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Water resources in Europe in the context of vulnerability

EEA 2012 state of water assessment

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Executive summary

Water plays a central role in the functioning of the biosphere and in supporting all life. Freshwater ecosystems are particularly important, providing a unique and diverse array of services upon which human society depends. These services include 'provisioning' services, such as the provision of water for agriculture and hydropower. They also include 'regulating' services, where water helps regulate our environment, such as by flood control or the breaking down of pollutants.

If our freshwater ecosystems are to continue to provide these services it is essential that there is water in sufficient quantity and of sufficient quality. This report primarily focuses on the problem of water quantity in Europe.

Water quantity varies naturally according to the seasons, the geography of Europe's regions, and the different types of water bodies (including lakes, rivers, wetlands and sub-surface groundwater bodies). This natural variation can be seen in periodic flooding and droughts, both of which have long been a feature of Europe's landscapes. Many ecosystems, habitats and species types have evolved to deal with precisely this type of variation in the hydrological cycle.

Today's threaths to water's natural variability

However this natural cycle of water availability is now coming under threat from a variety of different pressures, exposing water ecosystems and societies to man-made shortages and excesses of water, a situation known as 'water vulnerability'.

The first major driver of alterations to the hydrological system is change in land use. The growth of urban areas has several effects on the water cycle. Urban development usually leads to soil sealing by asphalt and concrete, meaning that water cannot seep naturally into the earth. Land use change also often places pressure on existing sewage and drainage systems. These two developments mean that in periods of heavy rain water can neither seep into the ground or be carried away by sewers, resulting in flooding.

Water abstraction is another cause of water vulnerability. Agricultural land is generally better at absorbing water than urban land, but this does not mean that agriculture always protects the soil and water beneath it. In many regions of Europe, agriculture is highly dependent on irrigation. Agriculture accounts for 33 % of total water use in Europe, and this dependence on water can reach up to 80 % in parts of Southern Europe. Usually, the periods of peak demand for irrigation come during the summer, when rainfall is already low and when regions are already suffering from drought.

The third main cause of water vulnerability is climate change. Climate change has a more indirect effect on water quantity than land use change or abstraction. Its effects are also more difficult to discern given the natural variability in the hydrological cycle. Nevertheless, the effects are increasingly visible. Since 1880, the average length of summer heat waves has doubled in Europe. It is predicted that climate change will exacerbate the frequency and severity of both droughts and floods in Europe over the coming decades. Climate change and its effects did not feature explicitly enough in the first round of River Basin Management Plans prepared by the Member States in 2009. However, the next round of River Basin Management Plans, which will be published in 2015, will consider the effects of climate change on river basins.

These human-induced changes in land use, climate, and water abstraction are combining to alter the natural 'flow regimes' that exist in water bodies. For this reason, it is important that human water use seeks to avoid creating situations of water vulnerability. We can do this by respecting the local 'ecological flow' — the quantity of water needed at different times of the year to maintain a water ecosystem.

Managing water sustainably — agriculture and regional policy

There are a range of different measures that can reduce water vulnerability and address the pressures currently acting on Europe's water. These measures are part of a risk management approach. Unlike a crisis approach, which seeks to deal with water-related crises when they occur, a risk management approach accepts that flooding and drought occur, but tries to mitigate their effects with preventive action. These risk management measures must view water as a resource to be managed in an integrated fashion, bringing together all aspects of water management and policy areas that have traditionally been considered as separate. Preventive measures can decrease the impact of floods, droughts, or insufficient water quality, and mostly do so at a lower societal cost compared to a crisis approach that focuses on response and recovery actions to limit damage during and after an event.

For example, agriculture is a major contributor to water abstraction, but we have not yet fully taken advantage of the synergies between water policy and agricultural policy. The CAP reforms currently under discussion propose to make receipt of certain agricultural subsidies contingent on meeting objectives in the Water Framework Directive, a measure known as 'cross compliance'. If these proposals are implemented and strengthened, they can lead to a significant decrease in agricultural pressures caused by water abstractions or hydromorphological changes. Other agricultural measures that can support sustainable water management include the cultivation of crops that require less tillage, or crops that can be sown earlier in the year to take advantage of early spring rain.

Regional policy is another sector that can benefit from integrating a water management perspective. Regional policy — including the EU's cohesion policy — is potentially a very powerful tool to influence decisions on land use and changes in land use, one of the main causes of water vulnerability. Together with development policy, regional policy can favour changes in land use that introduce natural water retention measures (NWRMs) to our landscapes. Natural water retention measures aim to safeguard the landscape's natural storage capacity by restoring or enhancing the natural characteristics of the water body. NWRMs include the restoration of wetlands, increases in forest cover, and enhancements of the natural features of floodplains. In cities, NWRMs include sealing surfaces with permeable materials or creating areas of unsealed land where water can seep to the ground. Many of these natural water retention measures are already cost-effective in that they are cheaper to implement than dealing with the effects of flooding or drought. Any future climate change scenario will only make the implementation of NWRMs even more cost-efficient.

Managing water sustainably — innovation, economics and information

Measures to encourage water efficiency are critical. New technology can play an important role, allowing for more efficient daily water use in the home, in industry, and on farms.

But efficiency on its own is not enough. Often, gains in efficiency are cancelled out by changing styles of consumption, a process known as the rebound effect. For example, more fuel efficient cars can lead to motorists using the same amount of petrol to drive further distances. To avoid this, it is important to introduce water pricing and water metering to manage water demand.

Other economic instruments such as taxes and subsidies can help discourage water use in certain places and times, and incentivise sustainable water use at other places and times. These instruments are a necessary complement to ordinary regulation, and in addition to helping reduce water scarcity they can also help allocate water resources between competing sectors.

Perhaps most important of all in managing water sustainably is knowing at any given time exactly what water is available for human use, and what water is needed for ecosystems. That is why the creation of a system of water accounts is so critical. Like financial accounts, water accounts will help water managers to better control water resources in their area. Current water account systems are compiled largely on a country-wide basis and presented yearly. This must change to present water data in a more detailed way, at least at the level of river basin districts and preferably on the level of sub-basins. Water account data also has to be more detailed in terms of time. Instead of annual data, water accounts should be updated monthly to take into consideration the seasonal variations in water flow.

More work needs to be done to ensure that the basic scientific data that goes into providing these accounts is of high quality and comparable across countries to get an accurate picture of the conditions of Europe's water resources.

1 Introduction

Water resource management in Europe is complex, owing to the diverse geophysical, 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, 2010b). Moreover, certain areas of Europe are susceptible to flooding and subject to its detrimental socio-economic impacts. Climate change is predicted to exacerbate the frequency and severity of both droughts and floods in Europe over the coming decades (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 undertaken, driven by the State of the Environment Reporting (SoER), and supported by the European Union (EU) and other international organisations. These assessments have primarily focused on the states and pressures of European waters, but a recent assessment (EEA, 2011b) has shown their scope to be too narrow. A shift in focus towards management and measures is called for.

Within the EU, there has been a gradual shift in water policy away from simply addressing human health or economic damage concerns, and towards a more holistic understanding of the environmental impacts of water users, and addressing the needs of the environment. This is epitomised in the adoption of the Water Framework Directive (WFD) (Directive 2000/60/EC (EC, 2000b) and its emphasis on 'good ecological status' (GES) or 'good ecological potential' (GEP). However, while the legislative framework is deemed adequate, fundamental weaknesses in implementation, and a need for better integration 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, also known as simply 'the Blueprint'). Historically, there have been few attempts to assess the vulnerability of European waters to future change when assessing the potential impacts of climate change on freshwater resources. However, this issue has notably been a key focus of the Intergovernmental Panel on Climate Change's (IPCC) Climate Change and Water Technical Paper (Bates et al., 2008), and more recently, the IPCC special report on managing the risk of extreme events (IPCC, 2012).

Environmental flows as a means of establishing sustainable boundaries for 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 that between the WFD and the Floods Directive (Directive 2007/60/EC) (EC, 2007b). 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 also requires some planning for an uncertain future. Incorporating the connectivity that exists between society and ecosystems into the uncertainty surrounding climate change will require policy decisions that place greater emphasis on risk and vulnerability assessment in planning activities.

1.1 Why a thematic assessment on vulnerability

Europe's water bodies are affected by several pressures, including water pollution, water scarcity,droughts, floods, inundations, and major modifications of water flow and morphology. The presence of a whole range of pollutants originating from many sources like agriculture, industry, transport, and households threatens aquatic ecosystems and raises concerns for health. In addition to pressures on water quality, structures built for hydropower, navigation, irrigation or flood protection physically changed European watercourses, and have potential adverse ecological consequences for many European rivers.

