (Rockström et al. 2010)

Land use changes are complex phenomena in space and time. E.g. the scenarios set up by Metzger et al. (2006) were developed for analysis at European scale. While this overall picture is their strength, the ignored regional heterogeneity and the limited number of distinguished land use classes are a weakness. They (Metzger et al. 2006) clearly state that more specific ecosystem services, especially these related to biodiversity and nature conservation, are hard to asses in a European scale study.

Land use has and will have an important influence on ecosystem services in Europe, although with large differences for different regions and across the services. (Metzger et al. 2006) Different land use scenarios and more or less (or different) land use changes have in most European regions a different potential impact on ecosystem services where the most notable distinctions are caused by the differences in between a more economic versus a more environmental friendly development (Metzger et al. 2006).

4. Pressures, state and outlook

4.1. Introduction

As highlighted in the previous Chapter, the added emphasis on ecosystem services represents a move away from perceiving water management within the traditional sectoral responsibilities of fulfilling an ever increasing human water demand and providing adequate flood defences. It is also clear that a good understanding of the spatial and temporal variability of water resources is an essential part of evidence based environmental policy making. The acknowledgement of variability as an inherit part of the water resources system necessitates the introduction of a more risk-based management framework, where concepts such as resilience and vulnerability should form the basis of future indicators rather than fixed target figures for water demand and flood defence levels.

This already complex task is then further exacerbated by the predicted impacts of change on the water cycle; through climate change and more direct interventions such as land-use management and urbanisations. Also, many cause and effect relationships between the hydrological and the socio-economic systems, and between hydrology and ecosystems, are not currently well-understood. Thus, there are considerable challenges in identifying notionally optimal strategies for effective water resources management. For operational purposes vulnerability and resilience are linked to incidents where a system state (e.g. flow, ground water level, pollution concentration, etc.) enters a domain that is considered unsatisfactory (or even bad); for example, too much (flood), too little (drought) or too dirty (water quality).

Given the close link between water and ecosystems combined, and with the added emphasis on resilience and vulnerability, it is essential to develop a good understanding of the water resources systems that are characterised by natural variability and, in particular, the water demand as well as the magnitude and frequency of extreme events (see also (EEA (report under preparation) 2012b), section 3.3). Of special concern is the impact of environmental change (climate change, land-use management, and urbanisation) on these aspects of the hydrological cycle and how they might affect social and environmental systems.

The purpose of this section is to review current states and trends of Europe's water resources and to identify external drivers of change with relevance for water resources management and the resulting pressure exerted on Europe's water resources. This will be followed by a review of the possible projections of future state of Europe's water resources. Effective management of water resources is required to ensure that throughout Europe a sufficient quantity of good quality water is available for people's needs and for the environment, as well as ensuring adequate protection against the adverse impacts caused by floods. The temporal and spatial scales characterising the hydrological system vary considerably across Europe. For example, a local flash flood can happen in a manner of hours, while regional water scarcity can develop over years and even decades.

4.1.1. An introduction to floods and drought in a European context

Before discussing the main pressures acting on Europe's water resources and the resulting impacts, a brief overview is given of the current situation with regards to water scarcity and droughts, and to flooding. First, the Water Exploitation Index (WEI) will be introduced, which is used for mapping the balance between water availability and demand across Europe. Next, a discussion of trends in flood occurrence will highlight the current lack of a coherent European program for collecting data and information on past floods.

The current state of Europe's water resources is perceived to be under increasing pressure from a range of external drivers primarily driven by increased population and associated resource requirements, climate change (Weiß and Alcamo 2011) and land-use changes (Metzger et al. 2006). These drivers will translate into physical pressures on the water resources systems through changes in both the climatological and terrestrial components of the hydrological cycle and their interactions.

Changes in the climate component of the water cycle ([2])

Temperature and precipitation are two key climate variables (EEA (report under preparation) 2012b, section 2.2). Time series show long-term warming trends of European average annual temperature since the end of the 19th century, with most rapid increases in recent decades. The last decade (2002-2011) was the warmest on record globally and in Europe. Heat waves have also increased in frequency and length. All these changes are projected to continue at an increased pace throughout the 21st century. Precipitation changes across Europe show more spatial and temporal variability than temperature. Annual precipitation trends since 1950 show an increase by up to 70 mm per decade in North-eastern and North-western Europe – most notably in winter - and a decrease by up to 70 mm in some parts of southern Europe. In Western Europe intense precipitation events have provided a significant contribution to the increase. Most climate model projections show a continued precipitation increases in northern Europe (most notably during winter) and decreases in southern Europe (most notably during summer). The number of days with high precipitation is projected to increase.

Besides the trends in average values, also the extremes of temperature and precipitation are of importance for water scarcity and droughts and floods. Extremes of cold have become less frequent in Europe while warm extremes have become more frequent. Since 1880, the average length of summer heat waves over Western Europe has doubled and the frequency of hot days has almost tripled. Extreme high temperatures are projected to become more frequent and last longer across Europe over the 21^{st} century. There are no widespread significant trends in either the number of consecutive dry or wet days across Europe. Heavy precipitation events are likely to become more frequent in most parts of Europe. The changes are strongest in Scandinavia in winter and in northern and eastern central Europe in summer.

Observed changes in temperature and precipitation have already been found to affect river flow, with substantial regional and seasonal variation across Europe (EEA (report under preparation) 2012b, section 3.3). In general, flows have increased in winter and decreased in summer since the 1960s. Climate change is projected to result in strong changes in the seasonality of river flows across Europe. Summer flows are projected to decrease in most of Europe, including in regions where annual flows are projected to increase.

Severity and frequency of droughts appears to have increased in parts of Europe. The impact of river flow droughts is currently largest in Southern and South-Eastern Europe. These impacts will further increase with prolonged and more extreme droughts. Minimum river flows will not only decrease in Southern and South-Eastern Europe but also decrease significantly in many other parts of the continent, especially in summer.

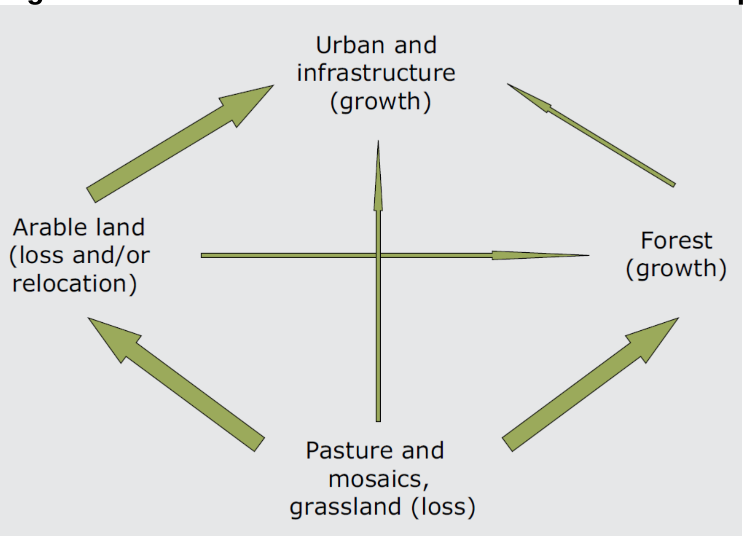
The rise in the reported number of flood events over recent decades results mainly from better reporting and from land-use changes. The effect of climate change is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood events in large parts of Europe. However, estimates of changes in flood frequency and magnitude remain highly uncertain. In regions with reduced in snow accumulation during winter, the risk of early spring flooding would decrease.

Changes in the terrestrial component of the water cycle

Most European countries expect a continuation of current land-use specialisation trends: urbanisation, agricultural intensification and abandonment, and natural afforestation (EEA 2010e). This happens in the context of an overall slow-down of total land changes observed in 2000–2006 and the substitution of residential area expansion with dominant growth of economic sites (EEA 2010e). Figure 4.1 shows the predominate net land conversion in Europe.

[2] This section is based on EEA (report under preparation), 2012b, where the reader is referred to for more detailed information and primary sources

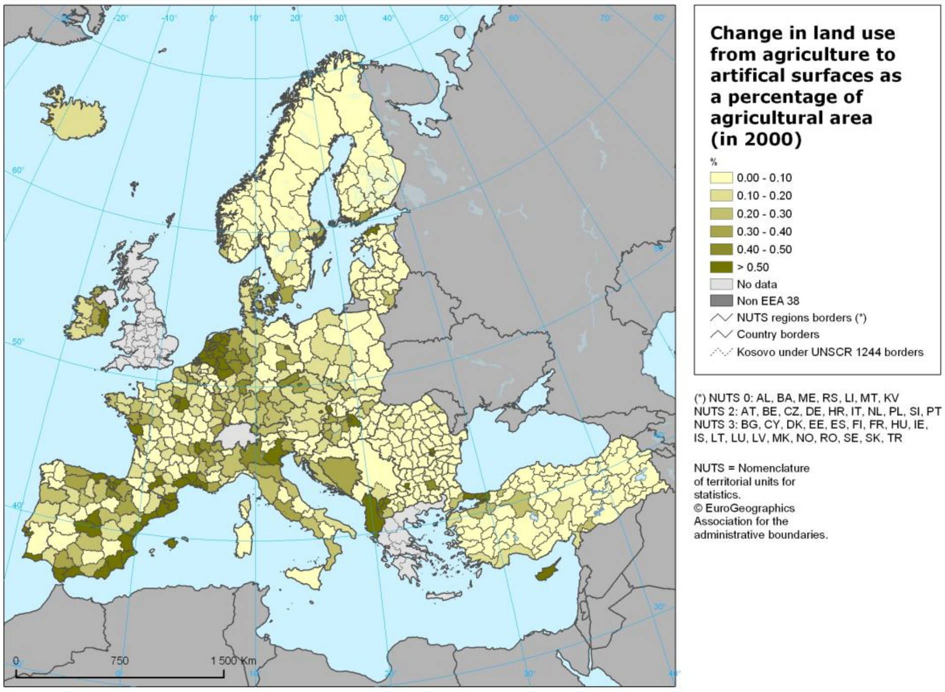
Figure 4.1 Predominant net land conversions in Europe 1990-2006



Source: EEA, 2010e
Note: based on Corine Land Cover Analysis

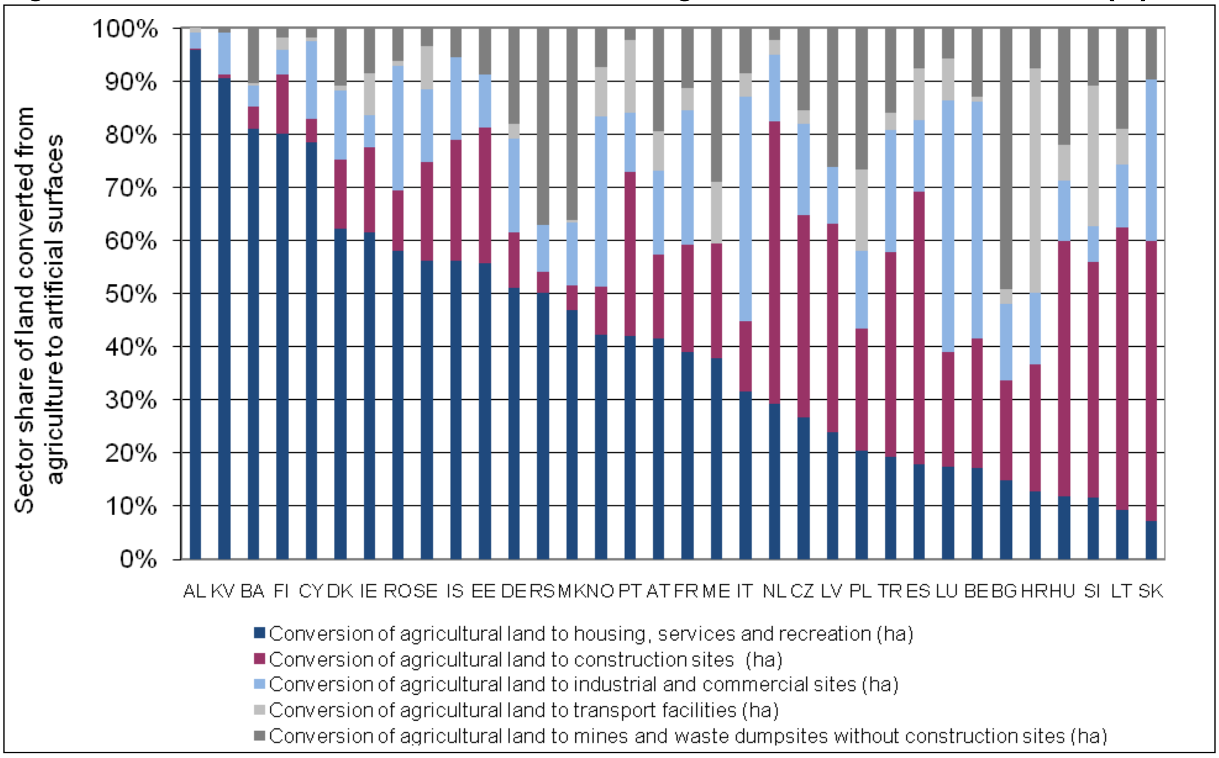
The total area of land use change from agriculture to artificial surfaces between 2000 and 2006 varies across Europe. At country level the highest share of land use change from agriculture to artificial area occurred in the EU-27 is in Cyprus (1.7 %), the lowest in Malta (0.0%) (Figure 4.2). In general the highest percentage of agricultural land (in 2000) converted to artificial surfaces (by 2006) occurred in urban regions. The sector share of land converted from agriculture to artificial surfaces indicates which sectors take up most agricultural land. Most of the agricultural land in Europe is taken by the housing sector (38 %), followed by construction sites (28%) and the industrial and commercial sector (18%) (EEA 2012a) (Figure 4.3).