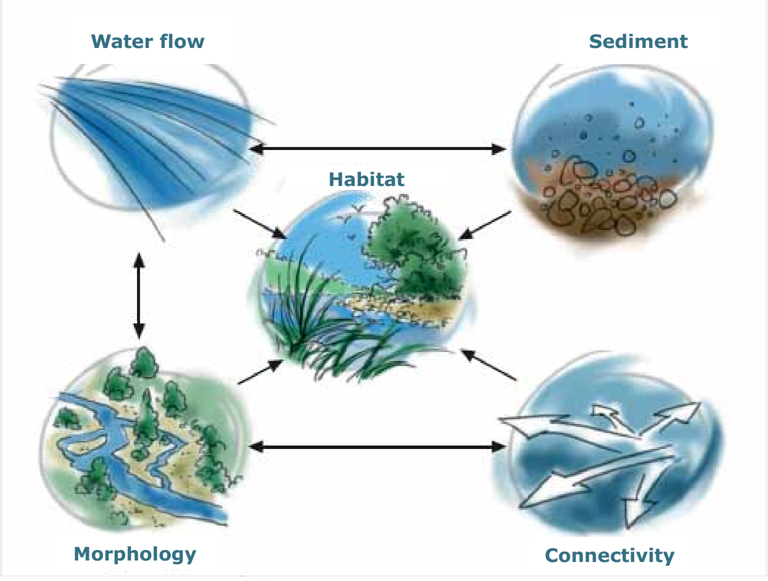
Water management in Europe is a complex task. Diverse geophysical, climatic, socio-economic, and policy realities exist across the different countries. There are numerous challenges to attaining the WFD objectives (EC, 2000b (Art. 4)) and the EU response is to provide a range of policy options to be embedded in the 'Blueprint to Safeguard Europe's Water Resources'. 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 achieve this ambitious objective by synthesising 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 overall EU water policy.

Hydromorphology

Europe's waters have been identified as being vulnerable to a diverse set of anthropogenic pressures (EEA, 2012a). For a very long time, centuries in some cases, surface waters in Europe have been altered by human activities like straightening and canalisation, disconnection of flood plains, land reclamations, dams or bank reinforcements. This enables different functions including agriculture, urban development, energy production or protection against flooding, but it changes the morphology and hydrology of the water bodies, together referred to as hydromorphology changes. The results are altered habitats with an impact on the status of the aquatic environment. Figure 1.1 illustrates how, together, water flow, sediment, morphology and connectivity define the freshwater-dependent habitat.

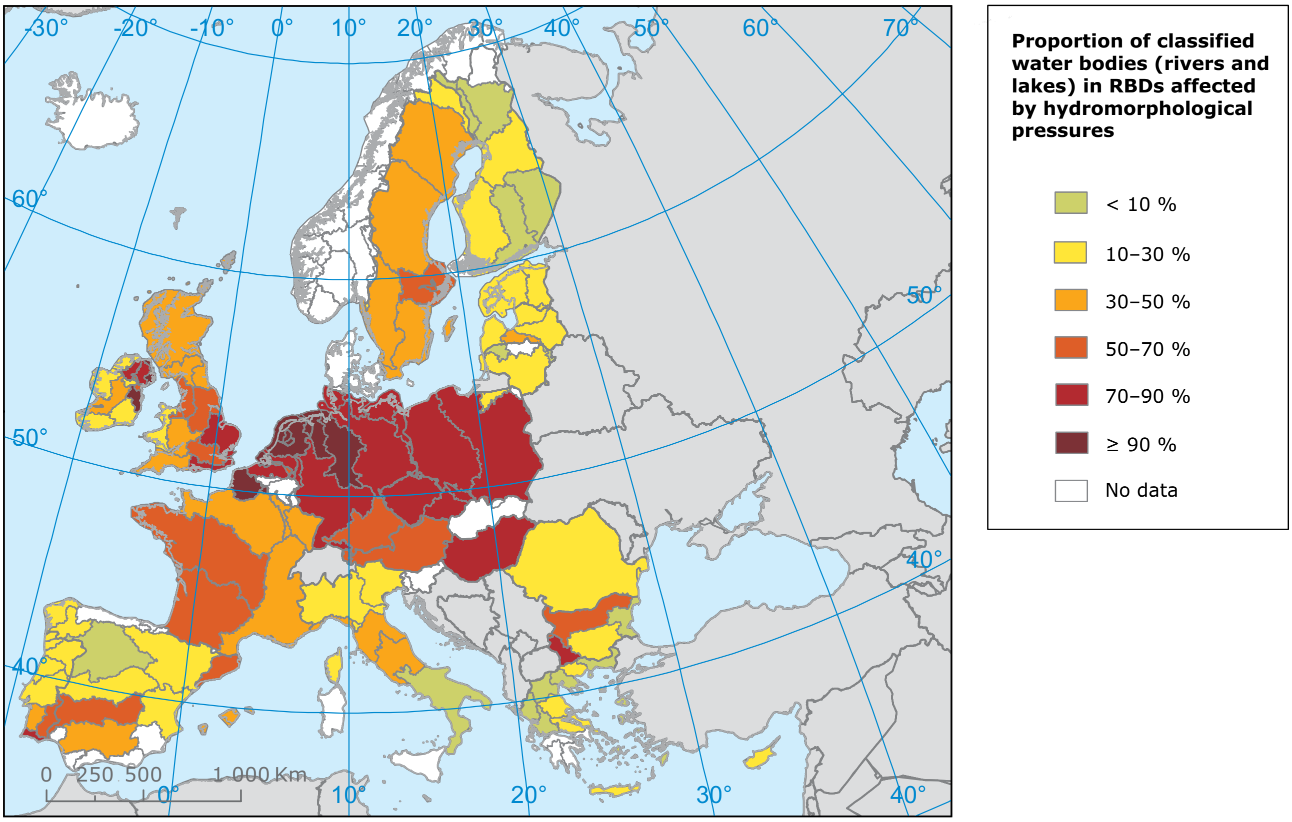
The WFD is the first environmental legislation on the EU scale where the impact on water bodies from hydromorphological modifications is addressed. These comprise all physical alterations of water bodies that modify their shores, riparian and littoral zones, water level, and flow. These modifications are the most commonly occurring pressure and impact on rivers, lakes and transitional waters in Europe. They affect over 40 % of rivers and transitional water bodies and one third of the lake water bodies (Map 1.1). Despite excluding streamflow alteration, almost half of the Swiss watercourses are to some extent affected by eco-morphological pressures (FOEN, 2011). If a waterbody has a degraded or largely changed morphology, it will not achieve its full potential as a habitat for wildlife, even when the water quality is good.

Figure 1.1 Relationship between habitats and hydrology (water flow), morphology, connectivity and sediment processes



Source: Redrawn from France Hydromorphology/Bourdin et al., 2009.

Map 1.1 **Proportion of classified water bodies (rivers and lakes) in RBDs affected by hydromorphological pressures**



Note: Based on WISE-WFD database, May 2012.

Source: EEA, 2012a.