Figure 4.2 Change in land use from agriculture to artificial surfaces as a percentage of agricultural area (in 2000)



Source: EEA 2012a
Note: for administrative regions NUTS 0, 2 and 3

Figure 4.3 Sector share of land converted from agriculture to artificial surfaces (%)



Source: (EEA 2012a)

Conversion of agricultural land to artificial surfaces, which is also known as soil sealing can have several environmental impact on soil, water and biodiversity resources. The sealing may increase the risks of soil erosion and water pollution. It also disturbs agricultural habitats, impact on animal migration patterns and affects the hydrological cycle (increased water runoff and decreased water retention) leading to an increased risk of floods.

But we have to avoid making urbanisation similar to increased flooding and agriculture ideal for water resource management. There's a menu of possibilities for managing flood risks in urban areas, on catchment scale, neighbourhood scale and for individual buildings (Shaw, Colley, and Connell 2007; EEA 2012c). Intensive agricultural practices can influence hydro-morphology of rivers, and lead to increased water use and pollution of groundwater when fertilisers and pesticides wash out if water is not used efficient (EEA 2012b).

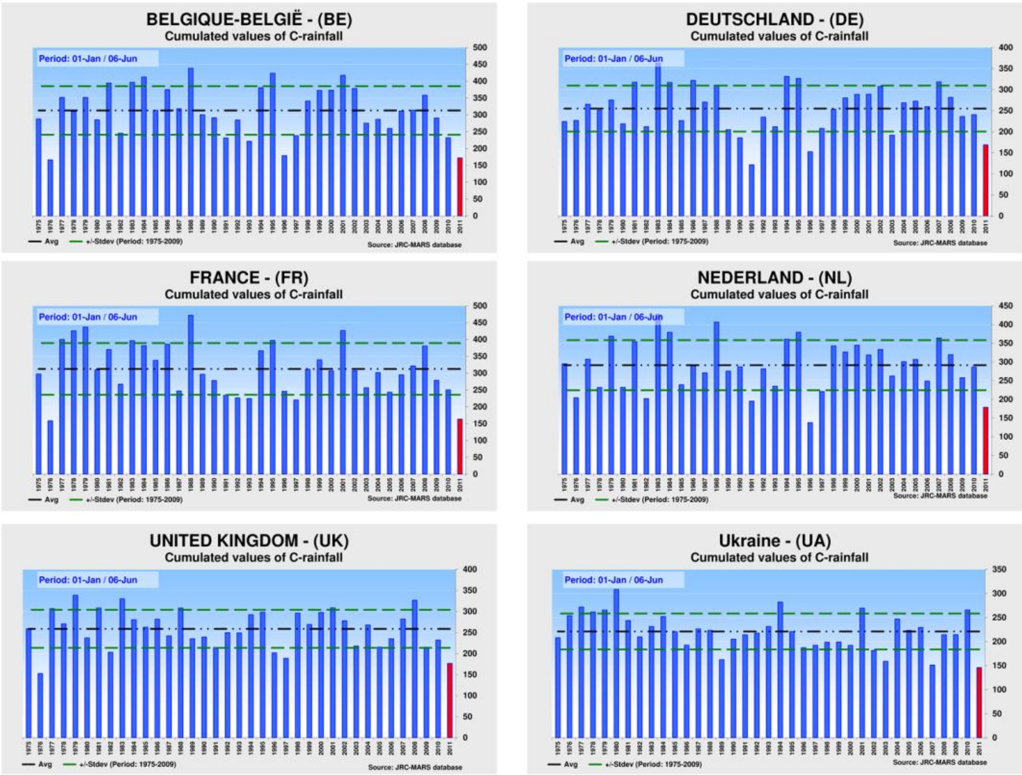
4.2. Water scarcity & droughts

4.2.1. Water accounts and water exploitation index

Over the past thirty years, drought events and the number of areas and people affected have dramatically increased both in number and intensity within the EU (Mediterranean Water Scarcity & Drought Working Group (MED WS&D WG) 2007). Severe events have been identified that on annual basis affected more than 800 000 km² of the EU territory (37%) and 100 million inhabitants (20%) in 1989, 1990, 1991 and more recently in 2003 (with an exceptional cost of 8.7 billion €, EC 2007a) and in 2007-2008.

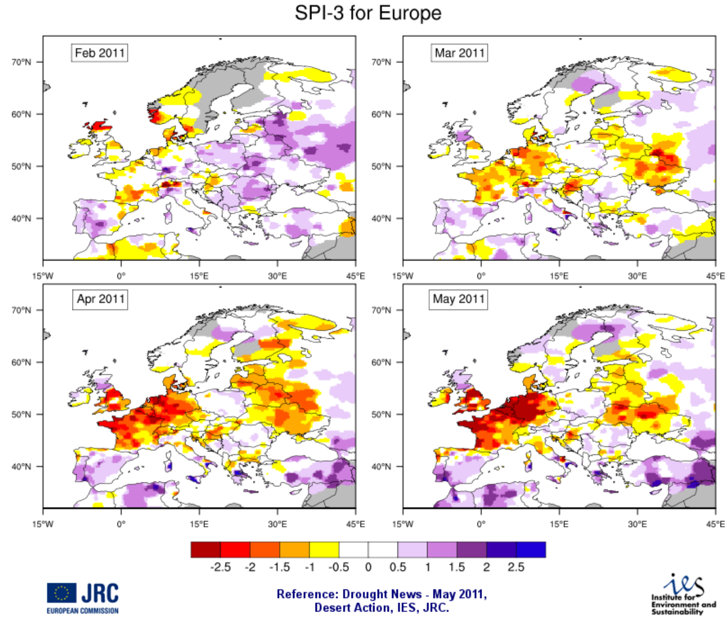
During 2011, in the period January to May, severe cumulated rain deficits were recorded in the EU , comparable to historic minima for many countries (Figure 4.4): in France (comparable to 1976), England (comparable to 1997), Belgium, The Netherlands (comparable to 1991, 1982, 1976), Germany (comparable to 1996), Denmark, parts of Czech Republic and Slovakia, almost all of Hungary, locally in Austria, Slovenia and Croatia, Ukraine (absolute minimum since 1975), Belarus and the Baltic countries (JRC 2011). The evolution of the 3-month Standardized Precipitation Index (SPI3) from February to May 2011 is in figure 4.5.

Figure 4.4 Accumulated rainfall for 1st of January to 6th of June 2011



Source: JRC (2011)
Note: Comparison of accumulated rainfall for 1st of January to 6th of June 2011 with the historic time series 1975 to 2010.2011 is highlighted in red. Black dot-dashed line: Average rainfall 1975-2010, green dashed lines: One standard deviation above and below the average (1975-2010).

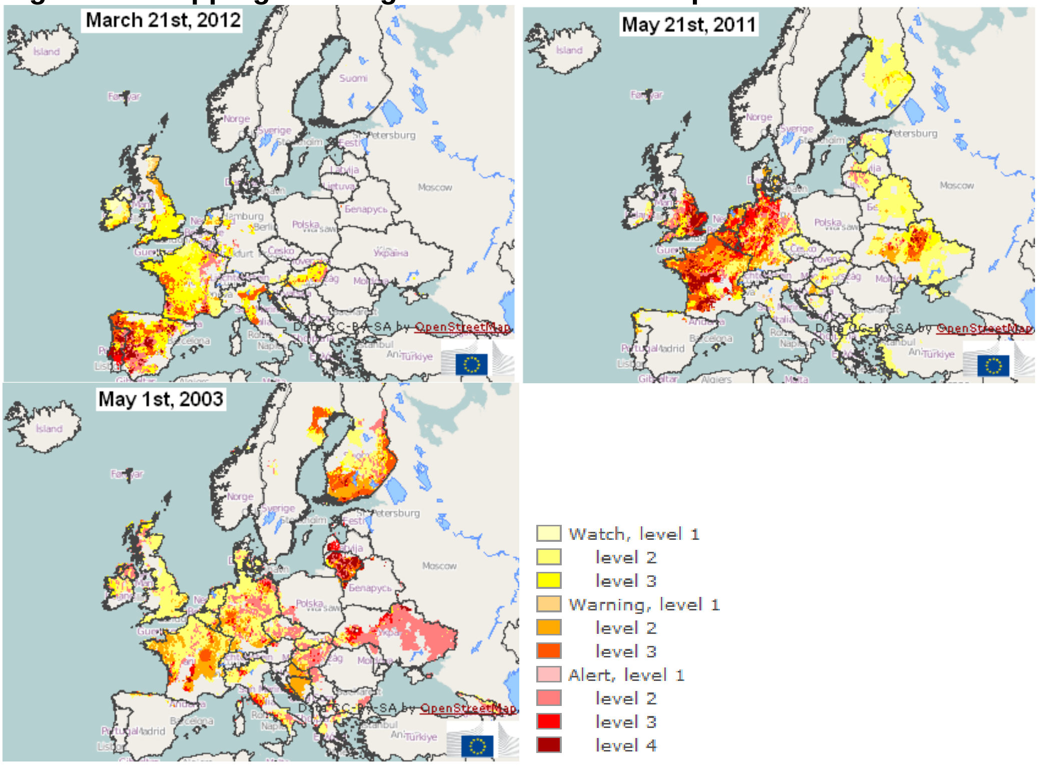
Figure 4.5 Evolution of the 3-month Standardized Precipitation Index (SPI3) from February to May 2011



Source: JRC (2011)
Note: Values below -1.5 indicate a severe meteorological drought. Grey shading indicates areas with insufficient reliable data to compute the SPI

In 2012, reduced rainfall, below normal levels, has been recorded during the winter months, impacting the water resources of extended parts of Southern and Central Europe (JRC 2012). Based on the Standard Precipitation Index (SPI1) for February2012, France, Spain, Portugal and England experienced extreme and severe drought condition, even more pronounced in the low cumulative rainfall as expressed by the SPI3 (December-January-February). Based on the daily soil moisture anomaly indicator the drought impacted Spain, Portugal, Southern France, Central Italy, Greece (locally), Hungary, Bulgaria and Romania, with affected areas were also evident in Denmark, North Italy (Po river) and Northern UK (JRC 2012). Figure 4.6 below presents snapshots of drought condition in Europe as calculated by the European Drought Observatory (EDO) using the Combined Drought Indicator, based on SPI, soil moisture and fAPAR.

Figure 4.6 Mapping of drought conditions in Europe



Source: European Drought Observatory (EDO), Joint Research Centre, European Commission
Available online: http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1146
Note: Mapping of drought conditions in Europe as calculated by the Combined Drought Indicator (based on SPI, soil moisture and fAPAR) for top left March 21st, 2012 top right May 21st, 2012 and bottom left May 1st, 2003 known as a dry year for large parts of Europe.
There are three classification levels: watch (when a relevant precipitation shortage is observed), warning (when the precipitation translates into a soil moisture anomaly), alert (when these two conditions are accompanied by an anomaly in the vegetation condition)

Note: A map or table to illustrate the statements above will be included in the final version based on the reactions of member states on the questionnaire on data, more specific the "Historic Drought events in Europe".

The Water Exploitation Index WEI (defined as the ratio of annual abstraction over long term annual availability (ltaa), see Box 4.1) is used to quantify the pressure (stress) exerted on the environment (i.e. the natural water resources) by anthropogenic activities (i.e. water abstraction).

TO DO BOX

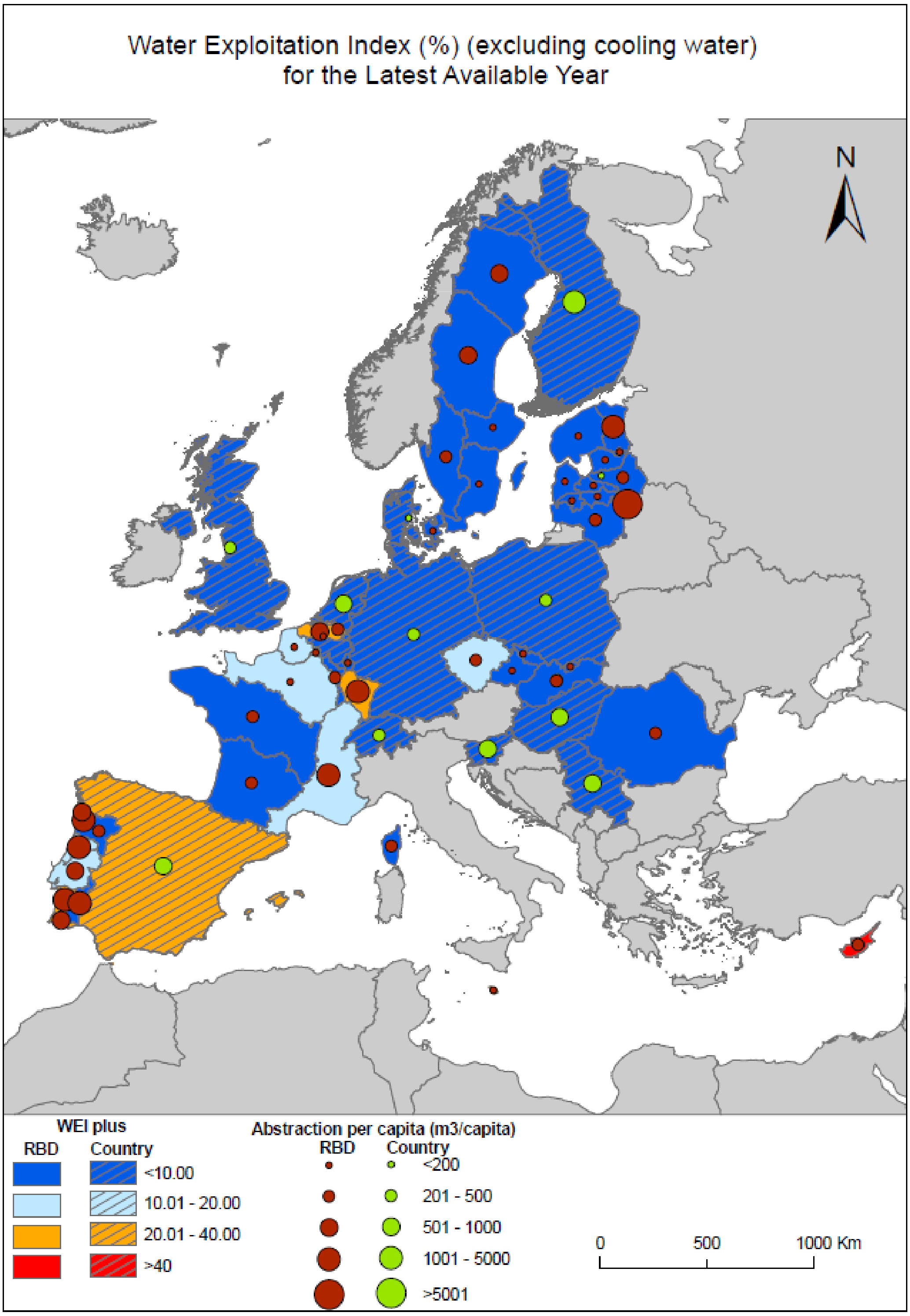
Action required during Member state consultation

The WEI+ maps are in map 4.1a and map 4.1b based on latest available year and ltaa respectively. We also refer to maps in a separate document (add link to document on forum) with yearly WEI maps from 2002 until 2006 on RBD and Country level.