Ecological status

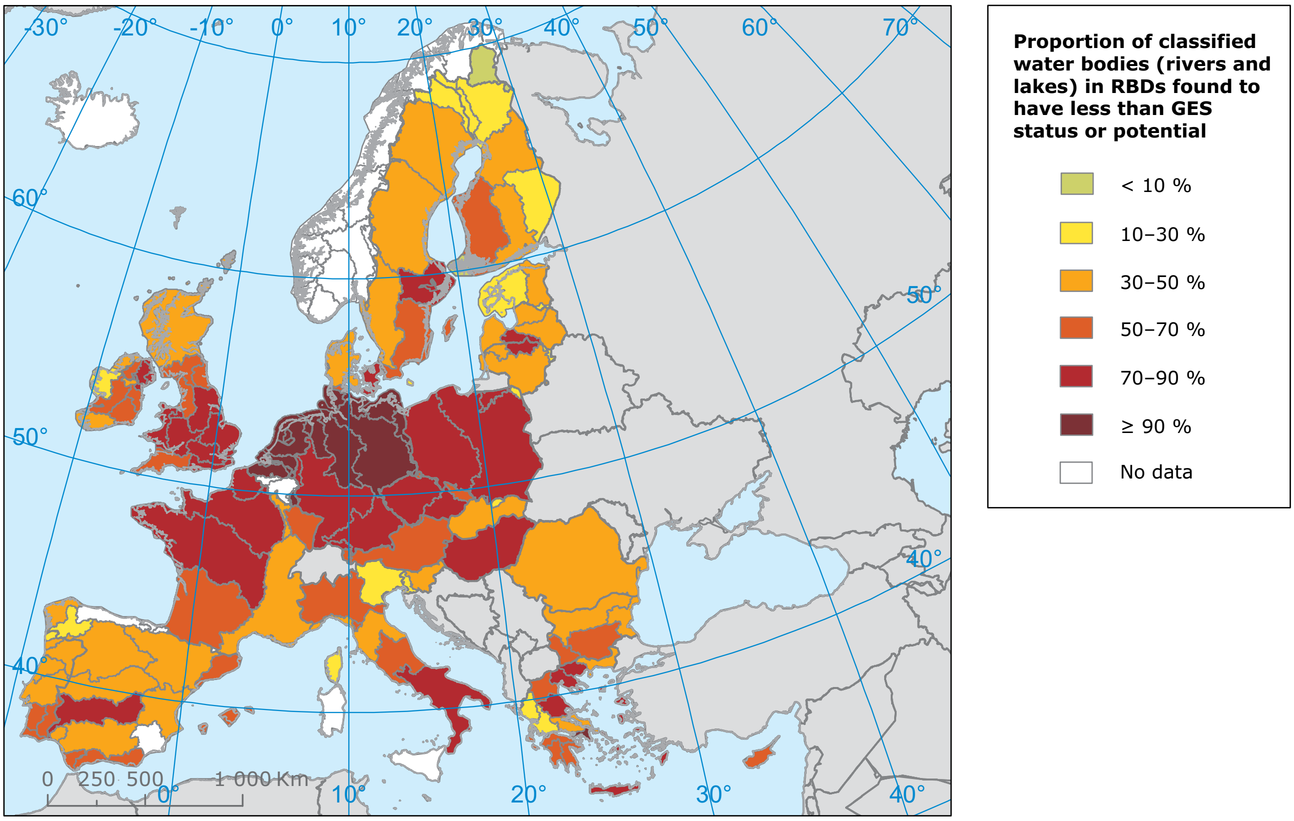
In addition to hydromorphological changes, more than half the surface water bodies in Europe are reported in the first-cycle RBMPs as not meeting GES or GEP, requiring mitigation measures in order to meet WFD objectives (Map 1.2). The main pressure responsible for this is diffuse pollution causing nutrient 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, 2012a).

In general, the worst ecological status or potential is reported in north-west Europe, where up to more than 90 % of the water bodies are in bad ecological status. Map 1.2 also illustrates the differences in ecological status within individual Member States. As the report on status and pressures concludes, intense agriculture and high-population density are the main driving forces for water bodies holding less than good status, consequently affecting the quality and resilience of the water ecosystems delineated within these water bodies.

Water resources

Water scarcity and extreme hydrological events in the form of droughts and floods are also contributory factors to not meeting GES and GEP, even though the WFD considers water resource aspects explicitly only in addressing good groundwater status. These water resource issues are discussed in detail in Chapter 3 and Chapter 4. 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. Drought management plans and flood risk management plans are supposed to be integrated into RBM planning so as to bring

Map 1.2 **Proportion of classified water bodies (rivers and lakes) in RBDs found to have less than GES or potential**



Note: Based on WISE-WFD database, May 2012.

Source: EEA, 2012a.

resource aspects as far as possible into the WFD. The Blueprint process will develop further policy guidance to implement resource aspects most effectively in the future.

More about resource-efficient technologies, economic instruments and the water–energy nexus can be found in the report *Towards efficient use of water resources in Europe* (EEA, 2012e). The current report focuses on the drivers of climate change and land use changes, and more specifically, their effect on floods and water scarcity. It builds on earlier EEA reports describing the state of Europe's water resources and the pressures they face (EEA, 2009, 2010b and 2011a).

1.2 Water quantity policies

EU water policy as formulated in the WFD is based on the objective of achieving good status for all EU waters by 2015. It examines in detail chemical and biological status, as well as changes in hydromorphology — expressed as ecological status. Except for groundwater, the WFD is not explicitly 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 its requiring environmental flow boundaries to sustain freshwater ecosystems.

In 2007, with the Floods Directive (EC, 2007b), 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. As in the Floods Directive, flood risk prevention for Switzerland includes preliminary flood risk assessment and hazard mapping by 2011. It also includes the promotion of a modern flood-protection policy with the aim of: ensuring adequate protection of areas vital to human livelihoods and economic development; limiting economic damage by means of a comprehensive prevention strategy; improving the handling of uncertainties and residual or remaining risks; and finally, understanding rivers and streams as essential linking elements in landscapes and nature (BWG, 2001).

The Floods Directive refers explicitly to the WFD for its contribution to mitigating 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 RBMPs 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 with regard to the environmental objectives of the WFD. To make coordination between the directives feasible, reporting timelines are aligned.

In 2007, the European Commission published the Communication *Addressing the challenge of water scarcity and droughts in the European Union* (EC, 2007c), which addressed the main challenges together with recommendations. They are grouped into seven categories: water pricing; allocating funding; drought risk management; water supply infrastructure; efficiency; water-saving culture; and knowledge and data. Several of the economic issues mentioned are dealt with in the EEA report *Towards efficient use of water resources in Europe* (EEA, 2012e). These include putting the right price on water; fostering water-efficient technologies and practices; fostering the emergence of a water-saving culture in Europe; and following measures to reduce demand, considering additional water-supply infrastructure. Other aspects are assessed in more detail within this publication. Mindful of the increasing importance of water scarcity risks, the Commission is developing the 'Blueprint to Safeguard Europe's Water Resources' in 2012. This policy process combines the review of: the WFD; the water scarcity and droughts (WS&D) policy; and the water-related part of the climate change vulnerability and adaptation policy into one review, and develops coherent approaches for water resource–related aspects in European policies.

The Blueprint includes a discussion on the right knowledge base for water resource management and promotes water accounts and detailed knowledge of water balances. In order to ensure that water is sustainably managed, water managers need to know the total amount of water that is available as well as the amount of water needed by the different users of water and by the environment itself. Another particularly important aspect for sustainable water management is land use planning, which together with climate change is considered one of the main drivers of increasing droughts and water scarcity. Changes in land use patterns and their effect on the hydrological cycle are also discussed in Chapter 3.

1.3 Report structure and the 2012 water assessments

This report constitutes one part of a series of thematic assessments that the EEA is publishing in 2012 to support discussion and development of the 'Blueprint to Safeguard Europe's Water Resources'. In 2012, the EEA produced three thematic assessments, as well as an overarching synthesis report on the 2012 state of Europe's water: 'Europe's water resources: Current Status and Future Challenges' (EEA, 2012b). The thematic assessments are:

1. *Towards efficient use of water resources in Europe* (March 2012) (EEA, 2012e);
2. *European waters — assessment of status and pressures* (November 2012) (EEA, 2012a);
3. *Water resources in Europe in the context of vulnerability* (this report).

In addition, a number of technical background reports were produced with the European Topic Centres (ETCs). Those related to this report are:

1. *Floods — vulnerability, risks and management* (EEA ETC/CCA, 2012);
2. *Vulnerability to Water Scarcity and Drought* (EEA ETC/ICM, 2012a).

Other reports contain more detailed information and results of the assessment of information from the RBMPs:

1. *Ecological and chemical status and pressures* (EEA ETC/ICM, 2012b);
2. *Hydromorphology* (EEA ETC/ICM, 2012c).

In this thematic assessment on vulnerability, Chapter 2 outlines a framework for assessing freshwater vulnerability and the resilience of ecosystem services — presenting the terminology and background science, and exploring their importance through examples. The approach of combining hazards and vulnerabilities in risk management is extended by considering concepts of ecological resilience and vulnerability, and their role in an ecosystem-based approach to water management.

Chapter 3 focuses on the pressures, state and outlook of Europe's freshwater, especially in terms of the 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 Chapter 4, the economic, social and ecological impacts of floods, water scarcity, and droughts are discussed. It deals with demand- and supply-side management strategies and presents potential categories of measures for sustainable water quantity management.

2 Freshwater ecosystem services and their vulnerability

This chapter of the report will identify key European freshwater ecosystem services (ESS), and seek to explain why a thematic assessment of vulnerability is needed for Europe's freshwater ecosystems and how this contributes to the preparation process for the 'Blueprint to Safeguard Europe's Water Resources'.