1. Latest available year is comparable to the definition as used for the WEI+, ltaa is continuation of methodology of previous WEI and less dependent of yearly variations in water availability.
2. We also refer to the questions (add link to document on forum) about the reported values and strongly suggest to have a detailed look at the data for your country and add or correct asap.
3. Based on the comments, a final WEI+ map will be included in the EEA report on Vulnerability, followed by an interpretation of the map

Also information on “Historic Drought events in Europe” is requested in this questionnaire.

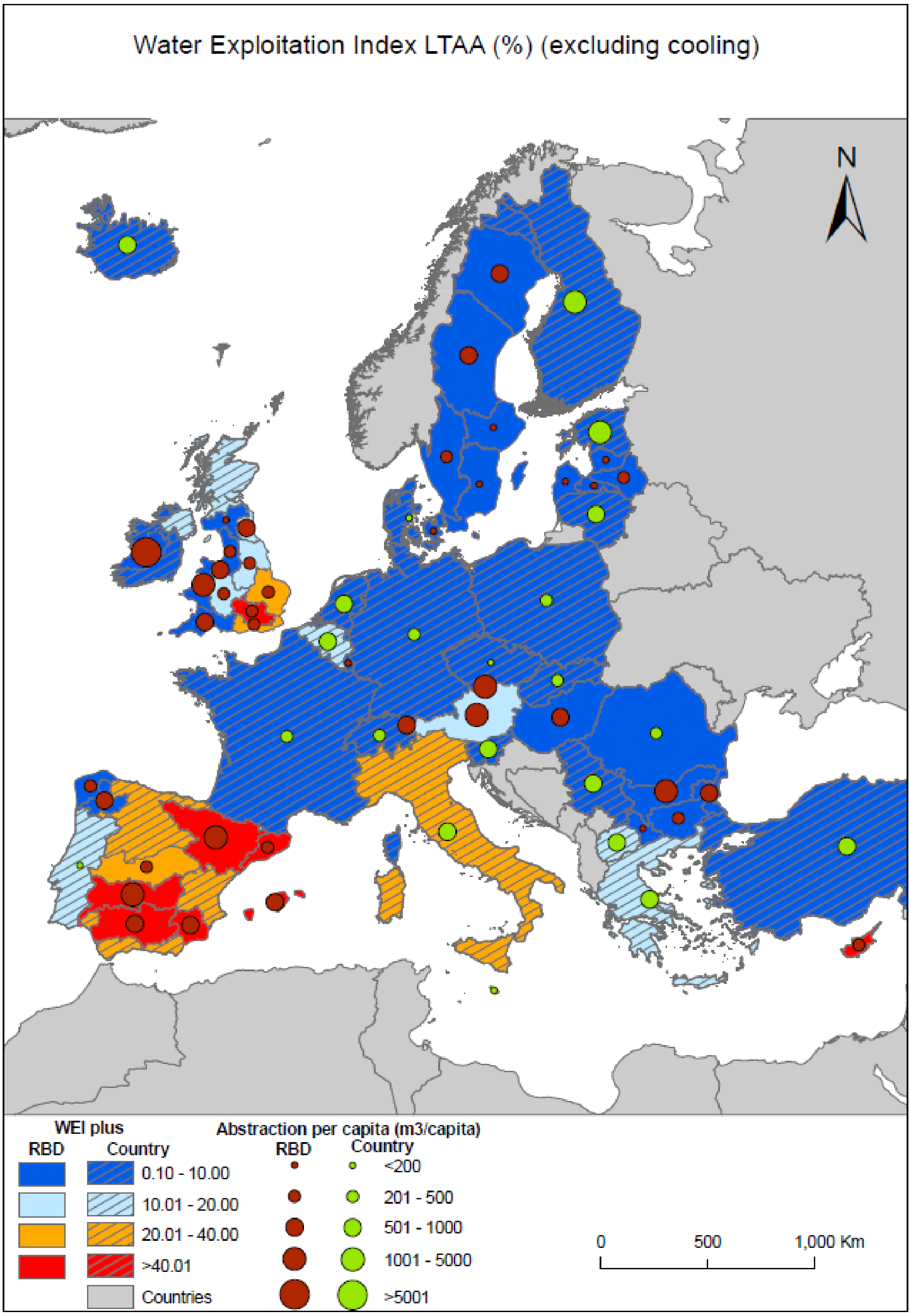
Map 4.1a Water Exploitation Index WEI and abstraction for European River Basin Districts (latest available year)



Sources: compiled by the ETC/ICM

Notes: Data come from multiple sources, Combination of WISE-SoE#3 and WFD: AT2000-Rhine, AT5000-Elbe, BG1000-Danube Region, BG2000-Black Sea Basin, BG3000-East Aegean, BG4000-West Aegean, SK30000-Vistula, SK40000-Danube / Combination of WISE-SoE#3 and websources: IEGBNISH-Shannon / Websources: ES014-Galician Coast, ES016-Cantabrian, ES020-Duero, ES030-Tagus, ES040-Guardiana, ES050-Guadalquivir, ES07-Segura, ES080-Jucar,ES091-Ebro, ES100-Internal Basins of Catalonia, ES110- Balearic Islands, ES120-Gran Canaria. web link: http://servicios2.marm.es/sia/visualizacion/lda/recursos/superficiales_escorrentia.jsp (*Total water resources in the natural system (hm3/year) Average value for the period between 1941-2009) Reported to DG ENV for the Interim Report: PTRH3, PTRH4, PTRH5, PTRH6, PTRH7, PTRH8 WISE-SoE#3: all other RBDs / Eurostat JQ IWA: all Country level data to be checked on completeness and correctness

Map 4.1b Water Exploitation Index WEI and abstraction for European River Basin Districts (ltaa)



Sources: compiled by the ETC/ICM

Notes: Data come from multiple sources, Combination of WISE-SoE#3 and WFD: AT2000-Rhine, AT5000-Elbe, BG1000-Danube Region, BG2000-Black Sea Basin, BG3000-East Aegean, BG4000-West Aegean, SK30000-Vistula, SK40000-Danube / Combination of WISE-SoE#3 and websources: IEGBNISH-Shannon / Websources: ES014-Galician Coast, ES016-Cantabrian, ES020-Duero, ES030-Tagus, ES040-Guardiana, ES050-Guadalquivir, ES07-Segura, ES080-Jucar,ES091-Ebro, ES100-Internal Basins of Catalonia, ES110- Balearic Islands, ES120-Gran Canaria. web link: http://servicios2.marm.es/sia/visualizacion/lda/recursos/superficiales_escorrentia.jsp (*Total water resources in the natural system (hm3/year) Average value for the period between 1941-2009) Reported to DG ENV for the Interim Report: PTRH3, PTRH4, PTRH5, PTRH6, PTRH7, PTRH8 WISE-SoE#3: all other RBDs / Eurostat JQ IWA: all Country level data to be checked on completeness and correctness

To assess the balance between water availability and demand, and to identify water stress areas, indicators that capture elements of the water balance are useful and simple tools. The spatial and temporal scales of application of all such indicators, as well as their methods of calculation, are crucial yet cautious interpretation should be applied to avoid biased conclusions.

Research suggests that 20-50% of the mean annual river flow in different basins needs to be allocated to freshwater-dependent ecosystems to maintain them in fair conditions (Smakhtin, Revenga, and Döll 2004). Excluding this volume from the available for exploitation water may result in changing the severity level of water scarcity conditions. Returned water (into the same hydrological unit where abstraction occurs) can also affect the water stress level of an area. Depending, of course, on the water quality and location where the return occurs (e.g. upstream enough to be exploitable by other users downstream) this volume may be an important addition to the system alleviating potential problems, and thus needs to be taken into account when calculating the overall balance between availability and demand of a region to define the relevant water scarcity. Finally, the temporal scale of analysis of water stress conditions is important, since the problem may not be apparent at an annual scale yet be acute at seasonal scale, especially during summer where the availability is usually lower and the demand picks up.

Box 4.1 the Water Exploitation Index+ (WEI+)

The Water Exploitation Index (WEI) was developed to formulate a harmonized message for awareness purposes on the state of the water resources, to provide an EU overview of water stress conditions, a hot spot analysis, and to be able to communicate the problem of overexploitation to other EU policy areas. Identifying the fact that the original WEI presented some limitations due to its simplified view of the water balance and its highly aggregated scale of implementation (i.e. country level), the EEA worked with the WFD CIS Expert Group on Water Scarcity & Drought towards an improved formulation of this indicator (the so called WEI+) with the purpose of better capturing the balance and critical thresholds between natural renewable water resources and abstraction, in order to assess the prevailing water stress conditions in a catchment. The proposed WEI+ aims mainly at redefining the actual potential water to be exploited (i.e. availability), since it incorporates returns and accounts for changes in storage, tackling as well issues of temporal and spatial scaling and proposing the use of environmental requirements for the formulation of adequate thresholds.

The WEI+ is formulated as follows: WEI+ = (Abstractions – Returns) / Renewable Water Resources

For the calculation of the Renewable Water Resources (RWR) two options have been suggested and selection relies on the available information and certainly (minimisation of bias) associated with each option.

Option 1 refers to the calculation of RWR based on the hydrological balance equation, using precipitation, external inflow, actual evapotranspiration and change in natural storage as components:

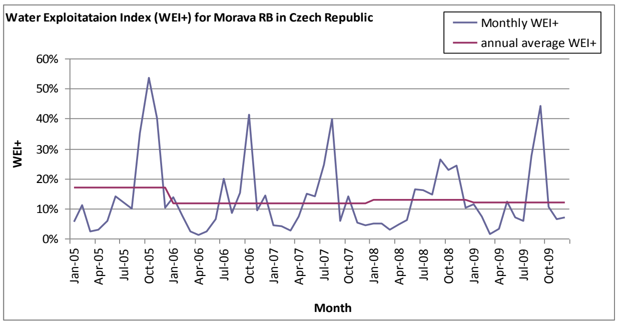
$$RWR = ExIn + P - Eta - \Delta S$$

Option 2 refers to the calculation of RWR based on the naturalization of stream flow, using outflow, abstraction, return and change in artificial storage as components:

$$RWR = Outflow + (Abstraction - Return) - \Delta sart$$

Environmental Flows should be conceptually considered in the WEI+. At the moment, due to the absence of a harmonized and comparable method for calculation, *eflows* should be left out of the WEI+ formula itself, and be considered instead in the definition of the relevant thresholds. For more information on these thresholds: see Box 4.2.

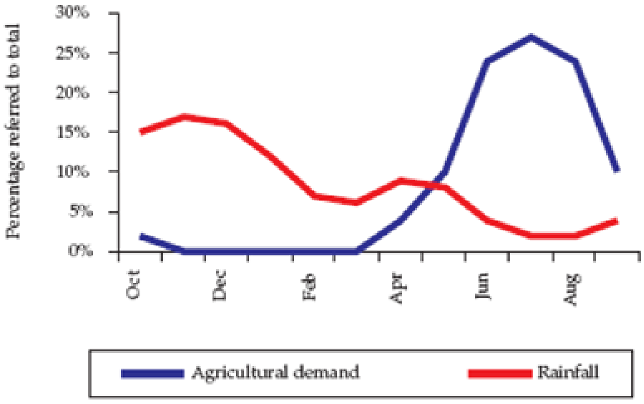
Figure 4.7 Variability of the Water Exploitation Index (WEI+) at Morava RB in Czech Republic for the period 2005-2009 at monthly scale.



Source: EG WSD, provided by the representative of Czech Republic

To further enhance interpretation of the acuteness of water stress conditions, a satellite index to the WEI+ is proposed, defined as the ratio of water abstraction to the actual water use. This indicator can depict cases where water use is higher than abstraction and met by other means (e.g. desalination) so that freshwater resources are not overexploited, or cases where abstraction is much higher than the actual use due for instance to high losses.