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

This chapter 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. The aim is to explore in detail the diversity of different concepts and applications that can exist across scientific and social science disciplines, but to 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 examines relevant pressures for water resource management and how these affect freshwater ecosystem services.

2.1 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. This section outlines the key ecosystem services that freshwater systems provide and explains how these are increasingly under threat.

2.1.1 What are (freshwater) ecosystem services?

Ecosystems provide valuable goods and services that have a significant, yet often undervalued, contribution towards continued human well-being, development and economic security. In many instances, this contribution cannot be replaced. Attempts at valuing these services at a global level (Costanza et al., 1997) have produced economic valuations in excess of global gross national product.

The goods and services of ecosystems, referred to as ecosystem services, can be divided into four categories: provisioning services, regulatory services, cultural services and supporting services. Some of the principal freshwater services on which human development relies are listed in Table 2.1. Both aquatic and terrestrial ecosystems require adequate freshwater resources and flows to maintain physiochemical processes and functions, species, and communities (Acreman and Ferguson, 2010).

The ecosystem services that both the aquatic and terrestrial ecosystems provide are thus dependent upon the flow of freshwater to and between these environments. Human regulation of the water environment and water resource development has affected the ability of many freshwater and terrestrial systems to function, and this pervasive alteration is contributing to significant biodiversity loss, and degradation of the goods and services that these systems provide (Poff et al., 2007).

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'. Maintaining this flow of natural capital is only as sustainable as the ability of ecosystems to regenerate following the extraction

Table 2.1 Freshwater-related ecosystem services

Provisioning services	**Examples**
Food	Fish, agriculture
Fresh water	Retention of water for domestic, industrial and agriculture
Wood and fibre	Wood for fuel and building, peat, fodder
Fuel and Energy	Hydropower
Biochemical	Medicine and materials from biota
Genetic material	Genes for resistance to plant pathogens
Regulating services	
Climate	Cooling effect of water
Hydrological flows	Groundwater recharge
Natural hazards	Flood control, storm protection
Purification	Dissolving substances
Disease control	Breaking down waste
Cultural services	
Spiritual	Religion, inspiration, health
Recreation and ecotourism	Recreational activities, social events
Aesthetic	Structuring the landscape
Supporting services	
Primary production	Aquatic and terrestrial biota
Sediment and nutrient transport	Distribution of nutrient rich sediments

Note: List contains important ecosystem services without being exhaustive.

Source: Adapted from Millennium Ecosystem Assessment, 2005; Blumenfeld et al., 2009 and Boelee et al., 2011.

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, 2005). 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 green economy is at the core of ensuring both resilience and efficiency and in this sense is faced with the dual challenge of (EEA, 2012g):

- 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).

Several of the EEA's reports in 2012 dealt with the resilience of freshwater-dependent ecosystems. While water quality aspects and hydromorphology are the main aspects defining the status of water bodies as defined by the WFD (EEA, 2012a).

This present report focuses on the quantitative volumes available for the environment. It assesses in more detail the more extreme situations in terms of water quantity — water scarcity, drought, and floods —in terms of the current situation and in relation to climate change and land use pressures. More about improving water resource efficiency can be found in other EEA reports (see the EEA (2012a) for the most recent).

2.1.2 *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). They 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, and the terrestrial and aquatic environment, as illustrated in Figure 2.1.

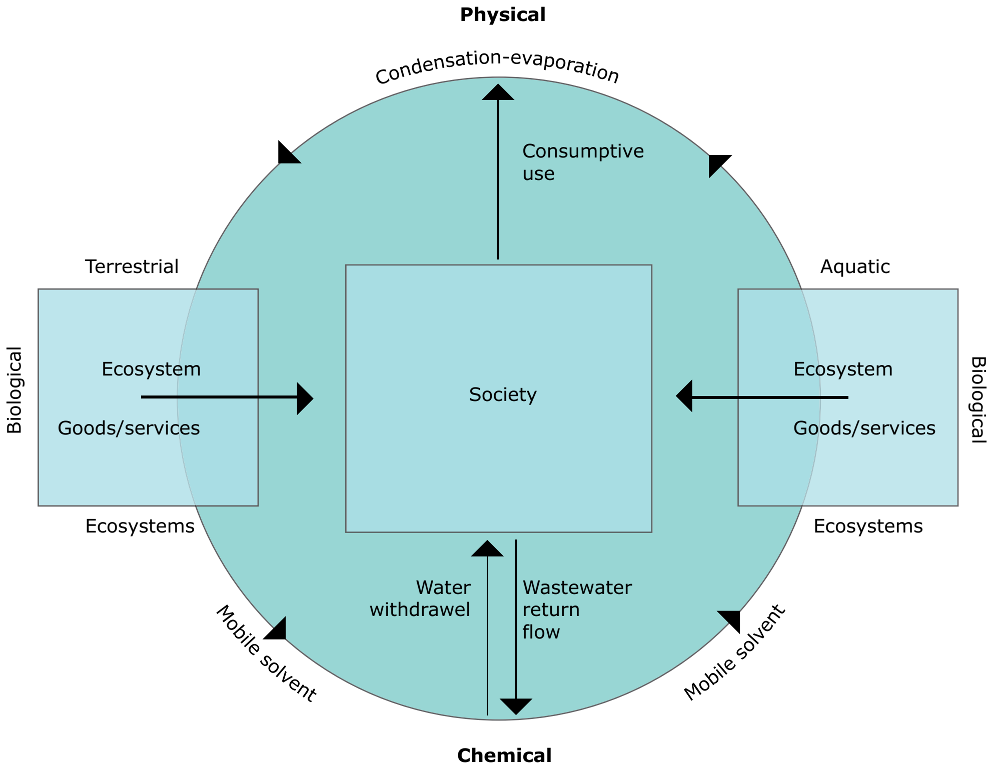
These systems are both dynamic and interacting. But given the increasing anthropogenic impacts on quantity and quality the fluxes cannot be maintained and are changing in volume and quality. This leads increasingly to negative impacts for the natural environment and the ecosystem services society depends upon (Poff et al., 2007).

2.2 Vulnerability, resilience and thresholds for managing for variability

The preceding section introduced the concept that anthropogenic disturbance of natural ecosystems can significantly affect the ability 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. The high level of natural hydrological variability like seasonal changes in flow, or extreme hydrological events such as floods and droughts play an important role in renewing and sustaining higher ecological functioning (Poff, 2009). Anthropogenic disturbance of such natural variability (for instance by abstraction for agriculture or regulation of flows by the construction of dams) might create more static environmental conditions, thus reducing the vulnerability of human populations to extreme hydrological events. But the vulnerability of the natural environment to such shocks can be increased by such measures. This can have repercussive impacts upon the 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', in line with the specific context. For example, the United Nations International Strategy for Disaster Reduction (UNISDR, 2009) 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 IPCC 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

Figure 2.1 Schematic illustration of water as the 'bloodstream' of the biosphere



Source: Falkenmark, 2003.

Box 2.1 Habitat rehabilitation in the Lower Danube River and Danube Delta

Photo: Drought damages Danube © Alexander Ivanov

The Lower Danube has remnants of floodplain forests and many well-preserved wetlands. The big hydropower dam at the Djerdap Gorge (Iron Gate), about 200 km downstream of Belgrade, Serbia created a reservoir with a volume of 3 200 cubic hectometres (hm^3). The reservoir serves as an important sink for nutrients and hazardous and toxic pollutants. The different ecosystems, created by cut-off oxbow lakes, flood channels, depression inlets, and remnants of wetlands are ecologically important with many endangered habitats and species for both flora and fauna in the Lower Danube and in the Danube Delta. Almost 30 million people are dependent on the river and its basin for drinking water, flood protection, income, industrial production or recreation.

The construction of the hydropower dam means that almost 75 % of the large floodplain of the Lower Danube was cut off from the river system and mainly transformed into fish ponds and drained agricultural land, reducing floodplain functions and typical habitats. The ability to protect the surrounding area against floods and droughts was partly lost, as was unfortunately demonstrated during the floods of 2005 and 2006 or the low discharges in 2011 (see photo).

The Danube River Protection Convention (ICPDR 1994), agreed in 1994, and the Lower Danube Green Corridor Agreement, signed by the governments of Bulgaria, Moldova, Romania and Ukraine in 2000, commits these governments to preserve large remaining areas, restore large areas of wetlands, and promote sustainable development along the Lower Danube. An important lesson learned in this process is that the protection of individual, separated high-quality reserves does not ensure provision of ecological functions over the long term. Only a sustainable ecological restoration including the full green infrastructure along the whole river results in improved wetland function, together with improved socio-economic functions and benefits for people and nature.

Source: Contribution by Gunilla Björklund, GeWa Consulting, Uppsala (Sweden) for UNEP (2009).

and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2008). Vulnerability in this report does not refer to a specific definition or concept; the term is intentionally applied in a more generic way (EEA, 2012c; EEA, 2012f) (see also Figure 2.2).

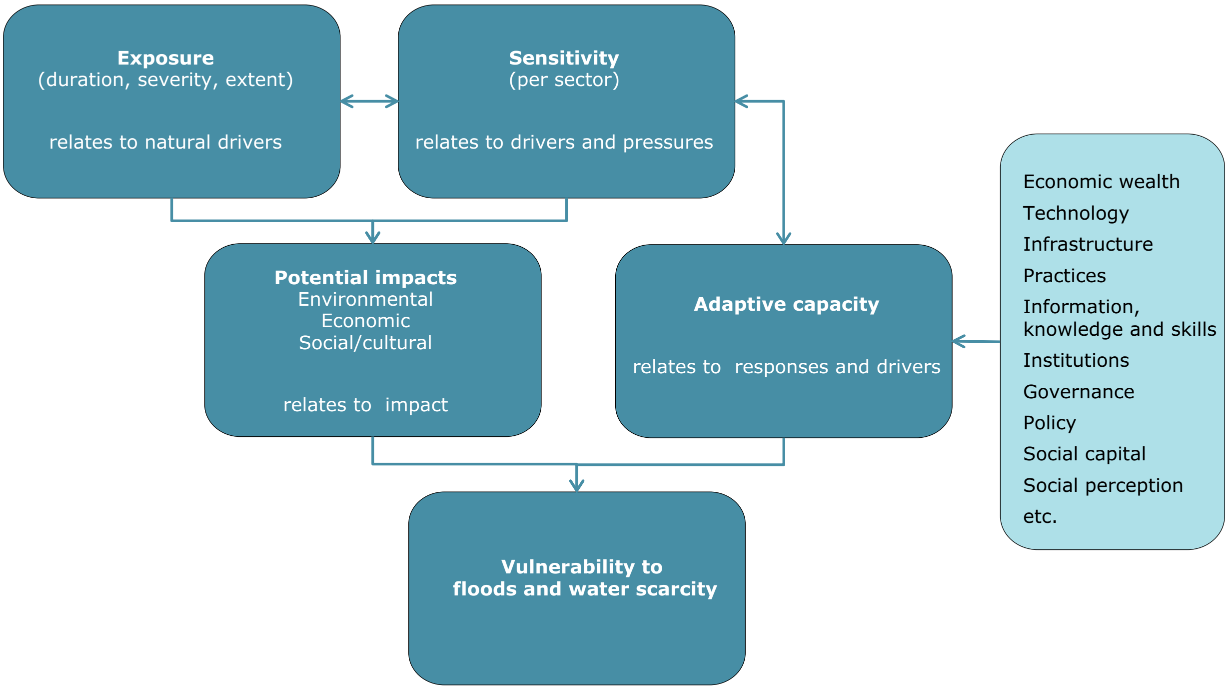
In the same way, 'resilience' — in more generic terms — is described as the ability of a socio-economic or ecological system to resist disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change (EEA, 2012f).

2.2.1 *Socio-economic vulnerability and resilience*

The transformation of natural systems in order to improve socio-economic development often has 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 interdependent, 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 viewed as being a function of 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 a 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,

Figure 2.2 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; and Uyttendaele et al., 2011.

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 systems to adapt to and even shape change (Walker et al., 2004).

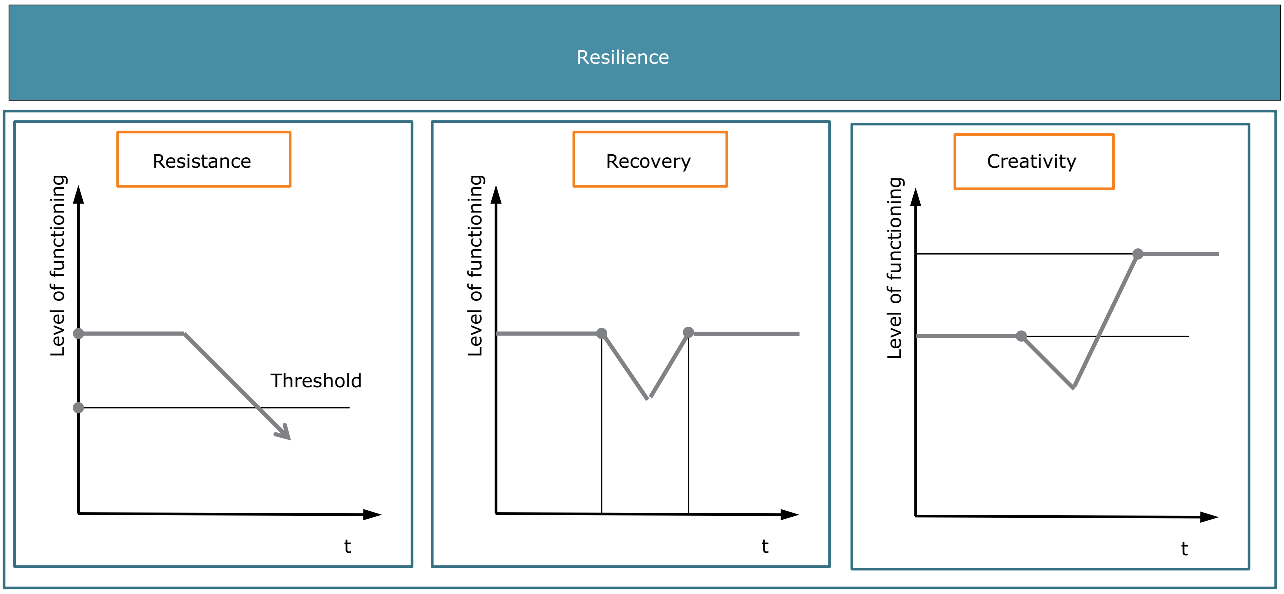
Based on the work of Adger (2000), the variable components that define the resilience concept are illustrated in Figure 2.3. Early definitions employed the measure of resistance to denote the degree of disruption the system can tolerate before a significant change past a threshold takes place. The inclusion of 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.

2.2.2 *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 their function and remain in a stable state. Ecological resilience denotes the capacity of an ecosystem to withstand disturbance without changing self-organised processes (Gunderson, 2000). The terms 'resilience', 'vulnerability', and 'adaptive capacity' to describe the response 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 disturbances 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

Figure 2.3 The components of resilience



Source: FREEMAN project, in Uyttendaele et al., 2011; CRUE Flooding ERA-Net, 2012.

state occurs (Gunderson, 2000). A certain amount of caution should be exercised in interpreting this equilibrium state: it is not GES as used under the WFD, as the environment could already have been significantly affected and thus already be in an altered stability domain. The biological status, however, can be taken a useful proxy (Box 2.3). Folke (2003) illustrates in Figure 2.4 how humans can drive a decrease in resilience that ultimately leads the ecosystem into a different state, termed a '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 overexploitation of predators causes the system to shift to a turbid eutrophied water state.

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

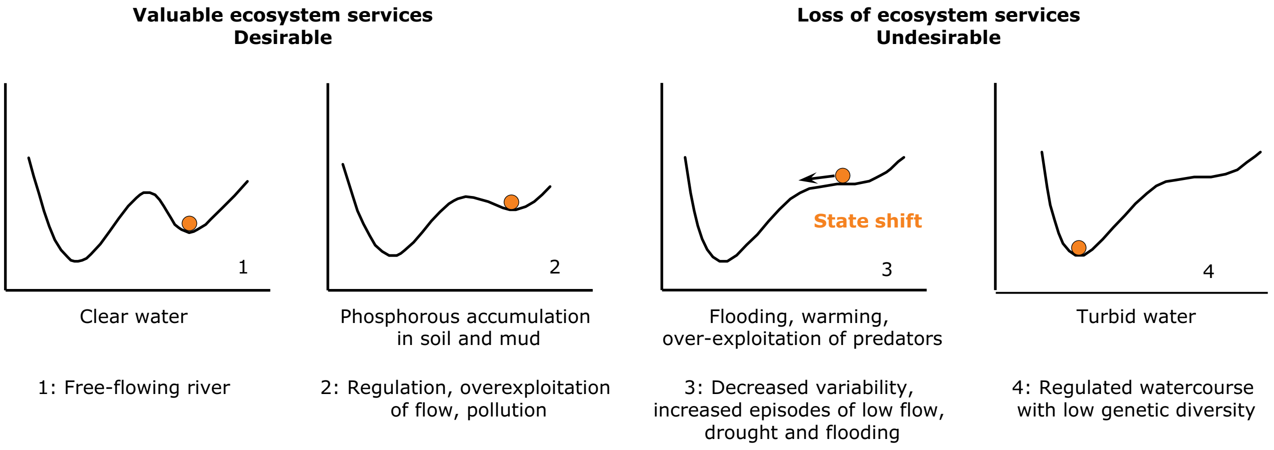
Box 2.2 Flooding in Athens (Greece)