Figure 4.8 Precipitation versus agricultural demand patterns



Source: Jucar Pilot RBMP

Box 4.2 Environmental flows

Relevant thresholds
Will be written later

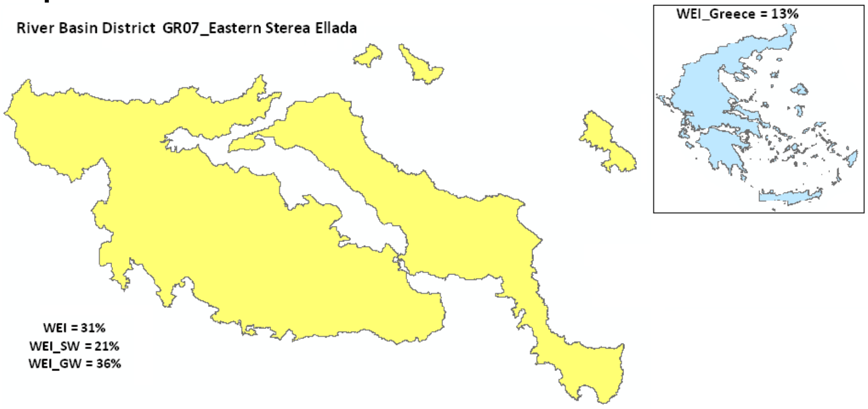
To evaluate the state of water resources in a more analytical manner (as opposed to indicators which represent aggregated information), as well as their relation to the economy, water account' approach provides an additionally useful tool. Water accounts focus on the quantitative assessment of the stocks and the changes in stocks which occur during the accounting period (e.g. month) and link information on the abstraction and discharge of water with information on the stocks of water resources in the environment. Thus they can describe the exchange of flows from the environment to the economy, within the economy, and from the economy to the environment allowing for the assessment of the pressure on water quantities exerted by the economy and the identification of the economic agents responsible for abstraction and discharge of water into the environment under different spatial scales.

Box 4.3 The importance of scaling and decoupling in the estimation of water exploitation and water stress

The spatial scale of analysis is essential in the accurate representation of water scarcity conditions. Highly aggregated scales like country level fail to depict the full problem as deficits between water resources availability and demand in one area can be leveraged by surpluses in other areas. Similarly, separating between surface and groundwater resources can further support the assessment of water exploitation. Cases where one of the resources (e.g. groundwater) is overexploited may not appear when availability and abstractions are calculated as sums.

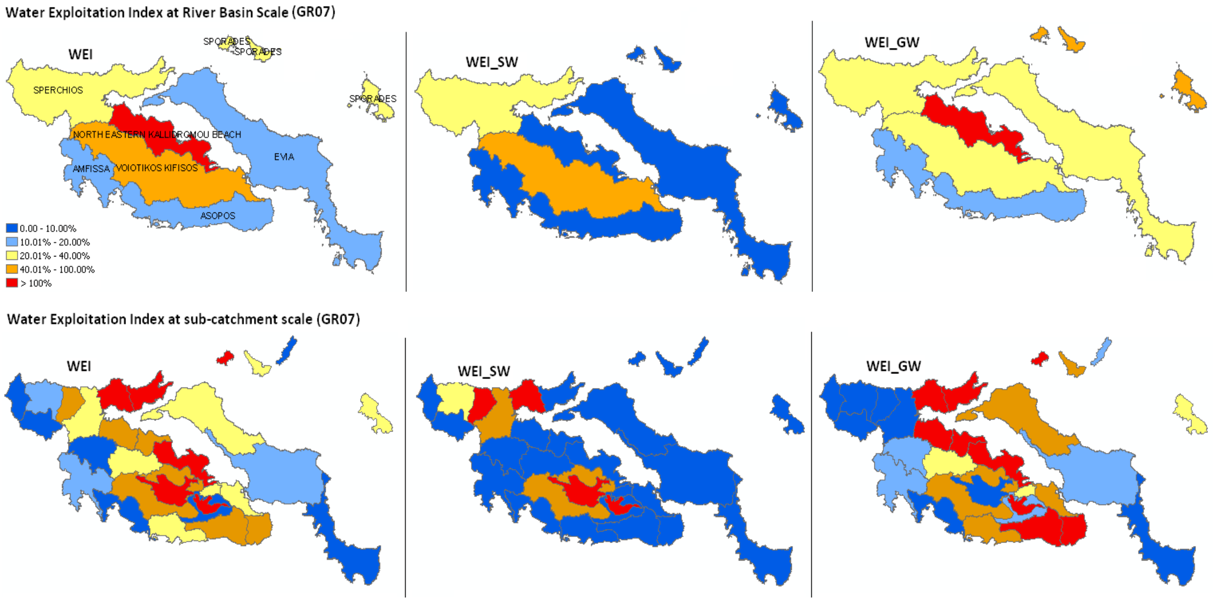
The Greek case of the RDB of Eastern Sterea Ellada (GR07) is a nice illustrative example. The Water Exploitation Index (WEI) calculated based on the long term average availability places Greece as a non-stressed country with a WEI of 13%. Yet, the RBD of Eastern Sterea Ellada has a much higher WEI of 31%, with its groundwater being overall more exploited than surface water (Map 4.2a). A further analysis conducted at River Basin scale and sub-catchment scale, decoupling also surface water (WEI_SW) and groundwater (WEI_GW) exploitation (Map 4.2b) shows great variability within the RBD, with some basins and catchments being overexploited while others are not-stressed and reveals a large range of exploitation rates of the surface and groundwater. This scale of analysis can better support the identification of the problem (together with additional management indicators) and guide targeted actions.

Map 4.2a The WEI for the Greek River Basin District Eastern Sterea Ellada (GR07).



Source: Compiled by the ETC/ICM based on data provided in the Drought and Water Scarcity Management Plan of GR07 (Hellenic Ministry of Environment, Energy and Climate Change and NAMA S.A 2012).
Note: WEI total (31%) and calculated for surface (21%) and groundwater resources (36%) separately, legend: see Map 4.2b, all values in class 20-40%

Map 4.2b The WEI at river basin and subcatchment scale within the Greek RBD Eastern Sterea Ellada (GR07).



Source: Compiled by the ETC/ICM based on data provided in the Drought and Water Scarcity Management Plan of GR07 (Hellenic Ministry of Environment, Energy and Climate Change and NAMA S.A 2012).
Note: WEI total (left), for surface (middle) and groundwater resources (right) at river basin (top) and subcatchment scale (bottom) within the Greek RBD Eastern Sterea Ellada (GR07).

Note: Currently the methodology and data quality are in public consultation (organized by European Commission, DG Environment). Based on the reactions on this consultation, the Water Accounts maps will be recalculated and presented at a meeting at DG ENV on 7 September. The final maps will be included in this report as well.

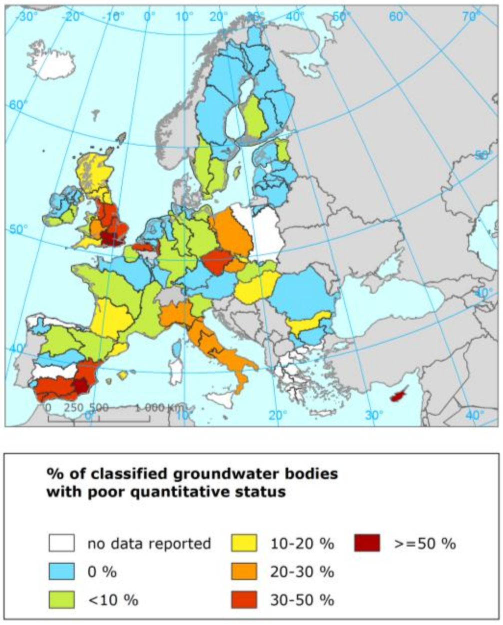
This part has to be completed with a short explanation of the water accounts calculations, the data used (as these are not only the data provided by member states through Eionet), the data quality and proxy's used.
This part will contain a / some map(s) with the results, focusing on availability, abstraction and water exploitation index and their interpretation / discussion of the results.

Box 4.4 Groundwater quantitative status

The definition of good groundwater quantitative status according to the WFD requires that the level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction.

From the total number of Groundwater bodies reported in the WFD RBMPs, only 6% (672 Groundwater bodies) are classified as being in poor quantitative status in 2009. Only a few countries, namely Spain, United Kingdom, Belgium, Czech Republic, Germany, Italy, Malta, have groundwater quantitative problems which are though mainly found in specific RBDs and not in the whole country, with the exception of Cyprus where approximately 70% of its Groundwater bodies are in poor status (Map 4.3).

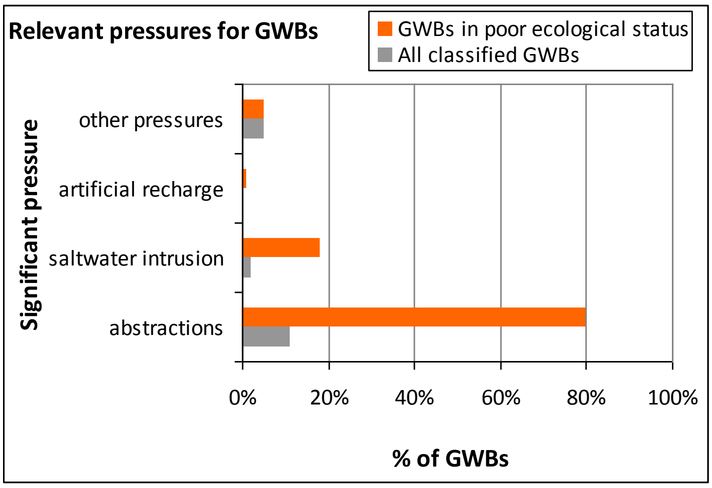
Map 4.3 Percent of Groundwater bodies in poor quantitative status in 2009 per RBD



Data source: WISE-WFD database, February 2012

There are four significant pressures that are affecting groundwater quantitative status based on the WFD. The most commonly reported pressures are water abstraction (in 11% of classified GWBs and 80% of GWBs which are in poor quantitative status), followed by saltwater intrusion (in 18 % of GWBs in poor status). Artificial recharges constitute a pressure in only 1% for GWBs in poor status and finally other pressures are responsible for about 5% of the GWBs in poor quantitative status (Figure 4.9).

Figure 4.9 Relevant pressures for GWBs



Data source: WISE-WFD database, February 2012

The main response measures across Member States (as identified in the WISE-WFD and the compliance check databases) are grouped into 11 categories, varying from voluntary, to regulatory, legislative and financial, as presented in Table 1.

Table 4.1 Groups of measures and popularity

No	Measures	Popularity
1	Promote and increase water use efficiency	Mostly applied (80-100% of times)
2	Controls over groundwater abstraction - including registers of abstractions and requirement for prior authorisation of abstractions	
3	Controls of artificial recharge or augmentation of groundwater bodies - including a requirement for prior authorisation	
4	Monitoring: abstractions (installation of meters), piezometric levels	
5	Investment in water saving irrigation techniques	Selectively applied (40-53% of times)
6	Management plans	
7	Awareness raising//advise/education	
8	(waste) water re-use and rain water management	
9	Artificial recharge (Increase resources by e.g. desalination)	
10	Science/Research/Risk and vulnerability Assessments	
11	financial incentives / pricing policy for sustainable use (charges/fines/taxes for GW abstractions)	Least applied (13% of times)

Note: analysis based on 15 RBDs that in 2009 were in poor quantitative status but the projections for 2015 are showing significant improvement

4.2.2. Future evolutions of droughts and water scarcity

Future of evolutions of droughts are described in (EEA (report under preparation) 2012b). River flow droughts are projected to increase in frequency and severity in southern and south-eastern Europe, the United Kingdom, France, Benelux, southern Scandinavia and western parts of Germany over the coming decades (Feyen and Dankers 2009).

Climate change will affect not only water supply but also water demand. Socio-economic factors such as population growth, increased consumption, and land use have a huge impact on water scarcity with climate change exacerbating the problem. Water resources are expected to decrease in Europe as a result of increasing imbalance between water demand and water availability. Water scarcity, mainly due to the increased projections for irrigation, is projected to increase in many regions in Europe. How water demand can evolve and how this can impact water scarcity figures is described in EEA (2012b). Initial research suggests that climate change may also have some effect on household water demand (Keirle and Hayes 2007). The challenges for cities are described in EEA (2012c, section 2.3).Many cities in southern and eastern Europe, as well as some in western Europe are already experiencing water stress during the summer. Future projections see an aggravation and also northwards extension of the problem. When cities want to overcome regional water scarcity through imported water they become more dependent on other regions with implications for water pricing.

4.3. Floods occurrence

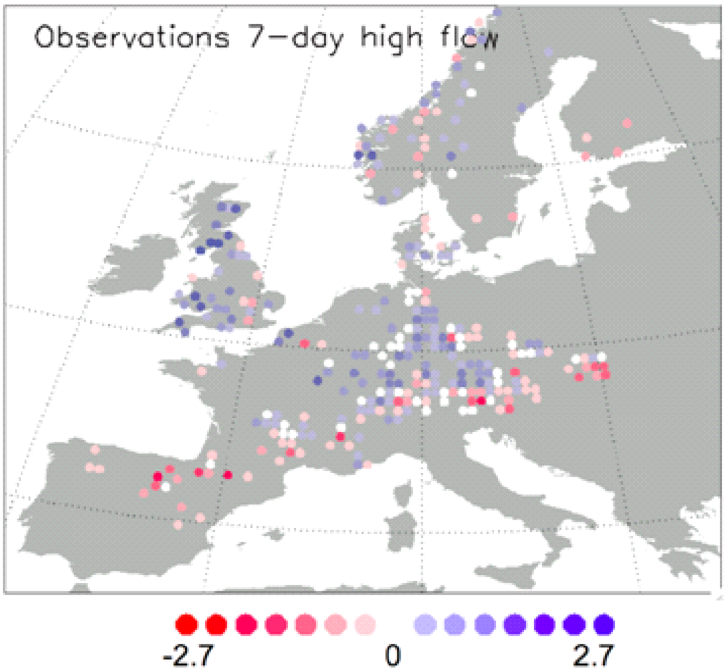
Through the ages and across Europe, damaging floods have been an ever-present peril to human settlements, and several studies have documented historical flood events in Europe going back several centuries (e.g. Brázdil, Kundzewicz, and Benito 2006; Bürger et al. 2006; Macdonald and Black 2010;

Glaser et al. 2010). Most of the large-scale disastrous inland events have been caused by prolonged periods of heavy rainfall, often coinciding with ice-breaking or snow melt (Glaser et al. 2010). An important question for flood risk managers is to establish if the flood hazard has changed in recent decades. When discussing changes and trend in flooding it is important to distinguish between, on the one hand, changes in the occurrence of period of high river flood and (this section) and on the other hand, changes in economic damage resulting from inundation and destruction of infrastructure (section 5.2).

4.3.1. Changes in flood flow

Available evidence suggests different patterns across Europe with increasing high flows in northern Europe, especially in western Britain and coastal Scandinavia. Regional patterns are, however, diverse, with many weak negative trends occurring in northern Europe as well, and a very mixed pattern in central Europe. Detection of a climate signal in hydrological observations of flood magnitude and frequency is difficult due to the confounding effects of long-term natural variability in climate, human disturbance of catchments and river systems, as well as the relatively short period of observation in most rivers. Stahl et al. (2011) analysed trends in 7-day maximum flows and found that the overall pattern largely confirms the results of national studies, i.e. – increasing high flows in northern Europe, with steepest trends in western Britain and coastal Scandinavia, but regional patterns are very mixed, with many weak negative trends also occurring in northern Europe, and a very mixed pattern in central Europe (figure 4.10). Conclusions from such evidence-based studies are limited in spatial scope to the areas where observed long-term flow data exists and are made available. For example, no data from south eastern Europe was included in the study by Stahl et al. (2011)

Figure 4.10 7-day maximum trends across Europe, 1962 – 2004



Source: Stahl et al. 2011
Note: Blue circles denote positive trends, red circles negative, with trend magnitude expressed in standardized units.

Climate variability associated with the North-Atlantic Oscillation (NAO) has been cited as a likely driver of observed high flow trends in some national-scale studies. In the UK, Hannaford and Marsh (2008) found relationships between the NAO index and high flow indicators in western Britain, which is likely to influence the upward trends seen in these areas. The NAO has also been posited as a mechanism for influencing stream flows in central Europe. For example, Villarini et al. (2012) found the NAO to be a significant factor explaining patterns of extreme flooding in Austria, although other studies from central Europe have been less conclusive (e.g. Schmocker-Fackel and Naef 2010). The association of flooding with modes of large-scale atmospheric circulation raises the question whether recent changes in flood frequency reflect anthropogenic climate change or the influence of multi-decadal variability. These two factors are not mutually exclusive, though, since modelling studies suggest that the recent evolution of large-scale patterns such as the NAO is also driven by anthropogenic forcing (Dong, Sutton, and Woollings 2010).

4.3.2. Future floods

Flood risk management needs to consider developments in both flood hazard and vulnerability. Scenarios for flood risk management thus have to combine socio-economic scenarios, such as projections for population growth, urbanisation and industrial developments with projections of future hazards resulting from a changing climate and hydrology. Recent studies (e.g. Dankers and Feyen 2009; Feyen et al. 2011) suggest that climate change can add significantly to expected damages in some parts of Europe over the coming decades. The scenarios of changes in flood hazard were combined with projections of socio-economic change. The results showed that the combination of climate change and economic growth will likely result in a strong increase in flood risks across Europe (Flörke et al. 2011). The ClimWatAdapt project focused on floods with an annual exceedance probability of 1% (equivalent to the predicted 100-year flood). The future scenarios showed that the occurrence of a 100-year flood event is strongly affected by climate change. However, the uncertainty related to the spatial distribution is still large, and different climate models gave very different results. Using the ensemble mean, the 100-year flood was projected to increase, especially in the north-western part of Europe and on the Iberian Peninsula (see also EEA (report under preparation) 2012b, section 3.3.3). Flash floods and urban floods, which are triggered by local intense precipitation events, are also likely to become more frequent throughout Europe (Christensen and Christensen 2002; Kundzewicz, Radziejewski, and Pínskwar 2006).

When accounting only for climate change, some regions dominated by snowmelt (for example the Vistula and Odra catchments in Poland) are likely to see a reduction in annual flood damages due to the strong reduction in snowmelt-driven and ice-jamming floods, which compensates for the increase in summer flood damage in these regions.

4.3.3. Types of flooding

Most of the examples in this report are from rivers or 'fluvial flooding'. But one has to keep in mind there are many sources of flooding, mechanisms of flooding and characteristics of the floods (WG F Drafting Group, Adamson, and Brättemark 2011). The main sources to be distinguished are:

- Fluvial (rivers, drainage channels, mountain torrents and ephemeral water courses and lakes);
- Pluvial (urban storm water, rural overland flow or excess water or floods arising from snowmelt);
- Groundwater ;
- Sea water (including estuaries and coastal lakes, e.g. due to extreme tidal level and/or storm surges or arising from wave action);
- Artificial water-bearing infrastructure (failure of infrastructure including sewerage systems, water supply and wastewater treatment systems, artificial navigation channels and impoundments like dams and reservoirs).

The main mechanisms of flooding are:

- Natural exceedance;
- Defence exceedance (overtopping defences);
- Defence or infrastructural failure (could include breaching or collapse of a flood defence or retention structure but also failure in operation of pumping equipment or gates);
- Blockage / restriction (flooding due to natural or artificial blockage or restriction of a conveyance channel, could include blockage of sewerage systems as well as restrictive channel structures such as bridges or culverts or arise from ice jams or landslides).

The main characteristics, in relation to the vulnerability of the flooded area are:

- Flash floods (quite rapidly rise and fall of the water level with little or no advance warning, usually the result of intense rainfall);
- Snow melt flood (possibly in combination with rainfall or blockage due to ice jams);
- Speed of onset (can be rapid, medium or slow);
- Debris flow;
- High velocity flood;
- High water level (deep) flood.

5. Impacts and Responses

Water managers in Europe, and beyond, are faced by a catalogue of challenges of hitherto unseen proportions. These challenges include a the move from a traditional sectorial approach towards a more holistic consideration of water within the broader concept of ecosystem services, combined with the increasing uncertainty of the future direction and magnitude of the drivers and pressures, for example climate or land use changes. The increasing complexity of water management requires a more integrated approach and a comprehensive policy response to ensure that Europe's finite water resources can continue to meet the competing demands from the existing and emerging stakeholders as well as increasing the resilience of socio-economic and ecosystems against negative impacts from extreme events such as floods and droughts. For example - the fundamental differences in both spatial and temporal nature of water scarcity & droughts compared to flooding requires distinct yet integrated policy responses.

5.1. Water scarcity & droughts (WS&D)

5.1.1. Impacts

Impacts of water scarcity and drought can be classified as either direct or indirect. Reduced crop and forest productivity, increased fire hazard, reduced water levels, increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat are a few examples of direct impacts from drought and water scarcity (Wilhite, Svoboda, and Hayes 2007). Economic losses and social disruption are examples of indirect impacts. Another classification may also be the division between economic, environmental and social impacts.

Besides agriculture, electricity production is vulnerable to climate change effects on river low flows and water temperature for their cooling water (EEA 2008; Förster and Lilliestam 2010). In Europe, 78% of the total electricity production is by thermoelectric power plants (van Vliet et al. 2012). Despite of the uncertainties in the modelling framework, the study of van Vliet et al. (2012) suggest that by 2040 the probability of capacity reductions of more than 50% increases by a factor 1.4, reductions over 90% by a factor 2.8. Short-term estimates (daily scale) are proposed as required to address the impacts of water extractions during low flows and water temperature changes on aquatic ecosystems and the economic water user (van Vliet et al. 2012).

Economic Impacts

Economic impacts relate to different economic sectors such as agriculture, industry, energy, navigation, tourism and include:

a. Losses in production (crop & livestock production, manufactured goods, energy production etc.) and respective losses in the income generated by the various economic activities (e.g. tourism);
b. Increase in prices of food, energy and other products (as a result of the reduction in supply). Even the need to import goods may arise or to change the transportation method due to low water levels in rivers;
c. Increased water prices due to compensating measures;
d. Cost of drought and flood mitigation measures (including water transfers, imports and other short term development options).

Box 5.1 Examples of experienced Economic Impacts of WS&D in EU Member States

Agriculture
In **Slovenia** the direct economic cost of the 2003 drought (mainly loss of agricultural production and aid to farmers) reached 100 Mio€ (Sušnik and Kurnik 2005). *'Damages due to drought in years 2000 – 2006 summed up to 247 M€; 86 M€ were allocated in national budget and spent for recovery measures; 3 M€ were allocated for preparedness measures. This ratio is not acceptable from public finances' point of view'.* (Gregorič 2009).

In **Romania** the drought of 2003 affected mainly agricultural production (i.e. wheat: 2500t/ha and rice: 0.5t/ha comparing to 7000t/ha and 0.5t/ha respectively of a normal year) (Anon. 2009)

In **Portugal,** during the summer of 2005, large amounts of crops were destroyed because of drought (60% loss of wheat and 80% loss of maize productions) (Isendahl and Schmidt 2006). The costs were over 500 Mio€.

The drought of spring 2011 had various impacts on farmers in different regions of the **United Kingdom**. Field vegetables were reported to be affected in Yorkshire (later harvesting period, lower quality), yields of grazed and harvested grass for livestock production were reduced in parts of the south east, midlands and east of England, horticultural and cereal crops were also affected in some parts of southern and eastern England and voluntary restrictions on spray irrigators were implemented in the Fens.

Energy
During nine summer periods between 1979 and 2007 the **German** government had to reduce production of nuclear power due to high temperatures of water and/or low water flow rates (Müller, Greis, and Rothstein 2007). The reduction of power output of the Unterweser nuclear power plant was reported at 90% between June and September 2003, while the Isar nuclear power plant cut production by 60% for 14 days due to excessively high temperatures and low stream flow rates in the river Isar in 2006 (Förster and Lilliestam 2010).

The drought of 2002-2003 affected most of **Norway**, **Sweden** and **Finland** with a considerable decrease in hydropower production and a consequent increase in the price of electricity (Kuusisto 2004).

Due to 2003 drought and heat wave **France** faced a 15 % reduction in its nuclear power generation capacity for five weeks, and a 20 % reduction in its hydroelectric production (Hightower and Pierce 2008 in Rübbelke, Vögele, and Centre for European Policy Studies 2011). During the 2009 summer heat wave, due to cooling water shortages the nuclear power generation industry in France, the biggest European electricity exporter, faced a shortage of about 8 GW resulting in import of electricity from Great Britain (Pagnamenta, 2009 in Rübbelke, Vögele, and Centre for European Policy Studies, 2011).

In **Portugal,** during the summer of 2005, hydropower production was reported to be 54% lower than the average, and 37% lower than in 2004. The costs of the 2004 and 2005 droughts on public water supply, industry and energy and agriculture were over 300 Mio€. (EC 2007a)

Navigation
In the **Netherlands**, during dry periods, low river discharges cause restrictions in the inland navigation sector leading to an important increase of cost. According to the Netherlands national drought study the long-term average annual cost due to low water levels in the navigation sector is estimated at 70 Mio€, while the total cost can increase up to 800 Mio€ in a year with extremely low discharge conditions.

In May 2011, river **Rhine** and river **Meuse** discharge was decreased by 58% and 68% respectively in comparison with the long term monthly average (van Loon 2011). As a result, the **German** Federal

Hydrological Agency reported that ships on these rivers were forced to navigate at 20-50% of their capacity (Vidal 2011).

Environmental impacts

Environmental impacts include:

a. Decrease of available water resources (jeopardized minimum vital flow);
b. Degradation of water quality (eutrophication, seawater intrusion etc.);
c. Loss of wetlands;
d. Loss of biodiversity and degradation of landscape quality;
e. Soil erosion and Desertification;
f. Increased risk of forest and range fires;
g. Changes in river morphology (terraces, gullies);
h. Ground subsidence.

Box 5.2 Examples of experienced environmental impacts of WS&D in EU Member States

Groundwater overexploitation and saltwater intrusion

For over the last 40 years groundwater overexploitation in the southern part of **Spain** has an enormous ecologic impact on the area (Ibáñez and Carola 2010), related to significant lowering of groundwater tables, drying out of springs, degradation of wells and boreholes and saltwater intrusion. In the Ribeiras do Algarve River Basin in **Portugal** increased water demand for tourism and agriculture during the last decades has caused serious pressure on the area's environment, including aquifers' over-abstraction, salinization and water resources' degradation.

The problem of salt water intrusion due to overexploitation is very common in several coastal aquifers of **Italy** (Antonellini et al. 2008). In coastal areas in Sardinia, Catanian Plain, Tiber Delta, Versilia and Po Plain freshwater resources are becoming scarcer due to drought, over-exploitation and salinization.

In the **Maltese Island** because of high water demand resulting in over-abstraction, main groundwater bodies face the risk of failing to achieve the environmental objectives of the WFD (MEPA and MRA 2010).

Loss of biodiversity

According to a research conducted from June 2003 to March 2008 in the Mondego estuary in **Portugal**, drought conditions have a significant impact on fish communities causing disturbances in their behaviour and functions (Baptista et al. 2010). More specifically, during drought periods due to increased salinity inside the estuary and low freshwater flows the estuarine brackish habitats moved to more upstream areas, while in downstream areas new marine adventitious species were found. Moreover, freshwater species no longer existed inside the Montego estuary during drought, and lower densities were observed for most of the species.

In **Romania**, severe drought events (i.e. in 2007 and 2009) are reported to negatively affect forest areas causing changes in the area of several tree species and the boundaries of vegetation zones (moving North and West of the silvo-steppe), encouraging also the appearance of certain Saharian species in the South area of Romania (Lupu, Ionescu, and Borza 2010). Hills and plains covered with forests in areas of South and East Romania, such as Dolj, Olt, Galati, Braila, Ialomita, are proved to be very vulnerable to drought. This vulnerability not only affects the environmental balance but also has a negative socio-economic impact on the population.