The intense development of the wider Athenian urban complex led to the degradation of many tributary streams, with the Kephisos River being the most important (Evelpidou et al., 2009). Although the river still drains 70 % of its natural catchment, it suffered much due to a significant decrease in its width as a result of illegal dumping and illegal construction/industrial development on its banks and in the riverbed. Furthermore, due to its topography (steep slopes) and climate (intense, short-duration rainfall) Athens is often subject to flash floods. This increases risk, particularly in view of its significant population density. 3 million people live within the 300 km^2 catchment of the Kephisos River, where almost 150 significant flood events have been reported between 1887 and 2007 (in which more than 250 people died, and with damage estimates in the order of hundreds of millions of euro).

The implementation of flood management measures in Athens in the 1990s resulted in a small decrease of flood risk in some upstream areas, but did not manage to eliminate the main problems close to the Kephisos. Furthermore, the continual urbanisation of the eastern suburbs and the coast increased flood risk in new areas (Kandilioti and Makropoulos, 2011).

Despite improvements in emergency planning, flood protection and awareness raising, catastrophic events — including loss of life — could happen again (Papathanasiou et al., 2009). This is because major flood management interventions dealing with the problem in an integrated way (see also Chapter 4) in the main urban rivers are still pending. However, community hubs such as the Kephisos River Managing Authority are attempting alliances at local level (between local authorities, business and general public initiatives and pressure groups) to raise the profile and reveal the true nature of the problems, pushing for control of illegal activity coupled with the economic and environmental regeneration of the area.

Figure 2.4 Shifts between states in lakes, from human-induced reduction of resilience



Note: The figure uses the ball-and-cup model 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).

Source: ETC/ICM, based on Folke, 2003.

system becomes overexploited and regulated to meet anthropogenic demands, natural variability is removed, flow is reduced, and pollution events become more regular and less diluted. Such changes erode the system's resilience to further disturbance. 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). This is reflected in reduced species diversity and loss of habitat.

The flow regime and the fluctuations in water levels, as well as the natural retention capacity, are a major determinant for ecosystem functions and services in rivers, lakes and the adjacent wetlands and ox-bows. There is the — sometimes large — natural variation in flow regimes to which the riverine systems and wetlands have adapted.

However, alongside these natural variations, many European rivers have flow regimes that are more affected by the various economic users. Water flow and water level regulation depends on use. Irrigation and storage for public water-supply reservoirs generally store water during wet seasons and release it during dry seasons. Downstream of hydropower plants, the flow can fluctuate on a daily basis, due to increased water volumes through turbines when electricity demand is high. When the major objectives of the water regulations are recreation or navigation, the regulated water levels are often more stable than the natural ones.

2.2.3 *Environmental flows and natural variability*

Ecologists now better understand how flow regime and natural variability, especially the extremes in the 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 now considers whole ecosystems containing diverse species with variable flow preferences, sustained by a dynamic flow regime (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 (Poff and Zimmerman, 2010). This variability, however, must be balanced against the requirements for society to be protected against the most extreme events (social vulnerability), something that will not always be possible through more 'soft' interventions. But reducing human vulnerability to floods through 'hard engineering' options like dams, dikes or channelisation could lead to a reduction of ecosystem functioning (e.g. flow regulation, loss of floodplain connectivity and retention capacity). A shift in mindset is required that moves management interventions away from this hard-engineered control in all situations, and towards an acceptance that change is inevitable (Folke, 2003) and that variability can be beneficial.

Despite some progress in dealing with pressures on European freshwater ecosystems, multiple

Box 2.3 Change in ecological state — eutrophication of rivers

The increase 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 on the communities that depend on freshwater from affected sources. Our current understanding of lake systems locates the predominant cause of the shift from macrophyte- to phytoplankton-dominated systems in 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, there is in fact a lack of evidence in short-retention–time rivers. 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 can range from a clear flowing river containing tall submerged plants; through to a river with a dominance of floating leaved plants, and emergent plants: before finally becoming a river with high nutrient loading dominated by filamentous algae. 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. It also highlights the difficulty in pinpointing how exactly such a system will respond to anthropogenic disturbance, and what essentially constitutes a loss of resilience. For a better illustration of these changes, see Hilton et al. (2006).

stressors produce a combined impact on freshwater biodiversity. In particular, severe flow modification plays a major role in degrading ecosystem integrity through different pathways. For example, low flows strongly influence water quality, diminishing the river's ability to dilute pollutants.

Maintaining the environmental flows that provide freshwater ecosystem services is an essential element in preserving biodiversity and ensuring resilience towards 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 nature's requirements if the goal of integrated water resource management is to be realised (Bernhardt et al., 2006).

This suggests that flow regime is a relevant factor when recovering freshwater biodiversity and in achieving GES under the WFD. Proper flow regimes improve the health of ecosystems by providing suitable habitat conditions, securing the protection of native species and improving the ecological status of water bodies. In addition, these positive effects will influence the range of ecosystem services provided, either as new emerging services, or by avoiding their degradation.

Environmental flows and the WFD

Such flow requirements as central quality elements for ensuring a good, healthy ecosystem are in line with the philosophy of the WFD and its objective of GES (EC, 2000b). This is despite the fact that the WFD does not explicitly use the term 'environmental flows'. However, a key issue in actually achieving such ecologically (acceptable) flows is how they are defined and implemented. In this sense, 'environmental flow' and 'ecological flow' can and should be used as synonyms.

In the WFD, the list of quality elements for each surface water category are divided into biological, hydromorphological, chemical, and physical-chemical elements. The hydrological regime is part of the hydromorphological quality elements, as a relevant variable affecting ecological status.

With the WFD, new and broader ecological objectives came into place to protect and — where necessary — restore the structure and function of the aquatic ecosystems, while at the same time safeguarding the sustainable use of water resources. The hydrological regime is part of the hydromorphological quality elements of the WFD, as a relevant variable correlated with many physical-chemical characteristics critical for preserving the ecological integrity of aquatic ecosystems (Poff et al., 1997). But the hydrological regime is equally relevant in the good quantitative status and water resource management attached to it, for instance when setting up drought management plans.

The 'Blueprint to Safeguard Europe's Water Resources', published by the Commission in autumn 2012, puts particular focus on the development of

Box 2.4 Implementation of environmental flows in Spain: a nexus between the BHDs and the WFD

The Spanish Water Laws (RDL 1/2001; L11/2005) assure environmental flows, understood as 'those that maintain, at least, the fish assemblages that naturally inhabit or would inhabit the river, and its riparian vegetation'. The objective of determining and managing environmental flow regimes is to sustainably maintain the functionality and structure of the aquatic ecosystems as well as the associated terrestrial systems.

Environmental flows are defined for over 400 water bodies based on the temporal distribution of minimum and maximum flow, the maximum rates of change, and the flood regimes. Hydrological methods are used for the analysis of monthly minimum flows, and are combined with hydrobiological methods to define the habitat suitability for target species. Annex II and Annex IV of the Habitats Directive (Directive 92/43/EEC) (EEC, 1992) are used to select the target species, where priority is given to those in peril or extinction, those sensitive to habitat alteration, those vulnerable, or those of special interest.

In a Mediterranean country like Spain, methods had to be applicable on temporary, intermittent, and ephemeral rivers as well. In case of extreme drought, some changes in the environmental flow will be accepted. But water management must still be developed progressively; avoid any unrecoverable alteration of the aquatic ecosystem; and be in line with the procedure in the Drought Plans that exist for all basins in Spain. In protected areas, the only exception that can be made is when human supply is at risk.

Source: CEDEX Spain in Magdaleno Mas, 2010.

sustainable water resource management and gives recommendations on how to better implement current policies to ensure good quantitative status of water bodies as part of the WFD good status.

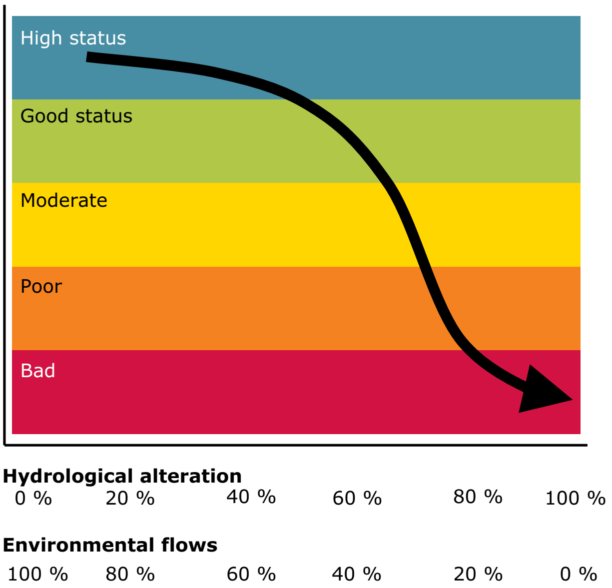
Environmental flows or ecological flows are not explicitly defined in the WFD, but GES is unlikely to be reached in a water body with significantly altered flows (Sánchez Navarro and Schmidt, 2012). Restoring a suitable flow regime can be a favoured or necessary measure for aquatic ecosystems that fail to reach GES (Hirji and Davis, 2009). And so, a hydrological regime that is consistent with the environmental objectives of the WFD is very close to the concept of environmental flows: 'Maintaining or partially restoring important characteristics of the natural flow regime in order to maintain specified, valued features of the ecosystem' (Sánchez Navarro and Schmidt, 2012).

To summarise, the theoretical relationships between the environmental flows and the classes for ecological status as defined in the WFD can be expressed as in Figure 2.5. The stress-response curve moves from a high status with no or low levels of flow modification, to bad status with high levels of hydrological alteration. For the conceptual development, see also Box 2.5.

Environmental flows in heavily modified water bodies

The category of heavily modified water bodies (HMWBs) was introduced in the WFD because many waterbodies in Europe have been subject to major physical alterations to allow navigation; flood protection; water storage for drinking water supply; electricity generation; irrigation; and recreation. The HMWB status allows the continuation of these specified uses and recognises their valuable social and economic benefits. Instead of GES, mitigation measures in the case of HMWBs contribute to achieving GEP as an ecological objective.

Figure 2.5 **Theoretical relationships between environmental flows and ecological status classes**



Source: Sánchez Navarro and Schmidt, 2012.

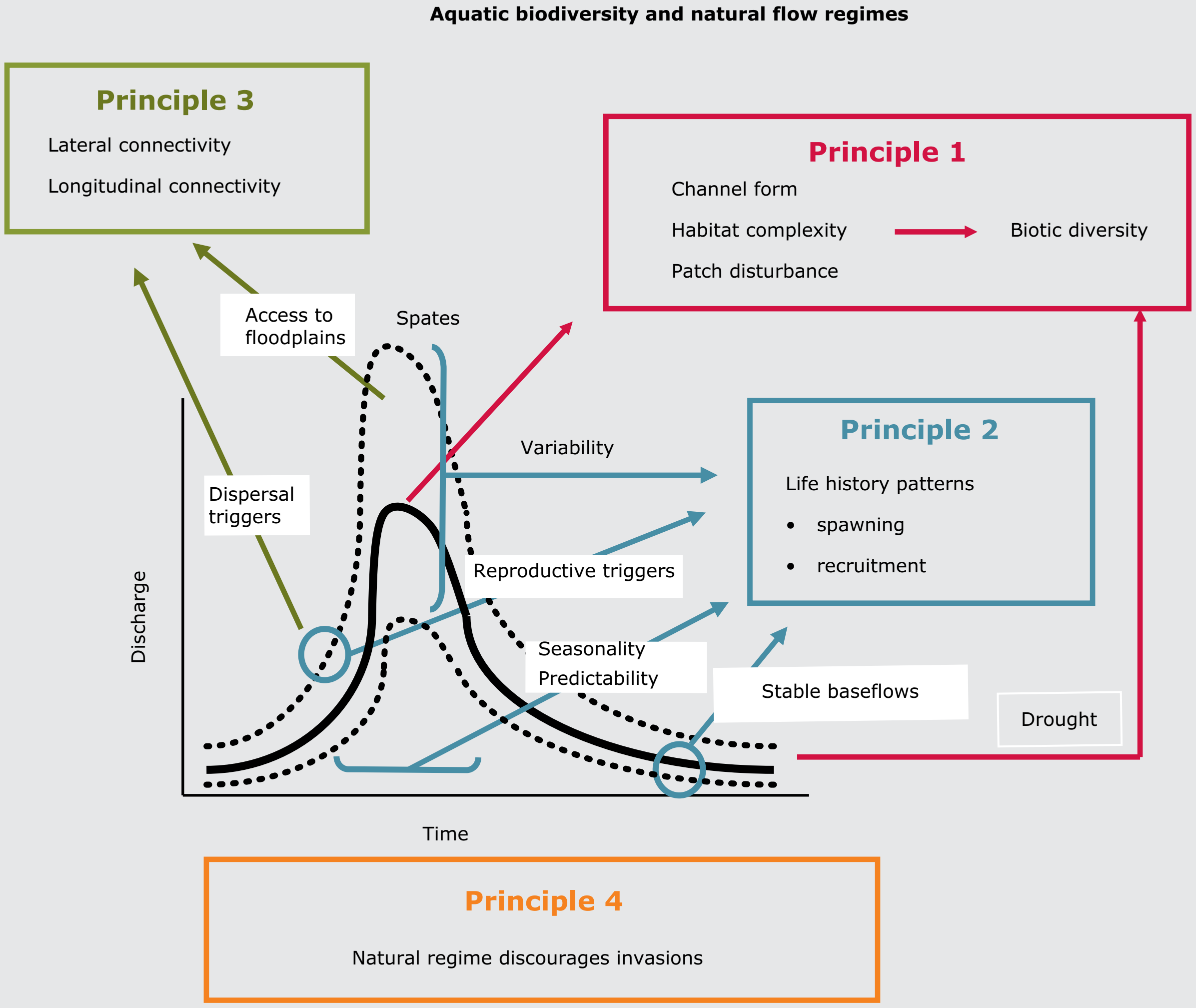
Box 2.5 Guidance on environmental flows in the WFD CIS process

Under the CIS of the WFD, water resource aspects have so far been dealt with by the Expert Group on Water Scarcity and Droughts (EG WS&D), whereas hydromorphological alterations and possible thresholds for sustainable flow regimes are discussed in respective expert workshops on the WFD and hydromorphology.

In both of these WFD processes, the so-called 'environmental flows' — water security for ecosystems — should play an important part, since they are understood as the quantity, quality and timing of water flows needed to sustain or restore freshwater, estuarine and near-shore ecosystems and the services they provide (EEA, 2012e).

However, environmental flow is a complex concept that has evolved in recent years. Current knowledge in this topic shows that the structure and functioning of aquatic ecosystems is largely affected by different kinds of flows (Figure 2.6) that vary throughout hours, days, seasons, years and longer (Poff et al., 1997). This has led scientists to reconsider environmental flow recommendations discussed so far in the context of water policies. Scientists now suggest that these recommendations no longer focus on invariant minimum flows and instead focus on natural variability (e.g. including high flow events and seasonal flows).

Figure 2.6 Key principles to highlight the importance of the natural flow regime



Source: Bunn and Arthington, 2002.

Box 2.5 Guidance on environmental flows in the WFD CIS process (cont.)

Determining the water needs of aquatic ecosystems is challenging, even when starting from a well-defined concept. Some authors have noted that there is an apparent gap between present recommendations involving flow thresholds and the ecological response of the ecosystem. Assessments mainly focused on fish species should be supplemented with new ecosystem components (e.g. vegetation or invertebrates). Studies on the water requirements of lakes, wetlands and groundwater-dependent ecosystems are still limited, despite their importance for providing ecosystem services and the hydrological connectivity that exists between them. Including environmental flow implementation is challenging when considering the specific conservation objectives of water bodies (e.g. GES, GEP or protected areas objectives) and the participation of water users in the watershed planning process.

Despite all these difficulties, environmental flows are a key tool for rational water management, allowing evaluation of the pressures placed on the system by the different economic uses. Efficiency efforts and environmental targets for environmental flows help us set the boundaries of sustainability to pursue in good water management.