In the **Czech Republic** during the dry years 2003-2004 an increased defoliation of tree species was noticed, especially dieback of unoriginal spruce forests and Pinus nigra. Forests weakened by drought were more vulnerable and consequently attacked by Armillaria ostoyae and bark-beetles (Czech Republic National SD Reports 2008).

In **Portugal** the 2004-2005 drought resulted in water level fall in many reservoirs (two major reservoirs, Funcho and Arade, completely dried out), reduced rives flows with a parallel degradation in their quality consequently affecting migrating species (e.g. lamprey in Minho river), water table decline in aquifers, salt water intrusion in transboundary waters bodies (e.g. Tagus Estuary), forest fires and removal of 220 tons of fish (Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional (MAOTDR) 2007).

Related hazards
In **Lithuania,** during the 2002 summer drought, 123 forest and peat bog fires burst out in July and 374 in August (Sakalauskiene and Ignatavicius 2003).

Social Impacts
Social impacts include:

a. Water shortage & interruptions (frequency, duration, extend) due to deficiency in public water supply;
b. Population affected from water restrictions (levels and duration);
c. Public safety and Health;
d. Rising conflicts between water users;
e. Reduced quality of life;
f. Inequities in the distribution of impacts.

Box 5.3 Examples of experienced social impacts of WS&D in EU Member States

Public water supply
In **Portugal** during the 2004-2006 drought, the cost for public water supply was over 20 Mio€, while 22,850 tankers were used in support of urban water supply in 66 municipalities with over 100,000 inhabitants. The cost of the inconvenience to the inhabitants affected was considered to be significantly higher than the direct costs reported (Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional (MAOTDR) 2007)

The 2008 extreme drought event left **Spain**'s reservoirs half empty. In particular, some reservoirs in Catalonia supplying almost 6 million inhabitants reached 20% of their capacity resulting in restriction in domestic water uses, such as swimming pools and gardening, as well as public water uses, i.e. fountains (Collins 2009).

During the 2011 drought restrictions on water use have been imposed in 78 **French** administrative departments, which lasted for an exceptionally long period of 18 weeks (1/3rd of a year) (Based on Direction de l'eau et de la biodiversité 2011 and communication through Eionet)

In **Greece**, serious water shortage problems, particularly interruptions, affecting water consumers occur during irrigation season, when about 87% of total freshwater abstraction is used for agriculture (Isendahl and Schmidt 2006).

Transfers and changes in flow regime
The Tagus-Segura water transfer in **Spain** raised conflicts between the autonomous communities of Castilla-La Mancha and Murcia and also created tensions between Spain and Portugal concerning the flow regime (Isendahl and Schmidt 2006).

5.1.2. Responses

The communication from the European Commission 'Addressing the challenges of water scarcity and drought in the European Union' (EC 2007b) is the primary policy document guiding effort in the EU to combat water scarcity and drought. The communication defines overarching policy options of which several are related to water economics and resource efficiency (see also section 2.2). Resource efficiency is seen as an important measure to reduce vulnerability, and is dealt with in detail in EEA

(2012a). Other policy options deal with water allocation, drought risk management and improved knowledge and data collection.

The WFD is not directly designed to address quantitative water issues, although its goal includes mitigation of drought effects and its environmental objectives include finding a balance between abstraction and recharge of groundwater. The River Basin Management Plans (RBMPs) can include more detailed programmes of measures for issues dealing with particular aspects of water management such as water scarcity and droughts. Some countries, especially those who face water scarcity and drought more frequently, have already implemented drought management plans (DMPs) at river basin scale (see, for example, box 5.4).

Box 5.4 Drought Management Plans in Spanish River Basins

The Spanish drought management plans are powerful tools coordinated by River Basin Authorities that prioritise uses and protect water ecosystems under stressed situations through agreed bases among stakeholders. They establish drought phases, describe appropriate measures to be applied at each phase taking into consideration homogenized national drought indicators, mitigate their negative effects and foster a comprehensive follow-up of drought episodes and evolution. As their main achievement, they have avoided applying restrictions in urban areas throughout the recent drought periods.

In the implementation of Spanish Drought Management Plans a wide variety of indicators are used in order to warn for a period of impending drought. These include monitoring reservoir levels, using classical drought indices and assessing uncharacteristic thickness of snow pack during winter. The threat level is then evaluated and defined by 3 consecutive scenarios, each of which require different actions to be undertaken:

1. Pre-alert scenario: The initial stages of drought have been detected but measures are restricted to low cost, voluntary actions such as information dissemination. This scenario is recognised when there is a 10% probability that full water demand will not be met.

2. Alert scenario: Drought is now occurring and actions include non-structural measures of low to medium cost (i.e. restrictions on recreational water use). This scenario is realised when there is a 30% probability that water deficits will occur.

3. Emergency scenario: Impacts of the drought are now visible and water supply is in danger. Infrastructure changes would be applied and urban supply may have to be sourced through different means. The probability of not fulfilling water demand must exceed 50% for this scenario to take place.

Source: Garrote et al. 2006

Clearly, responses and adaptation measures differ, depending on the issues and priorities of each region and are designed to either increase supply (supply–side strategies) or reduce demand (demand–side adaptation strategies). The effectiveness of the response measures is difficult to assess, as it relates to the inherent complexity of water scarcity phenomenon, which has its roots both on natural and anthropogenic drivers, which in turn result in pressures, adversely changing the state, and causing multiple impacts on the environment, economy and society.

Demand–side adaptation strategies

In some regions improving efficiency is the main priority. Improvements in infrastructure and practices especially in the agricultural sector are a key area. Agricultural demands may also be decreased through the promotion of better crops and cultivars with lower water requirements (EEA 2012b). Another – complementary - strategy is the development of awareness and education campaigns to promote more efficient agricultural practices in response to decreased availability of water (e.g. precision agriculture or deficit irrigation). Subsidies through economic policy instruments could facilitate the conversion to better practices and/or the modernisation of the existing infrastructure (e.g. reducing leakage).

In many situations subsidies can lead to inefficient use of water or can even create false incentives to increase water use. Removing environmentally harmful subsidies, notably in the agricultural sector but also in other sectors of the economy, can help to reduce water use and will contribute to efficiency gains.

An important, but potentially controversial, area of demand-side adaptation is water pricing. Common measures include charges for water usage, charges for pollution, environmental taxes and fines. The idea behind water pricing strategies is to make water use as efficient as possible and to ensure water quality. One of the main prerequisites for putting appropriate water pricing mechanisms in place is the availability of metering systems, particularly apparent in regions with greater water stress, and registration of illegal abstractions. Efficient metering will allow accurate water pricing based on volume usage and may be useful for establishing a sector-by-sector approach to demand-side adaptation (EEA 2012b).

Many demand-side strategies have the potential to create conflicts between competing demands, by economic sector, geographical region, etc. However, in the face of decreased water availability navigating such potential conflicts is a necessary task. This means that society needs to become aware of the threats to water resources and also of the current state of water usage at the local level. Cooperation will be a primary goal and will require appropriate institutional frameworks in order to guarantee that water users "play by the rules" – this does not only require enforcement; public participation and awareness are even greater priorities in order to ensure that the threats to water resources are understood and appreciated.

Box 5.5 Adaptation to water scarcity and drought in the agricultural sector

In many European countries and particularly in the south, agricultural water use represents the highest sectoral abstraction of water. The impacts of water scarcity and drought on this sector are felt not only at farm and regional level but, in the case of widespread or longer term droughts, can have international impacts on commodity prices and food security. It is therefore a priority to reduce the impacts of water scarcity and drought episodes on agriculture now and to prepare for potential increases in the frequency and intensity of these events. This is already occurring to some extent in Member States and important advances will have to be made in the next few years. Policies generally concentrate on research and development, education, introduction of more suited crops, efficiency improvements.

Agricultural adaptation options can be divided into autonomous adaptations (such as changes in varieties, sowing dates and fertilizer and pesticide use) and planned adaptations, referring to major structural changes such as land allocation, farming system and the development of new crop varieties (Bindi and Olesen 2010; Moriondo, Giannakopoulos, and Bindi 2010). The most appropriate adaptation strategy is likely to be a combination of these and will depend on the impact to be experienced as well as the particular vulnerability of the system being considered. It is important to take into account the local conditions, including farm intensity, size and type, which are factors that have been found to play an important role in determining vulnerability to climate change in the agricultural sector (Reidsma et al. 2010).

Although relatively simple and non-cost adaptation options may be easily implemented to tackle the expected change, others will have to be evaluated for cost and feasibility and impacts; in some cases, certain cultivations or agricultural activities may become unviable.

Source: Reidsma et al. 2010; Falloon and Betts 2010; Moriondo, Giannakopoulos, and Bindi 2010; Bindi and Olesen 2010

Supply-side adaptation strategies
Policies for dealing with and adapting to water scarcity and drought should primarily concentrate on efficiency improvements and reducing demand as described in the previous section. However, in some circumstances, it may be necessary to balance demand side policies with the exploration of supply side measures. This is particularly true in arid regions and in those areas where water scarcity and drought are already causing considerable adverse impacts on certain sectors or on the population in general.

In these cases, different options must be evaluated for their potential environmental, economic and social impacts. In some areas, desalination plants have been built or are being planned. Particularly in coastal communities where water resources are often limited and groundwater is being affected by salt water intrusion and sea-level rise, this can offer a viable source of freshwater. Drawbacks include the cost of the technology, running costs, high energy consumption and the generation of brine with resulting environmental problems. In southern European countries, but also in some large urban centres such as London, desalination plants have been included in plans to adapt to growing water demand and reduced supply of water resources. (to be further expanded with examples)

Other sources of water include considering alternative sources such as municipal wastewater, grey water and rainwater. This often requires investments in infrastructure and information and campaigns to overcome public stigma and in some cases alignment of regulations. The treatment of municipal wastewater for reuse is growing in importance in different European settings. Technology can effectively ensure that all pollutants and pathogens are removed and that its use is safe. (examples; parks in Mediterranean).

5.2. Flood risk management

5.2.1. Impacts

Worldwide databases for natural disasters in general like EM-DAT (2012) or NatCatService (2012) or more specific for floods, e.g. Dartmouth Flood Observatory (2012) are nowadays the main data sources available for European wide studies. Details on damages have been compiled in the EM-DAT database, which contains floods fulfilling at least one of the following criteria:
- ten or more people reported killed;
- one hundred or more people reported affected;
- declaration of a state of emergency;
- call for international assistance.

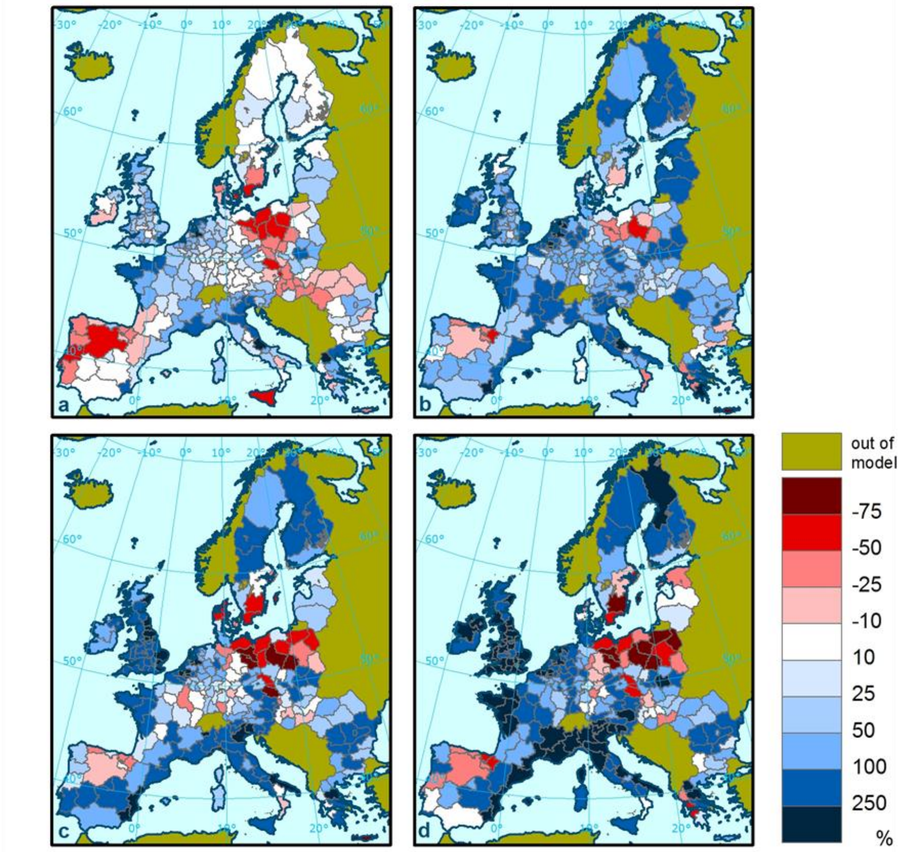
The thresholds used to include an event in the database makes then less accurate for smaller events, still having a significant impact. In the reporting of the preliminary flood risk assessment for the European directive on the assessment and management of flood risks (EC 2007c), EU member states gave an overview of significant past floods. In addition, a European flood impact database can bring together publicly available inventories of flood events. Therefore, the EEA collected metadata of existing national and regional hazard and impact databases from all over Europe exploring possibilities for a common European data entrance.

Several severe flooding events have occurred in Europe over recent decades, causing loss of life, displacement of people and heavy economic losses (EEA 2011a). Since 1980 to 2011, more than 325 major river floods have been reported for all EEA member countries and co-operating countries, of which more than 200 have been reported since 2000. The rise in the reported number of flood events over recent decades results mainly from better reporting and from land-use changes. According to EM-DAT (2012), floods (including flash floods) have resulted in more than 2,500 fatalities and affected more than 5.5 million people in the period from 1980 to 2011. Direct economic losses over this same period amounted to more than EUR 90 billion (based on 2009 values).

ClimateCost - a European project - made an assessment of future changes in the cost of floods in Europe. To achieve this, changes in the frequency of floods were combined with information on exposed assets, depth-damage relations and population density to estimate economic damages as well as the number of people living in flood risk areas. Under current conditions, the Expected Annual Damage (EAD) was estimated to be approximately €5.5 billion for the EU27.

On average, higher flood damages were projected for all countries within the EU (Figure 5.1). Taking into account both climate and socio-economic changes under the A1B scenario (more details about scenarios in (EEA (report under preparation) 2012b, section 5.2), the EAD was projected to increase to € 20 billion by the 2020s, to over €45 billion by the 2050s, and almost €100 billion by the 2080s for the ensemble mean results. A significant part of this rise will be due to socio-economic change. Nevertheless, the isolated effect of climate change alone amounted to almost € 10 billion by the 2020s, almost €20 billion by the 2050s, and €50 billion by the 2080s. More about ClimateCost can be found in (EEA (report under preparation) 2012b, section 5.7.1) as well as other major flood impact research projects like PESETA and the ESPON Climate project (chapter under construction)

Figure 5.1 Relative change in expected annual flood damage (EAD)



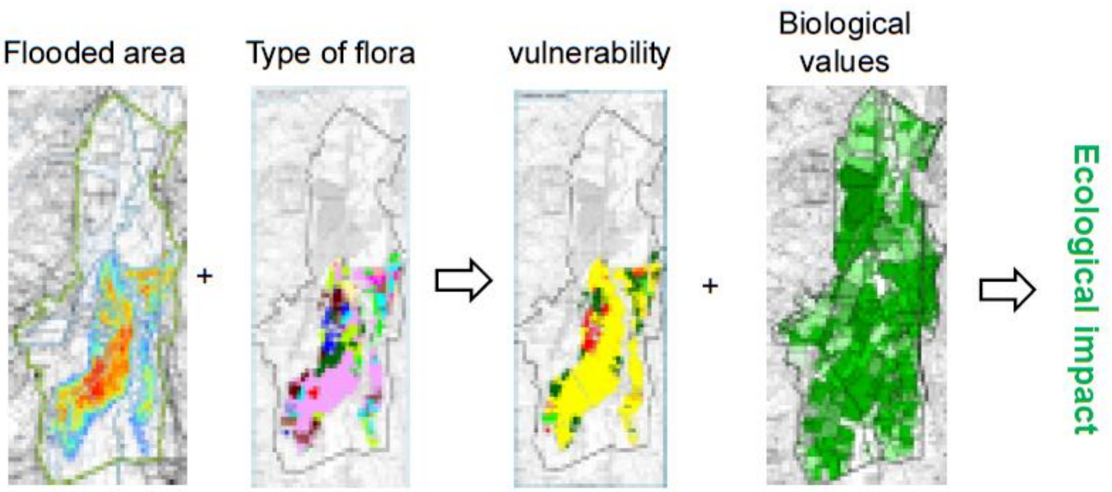
Source: ClimateCost / reported in Flörke et al. (2011)
Note: Relative change in expected annual flood damage (EAD) due to climate change between future time slice and baseline period. a) 2000s (1981-2010); b) 2020s (2011-2040); c) 2050s (2041-2070); d) 2080s (2071-2100). Current 1 % annual flood probability level assumed as protection level in all time periods (i.e., no adaptation to future changes in flood risk).

Box 5.6 Impact of flooding on human health, ecology, cultural heritage and economic activity

The Floods Directive (EC 2007c, Art. 1) states its purpose as "*to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community*". In the Floodresiliencity different techniques of mapping and combining the different categories of negative consequences are tried for the Dijle catchment (Belgium) at the city of Leuven and upstream.

The most important economic receptors were material damages to houses, building and industries, infrastructure and cars together with agricultural damages. Social and health impacts were evaluated by a proxy using number of affected people together with a score based on their exposure, susceptibility and adaptation capacities. Cultural heritage was evaluated counting the architectural relics and entities in the medieval city, the monuments and especially world cultural heritage by UNESCO. The ecological impacts were mainly upstream of the city and were based on a combination of vulnerability and biological values (see figure 5.2).

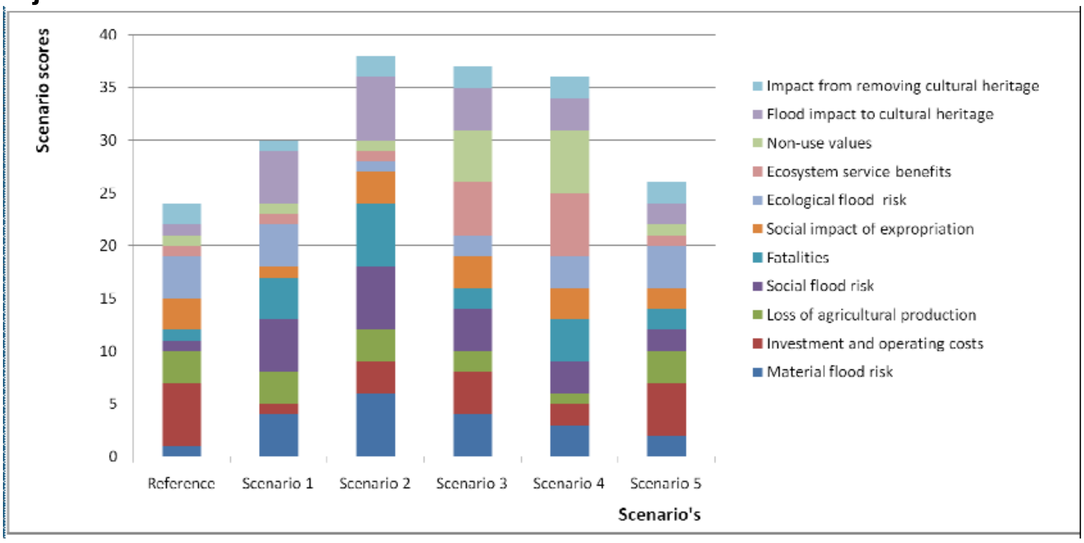
Figure 5.2 Ecological impacts of flooding in the Dijle catchment upstream of Leuven



Source: VMM 2011 and CIS WG Floods Workshop on Floods and Economics, Ghent, 25-16/10/2010

A cost-benefit analysis and multi-criteria analysis with criteria for all 4 types of negative consequences were applied on the different scenarios of measures. A basic result can be found in figure 5.3 but the final ranking are depending on the stakeholders involvement, their visions and their weights.

Figure 5.3 Score of the different scenarios of measures in the MCA analysis for the Dijle around Leuven



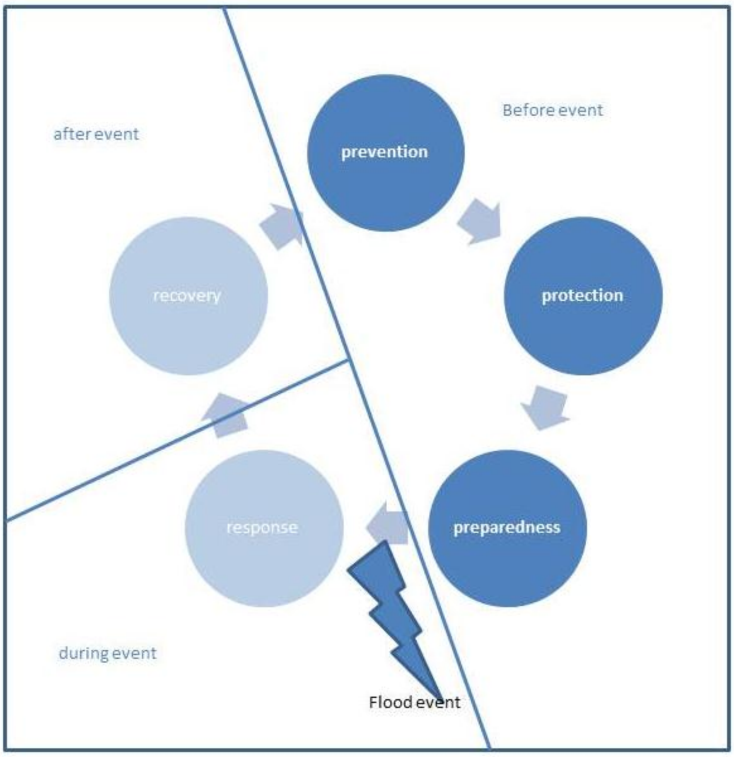
Source: VMM 2011 and CIS WG Floods Workshop on Floods and Economics, Ghent, 25-16/10/2010
Note: reference = actual situation including already decided measures, scenario 1 = flood conveyance (infrastructure works in the city), scenario 2 = flood storage concentrated in nature areas upstream, scenario 3 = flood storage distributed in the valley, scenario 4 = further upstream flood storage in Wallonia, scenario 5 = non-structural measures (prevention, flood forecasting, resilience measures and improved assistance)

Source: VMM 2011, FloodResilienCity (www.floodresiliencity.eu), http://whc.unesco.org

5.2.2. Responses

The assessment and management of floods in the EU Floods Directive are addressed in a risk-based framework to effectively cope with the random and uncertainty nature of the flood phenomenon. A risk management framework for floods should include: preventive and protection measures including spatial and land use planning to avoid damages and infrastructure works, preparedness measures including early warning systems, response measures for an effective crisis management during floods and recovery actions for an efficient return to a well-functioning state of people, economies and ecosystems and to make sure important lessons are learned.

Figure 5.4 Flood Risk Management Cycle, with focus of EU Floods Directive on prevention, protection and preparedness



Source: EEA

The Floods Directive (EC 2007c) seeks to improve the international cooperation in between regions and member states using a structured three-step approach to floods risk management:

1. Based on available or easy derivable information, a preliminary flood risk assessment (PFRA) is made using information from past floods and their impacts, hydrological modelling and of available projections (including climate change scenarios) indicating potential future flood risks. In principle all types of floods are taken into account, including but not limited to fluvial, coastal, pluvial, and groundwater floods. Based on this PFRA a selection of areas with potential significant flood risk (APSFR) is made where more in depth analyses are carried out.

2. For the APSFR a more detailed analysis is made, starting with two series of flood maps ready by the end of 2013 at the latest. The flood hazard maps describe the physical aspects of the flood such as the extend of the flood, water depth, flow velocity etc. for events with a high, medium (at least 1% annual probability) and low probability of occurrence. For each of these events actual flood risk maps are developed, indication the impact and consequences of these floods. Not only people (victims, evacuated and affected persons etc.) and economic consequences are taken into account, but the EU Floods Directive explicitly mentions ecological impacts and consequences for cultural heritage as well. These maps are the knowledge base for the third step

3. The third and final step in the cycle is the establishment of flood risk management plans (FRMPs) for the APSFR by 2015. The FRMPs have to be coordinated at the level of the whole catchment as rivers and floods are not necessarily confined to administrative borders. The member states have to establish appropriate objectives and the FRMPs should include and prioritise measures to reduce the consequences of flooding for human health, the environment, cultural heritage and economic activities by addressing all phases of the flood risk management cycle, particularly focusing on prevention, protection, and preparedness. FRMP shall take into account relevant aspects such as costs and benefits, flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains and the environmental objectives of the Water Framework directive. Explicitly mentioned issues to make the link in between the floods directive and the environmental objectives of the water framework directive are soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure.

Due to the nature of flooding, notwithstanding the enumeration of elements to take into account, much flexibility on objectives and measures are left to the Member States in view of subsidiarity. Not only must FRMP be made available to the public, as for the PFRA, APSFR and the flood hazard maps and flood risk maps) but an active involvement of interested parties shall be encouraged.

After 2015 a new 6 year cycle starts consisting of the same 3 steps. A central element in effective flood risk management is the identification of measures, e.g. as categorised in Table 5.1.

The highest costs are usually associated with structural measures and technical flood protection measures. However, more cost efficient measures can often be achieved through a combination of structural and non-structural measures such as spatial planning, behavioural adaptation and catchment management. A distinction that should be made here is the difference in between effective and efficient flood measures. Effectiveness is a result-based term and describes the degree of goal achievement in terms of risk reduction or effects towards risk reduction. Efficiency is a yield-based term and describes how economically an intended risk reduction or an effect towards risk reduction has been achieved. The term "economically" relates to the expenditure of both time and effort (CRUE et al. 2009).

When floods occur the focus is on crisis management. Contingency plans have to ensure that information flows between all responsible actors, bringing the information together to support operational actions. Many actors are involved including water managers, emergency services, volunteers and those responsible for infrastructures and their maintenance. Flood event management includes forecasting and the provision of warnings, deployment of temporary flood protection structures and emergency response.

A real time early warning system can be an effective non-structural management tool. It enables authorities to start implementing contingency plans, such as evacuations of inhabitants and the mobilisation of rescue forces. Several countries have developed systems for flood warning at national, regional and local level that are connected with systems for initiating evacuation actions. For example, Finland has a real time web based Catchment simulation and forecasting system which provides information on floods and flood warnings. (see Box 5.7 for more details)

After a flood disaster relief, reconstruction actions and financial compensations become part of the management activities. Flood events may also change past risk assessments, put pressure on developing flood defences and lead to the adjustment of regulations and norms (Merz et al. 2010). Careful documentation of the event is necessary in order to learn from the experiences. General flood impact databases such as EM-DAT (2012) or Dartmouth Flood Observatory (2012) exist to give a general overview, but for true learning more detailed documentation is needed. The development of such detailed flood impact data bases is going on in several EU member states and also at the European level.

Table5.1 Potential measures for flood risk management

Functional group	Type of measure	Measure (Examples)	Underlying instrument
Structural Measures			
Flood control	Flood water storage	Dam	Flood protection standard; investment programme
		Flood polder	
	River training	By-pass channel	
		Channelization	
	Flood protection	Dike	
		Mobile wall	
	Drainage and pumping	Urban sewer system	
		Pumping system	
Non-structural measures			
Flood control	Adapted land use in source area (catchment of the headwater)	Conservation tillage	Restriction of land use in source areas; priority area Flood control “flood prevention”
		Afforestation	
	River management	Dredging of sediments	Investment/maintenance programme
Use and retreat	Land use in flood-prone area	Avoiding land use in flood prone areas	Restriction of land use in flood zones; building ban; hazard and risk map; insurance premium according to flood zone
		Relocation of buildings from flood prone areas	
	Flood proofing	Adapted construction	Flood forecasting and warning system; civil defence or disaster protection act
		Relocation of susceptible infrastructure	
	Evacuation	Evacuation of human life	
		Evacuation of assets	
Regulation	Water management	Restriction of land uses in floodplains and source areas	
		Flood protection standards	
	Civil protection	Civil protection and disaster protection act	
	Spatial planning	Priority area “flood prevention”	
		Building ban	
Financial stimulation	Financial incentives	Investment programmes (e.g. for river works)	
		Subsidies for relocation or adaptation	
	Financial disincentives	Insurance premium according to flood zone	

Information	Communication/Dissemination	Information event	
		Brochure	
	Instruction, warning	Hazard and risk map	
		Forecasting and warning system	
Compensation	Loss compensation	Insurance payments	

Source: Flood-ERA / Schanze et al. (2008)

Box 5.7 Flood risk forecasting in Finland

Flood risk assessment and flood control in Finland has been developed in a series of research projects and continuous development work. This has led to the creation of a flood forecasting and warning systems and specific projects for floodwater management.
The basis is a hydrological watershed model system (WSFS) maintained by the Finnish Environment Institute (SYKE). It uses observation and forecasting input from the Finnish Meteorological Institute on weather and combines it with a network of hydrological and meteorological observation points and remote sensing information.

Figure 5.5 Flooding at Vöyrinjoki River in the summer 2004

Photo: Unto Tapio

The WSFS is used for flood forecasting, real-time monitoring, nutrient load simulation and climate change research. Hydrological water balance maps are created in real time. Forecasts are made daily for over 500 discharge and water level observation points. Forecasts are used for lake regulation planning and flood damage prevention. The information is available on the internet to public and authorities.

Interactive maps allow users to zoom in on their area of interest. It includes information on hazards by providing, for example, flood and water level warnings and precipitation warnings both for the last 24 hour and 3 day forecasts. Warnings are graded and expressed with colour symbols.
In addition to the warnings the system provides continuously updated information on, for example, runoff, precipitation, snow cover, water equivalent of snow, snow melt, soil moisture deficit and water level. Furthermore nutrient loads are simulated.

For more information see: http://www.environment.fi/floods and http://www.ymparisto.fi/default.asp?contentid=373979&lan=en&clan=en

Box 5.8 Room for the river or retaining water in the landscape

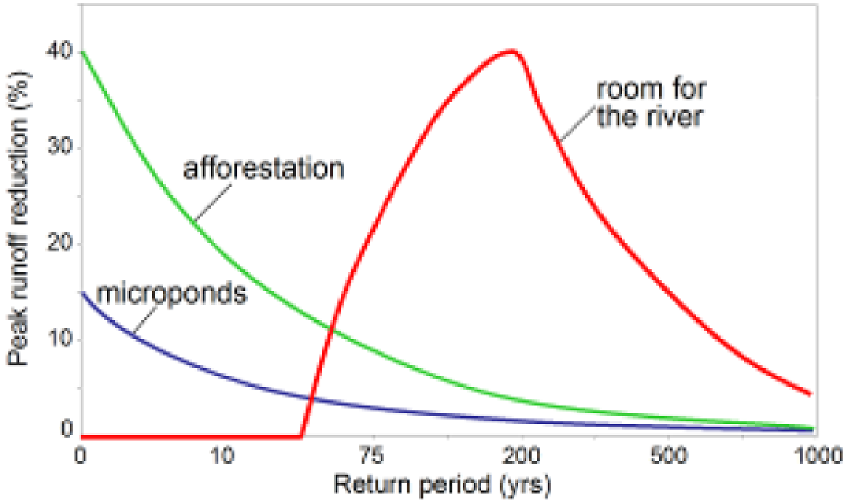
"Room for the river", also known as "space for water" or "Ruimte voor de river" is a group of measures taken within the floodplain and involving natural and forced (polders) flooding areas.
For the Kamp catchment in Austria, the effectiveness and efficiency of "Room for the river" was compared with the one for retaining water in the landscape by micro ponds or afforestation (Francés et al. 2008). For afforestation, the reduction is higher in dry initial conditions than in wet conditions, because the initially available soil storage capacity and the available interception storage is higher. For retention elements on the slopes (micro-ponds) or in the channel network (dams) the wet conditions produce higher peak reductions.

In general, the potential additional storage capacity resulting from afforestation and micro-ponds will have a physical limit which can be exceeded only by intensive measures such as dams. If the potentially damaged values in the flooded area have a high risk exposure, the smaller and more frequent events can have a large contribution to the total risk compared to the exceptional events. The effect of retention measures in the landscape is much higher for small events than for large events. As a result the risk reduction for these types of measures can be higher than expected from the hazard reduction.

In the Kamp catchment, significant reductions in the flood peaks can be obtained when retention basins along the main stream are constructed and the flood plains are inundated. However, a lot of room is needed for these measures. The main advantage of the room for the river methodology is that the polders/retention basins can be designed in a way that there is no retention for small flood discharges which leaves the full storage capacity for larger floods at the time of peak.

The peak runoff reduction of "retaining water in the landscape" measures is a function of flood return period, reducing its effectiveness with the flood magnitude. "Room for the river" seems more effective for medium return periods (see figure 5.6). It may be useful to combine these measures with other positive effects such as soil conservation, sediment transport reduction and environment protection.

Figure 5.6 Estimated flood peak reductions for different measures in the Kamp catchement (Austria)



Source: Room for the river / Francés et al. (2008)
Note: "room for the river" method =retention basins and flood inundation along the river reaches, "retaining water in the landscape" methods = micro-ponds and afforestation

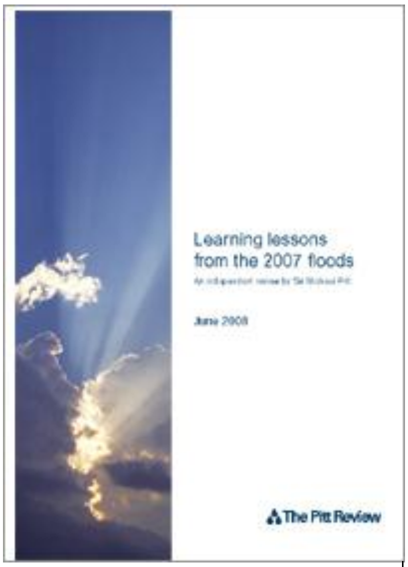
Source: Francés et al. 2008; CRUE et al. 2009

Urban flood risk management
Many cities and towns are situated in locations that are prone to fluvial flooding such as deltas and flood plains. Cities that are far away from water bodies prone can also be liable to pluvial flooding as a

result of intense rainfall, often exacerbated by extensive land sealing and drainage networks with insufficient capacity. Urban floods affect infrastructure, assets and urban activities, including transport. They can cause health risks due to overflowing sewers and intrusion of surface water into water supply systems. Urban floods also increase the risk of pollution of water courses into which storm water and flood water drains.

There is a general consensus that society needs urban areas to be more resilient to flooding. Flood-proofing of buildings is a well-known measure towards achieving this, sustainable urban drainage another. Green infrastructure can also provide opportunities for addressing problems caused by land sealing in urban areas (EEA 2010c; EEA 2012c). Reducing the vulnerability of urban areas to floods requires detailed knowledge of local conditions. Measures have to deal with water supply, waste water treatment, rain water runoff and special conditions such as snow melt. There is a need for research into the effects of extreme weather events on urban drainage, water management and water treatment. Urban water management approaches have to be developed that take into account both risks and all positive aspects of water in the urban environment. Water is a necessary element in a sustainable urban environment, but climate change may change conditions for current practices related to urban drainage, water management and treatment. More details on Urban adaptation and water can be found in EEA (2012b).

Box 5.9 Flooding in the UK 2007 – lessons to be learned



The flood events experienced in the UK in the summer of 2007 were in large parts caused by three storms of record-breaking magnitude and spatial extent. For example, the storm of the 19th-20th July produced up to 140 mm of localised rainfall, estimated to have a return period of about 100-years (Marsh and Hannaford 2007). The resulting flood peaks exceeded previous maximum recorded flow in numerous locations, and estimated return periods exceed 100-years in several places. The extensive flood damages caused by the unusual hydrological conditions of 2007 are well-documented. Over 55,000 homes and 6,000 businesses were flooded; the related insurance claims were approaching €4.5 billion by late-2007. Many flooded and low-lying localities had to be evacuated

Following the summer 2007 floods, the UK Government asked Sir Michael Pitt to undertake a comprehensive review of the lessons to be learned from the events. During the fact-finding over a 10 months period, the review team examined over 1000 written submissions, considered experiences of other countries and visited communities affected by flooding. The outcome of the review was a report published in June 2008 containing 92 recommendations on how to improve flood risk management (Pitt 2008). Actions following the review included the need for a step change in the quality of flood warnings, a greater role for local authorities in flood risk management, better planning and protection for critical infrastructure, and raising public awareness of flood risk. Many of the recommendations have now been put into practise (Defra 2009).

Dam safety

The Floods Directive (EC 2007c) does not specifically refer to flooding resulting from dam breaks and dike breaches, and it does not deal with the technical aspects of dam safety. However, it does require flood hazard maps to be produced for floods with a low probability, implying consideration of extreme event scenarios, such as dam breaks. There are no EU wide regulations devoted exclusively to dam safety, but the SEVESO II Directive (EC 1997) on the control of major accident hazards involving dangerous substances, and its amendment (EC 2003), addresses aspects that are relevant to dam safety, by demanding, for example, emergency plans.

Regulation of dam safety is an important factor in the prevention of disasters, and concerns not only pluvial or fluvial floods but is also an essential element in industrial operations that use tailing dams. Many countries have a long history of regulatory frameworks for dam safety (Bradlow et al., 2002). Important aspects include the legal form of the regulation, the institutional arrangements for regulating dam safety, the powers of the regulating entity, and the contents of the regulatory scheme. Historically some countries have focused on the safety aspect only, whereas others have also included dam construction, operation, maintenance, and surveillance.

The concern for dam safety has also resulted in the creation of organizations devoted to dam safety, for example, the International Commission on Large Dams (ICOLD). In many countries dams have been classified according to the hazard potential; the class 'high' generally indicates that the failure or *mis-operation* will probably cause loss of human life. Dams assigned a high hazard potential should fulfil very strict technical and hydrological criteria in their construction and maintenance. Emergency Action Plans and Early Warning Systems are necessary non-structural tools to minimize the impacts of dam failures.

6. Conclusions

To be finalised in a later stage, based on comments during member state consultation

Initial structure / initial points:

Assessing vulnerability is an extremely complicated process with a multitude of conceptual frameworks that have been proposed, yet little in the way of practical tools that can achieve an ecologically-realistic or comprehensible assessment of use to decision makers. A thematic assessment of European water vulnerability that moves beyond hazard and risk to society and includes ecosystem assessment and ecosystem goods and services will play an important part in setting the knowledge base, framing the policy need, and identifying the appropriate research required to better incorporate them into policy decisions.

Ecological concepts that relate vulnerability, resilience and adaptive capacity are nowadays gaining more mainstream consideration and coverage in the debate over how to manage freshwater ecosystems and appraise the services they provide to society. The inherent uncertainty in these complex systems of how changes to timing and flow will affect ecosystems requires a risk-based approach to vulnerability and resilience that are increasingly being adopted by climate change policy and adaptation strategies. Such assessments require identification of ecosystem sensitivities / vulnerabilities to significant pressures with the potential for causing negative shift in ecosystem structure. Key vulnerabilities can be identified when a system suffers from shocks such as episodic drought, floods, or pollution events.

European water policy – opportunities to increase freshwater ecosystem resilience

1. A holistic vulnerability assessment should go beyond sectoral considerations to encompass ecosystem services and integrated socio-environmental systems (What's available / missing?);
   - Given the knowledge gaps between ecosystem services and the hydrological cycle, given the diversity of freshwater ESS;
   - How can we decrease the Vulnerability? (Where are the opportunities for ecosystems, economy and human-being?)
2. A solid understanding of the spatial-temporal variability of water resources is an essential component in the ecosystem services assessment;
   - dynamic and complex pathways by which an ecosystem maintains a functioning state that would be referred to as a reference condition and how this can change;
   - natural hydrological variability can be an important determinant of ecosystem resilience, whereby dynamic variation in flow is essential in sustaining the ecosystem
3. Understanding effects / pressures of environmental change (climate change and direct human catchment interventions) on water resources is key for future planning;
   - Given governance issues, connecting different scales, different priorities, …
   - Where are the win-win effects (in times of budget cuts)? Can we make general recommendations for 'no regret' options?
4. Human water demand and the occurrence of extreme hydrological events (floods and droughts) are driving the vulnerability of both ecosystems as well as economic and human social systems.
   - Goods and services ecosystems provided are diminished through poor management of water resources;
   - The inherent complexity of ecological systems combined with the uncertainty concerning the impacts of climate change requires a risk-based approach to vulnerability

Repeat link to other assessments (e.g. on Water Quality and Resource Efficiency).
Repeat how this links to the Blueprint, this report on water resources / water quantity

- Link to relevant policy (mainly WFD, Floods Directive and COM WSD)
- Others are implicitly included in link to other assessments

Climate Change: White Paper on Adaptation
Land use change: incl. CAP reform
Knowledge and Research: 7th EAP, Horizon 2020

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