All these aspects and ongoing discussions have led the European Commission to initiate a debate of environmental flows as a relevant part of EU water policy within the framework of the WS&D EN. It has also led the Commission to start developing a guidance document to reach a common understanding between Member States and competent authorities on how to develop and apply environmental or ecological flows in the most efficient and targeted way.

A first draft of this guidance document was developed and discussed by the EG WS&D in 2012 (Sánchez Navarro and Schmidt, 2012). The initiated work will continue after the publication of the 'Blueprint to Safeguard Europe's Water Resources', on the assumption that implementation of proper environmental flows is essential to ensure effective protection of aquatic ecosystems and promotion of sustainable water use.

Source: Tockner et al., 2009; EC, 2009c; Kottelat and Freyhof, 2007; EEA, 2010a; EEA, 2012e; Sánchez Navarro and Schmidt, 2012; Bunn and Arthington, 2002.

A waterbody can be described as heavily modified when the hydrological changes are permanent and substantial, and if environmental measures to restore the environmental flows have significant adverse effects on the wider environment or the uses specified above, and there are no other feasible possibilities to achieve the beneficial objectives served by modification of the waterbody.

Environmental flows are an important element in defining HMWBs, as they establish the thresholds beyond which significant effects on aquatic ecosystems due to hydromorphological changes are expected. They are also designed to ensure the functioning of a specific type of ecosystem. Flow values under certain thresholds are an indicator of the likelihood of failing to reach GES.

Environmental flows in protected areas

Environmental flow estimates are necessary in order to maintain the quality levels of the surface water and groundwater in the protected areas, as well as to meet the ecological requirements for ecosystems, habitats and species. Where more than one objective applies to a waterbody, the most stringent objective shall be applied.

The WFD makes reference to the Habitats Directive (EEC, 1992) and the Birds Directive (Directive 2009/147/EC) (EC, 2010a) to ensure that protected areas of the Natura 2000 network (2) are integrated into the river basin strategies. Any Natura 2000 site where one or more habitats or species (of which the presence has been the reason for the designation of the area) are directly dependent on the water status is defined as a protected area in the WFD. Although there is no definition of 'ecological requirements' in the Habitats Directive, the context indicates that these involve all factors required to ensure a favourable conservation status of the habitat types and species, including all relations with their environment like water, air, soil and vegetation. (EC, 2000a; Sánchez Navarro and Schmidt, 2012).

2.3 Environmental pressures and environmental change

In considering climate change and its impacts on society and the environment, it became clear that the severity of impacts depends not only on the event extremity but also on the exposure and sensitivity of the affected systems (see also Figure 2.2). Vulnerability was thus brought to

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(2) For relevant aquatic habitats in the Natura 2000 network, see Chapter 6 of the EEA water 2012 report: *European waters — assessment of status and pressures* (EEA, 2012a)

Box 2.6 Vulnerability assessment of groundwater resources

The semi-arid Mancha Occidental aquifer in Spain is an example of intense groundwater use for agriculture. Irrigation has been the catalyst for welfare in the region since the 1980s, but it has come at a significant environmental cost and with serious concerns about sustainability in the medium- and long-term. Numerical modelling was combined with key water stakeholder involvement to define scenarios. The good status of the WFD was used as a mandatory objective and the implications of the different scenarios were scored against this objective. Several main drivers for change were identified: the reform of the Common Agricultural Policy and the Water Law; tackling the problem of illegal water and climate change; and the reallocation of the large Tajo-Segura water transfer.

The involved actors were in general positive about the combination of modelling and the stakeholder approach (transparent, well-defined scope, well organised, enough information to participate, etc.). They largely agreed that the exercise had been undertaken at a sufficiently early stage to exert influence, but they were not convinced that their recommendations will be implemented by water managers and decision-makers.

Source: Martínez-Santos et al., 2008.

the fore 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). Vulnerability also 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 policymakers 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 there is also a particular need to represent the interactions between society and ecological systems. A range of vulnerability assessment models exist that can be enlarged and revised to include the capacity to consider coupled human–environment systems. A revised assessment architecture is proposed, that incorporates the following: (i) links with broad human and biophysical conditions; (ii) perturbations and pressures that emerge from these processes and conditions; and (iii) the coupled system in which vulnerability rests (Turner et al., 2003).

Such a methodology clearly illustrates the complexity of managing water in a coupled human-environment system. Freshwater policies urgently need to consider vulnerability if sustainable management and informed policy trade-offs are to be achieved.

2.3.1 *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). Real perturbations such as major floods and droughts represent direct hazards to human settlements and might require engineering solutions to reduce the sensitivity and exposure of population and infrastructure, including their potential for human and economic loss (Gallopín, 2006). More gradual changes, such as decreased groundwater availability, are typically a function of how the social-economic-ecological system operates, and represent the overexploitation and mismanagement of natural resources. This also reflects the differentiation between drought and water scarcity, for instance, which is discussed further in Section 3.2.

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 a reduction in those services (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 impacts on the freshwater environment and the resulting ecosystem services (see Table 2.2). An additional important driver is riverbed alterations like straightening and canalisation.

The drivers' are usually the result of 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, 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 generates greater vulnerability for the society that depends upon those services.

2.3.2 *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 land use and climate can result in large changes in ecosystem service supply, often accompanying an increased vulnerability of these ecosystems. The provision of many ecosystem services relies directly on land use (Metzger et al., 2006). When local socio-economic scenarios and local climate models are combined, the socio-economic changes that are forecast 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 development, infrastructure, fairness, and power, resulting in a greater capacity for society to adapt to change (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 viewed as two separate management problems (Valenzuela Montes and Matarán Ruiz, 2008). A modern view on land use policy aims to achieve a sustainable

Table 2.2 Summary of direct drivers

Human activity (direct driver)	Impact on ecosystems	Services at risk
Dam construction	Alters timing 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	Eeliminates 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 2.7 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. They are also 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 in part due to the underestimation of ecosystem goods and services that are not fully accounted for by its different users. 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.

Photos: Views over the Windermere lake system and catchment © Stephen Maberly/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 made the lake more sensitive to meteorological change (McGowan et al., 2012). Climate change impacts have been detected in Blelham Tarn (Foley et al., 2012) showing that over 40 years, the length of time during which the lake has a clear stratification (with different depths of the lake having different temperatures) had increased by nearly 40 days, as had the hypolimnetic anoxia period. A study of *Daphnia galeata* (Thackeray et al., 2012) data collected over 80 years indicated change in 9 of 10 phenological metrics, primarily driven by phytoplankton phenology and spring water temperature, both linked to climate change.

harmonisation of economic, social, cultural and environmental interests in the society at regional to local level (Viglizzo et al., 2012). Integrated water management considers the spatial correlations between water and spatial development, and in doing so, takes into account the WFD (EC, 2000b) as well as the EU Strategic Environmental Assessment Directive (Directive 2001/42/EC) (EC, 2001).

Land use changes can seriously influence both low flows and water availability as floods and inundations, especially when land use change means sealing of soils and transforming open areas — like agriculture or nature — into urban areas, industrial zones or construction sites, often alongside 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 the latter is plastic sealing in agriculture as a protective cover to adjust soil temperature and to control erosion or weeds. The sealing of surfaces also has evident consequences on neighbouring areas, as they increase the amount and the speed of the run-off 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 unsealed soil, managed appropriately, can buffer (smaller) flooding and mitigate or reduce the transfer of pollutants. When not managed appropriately, it can exacerbate problems by 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 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 puts additional pressure on sewage systems — by increased speed and amount of run-off — increasing the risk of urban flooding (Natale and Savi, 2007). This can also have consequences for water quality due to direct run-off and a reduction in the filtering capacity of the water that does pass 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 returning infiltration).

In general, forests and afforestation are considered to be positive for 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 is 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 et al., 2008). 'Compaction' — the compacting of the earth 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 et al., 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).

Land use changes are complex phenomena in space and time. For instance, the scenarios set up by Metzger et al. (2006) were developed for analysis at European scale. While this broad overview is a strength, the disregarded 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 those related to biodiversity and nature conservation, are hard to assess in a European scale study.

Land use has and will have an important influence on ecosystem services in Europe, albeit presenting large differences across regions and services (Metzger et al., 2006). In most European regions, different land use scenarios and more or less (or different) land use changes have a different potential impact on ecosystem services: the most notable distinctions are caused by the differences between a development path that only considers the economy narrowly defined versus a more environmentally friendly path of development (Metzger et al., 2006).

2.3.3 Climate change

Any change in climate will lead to changes in regional weather and exert a 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 also 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. In the chapter on freshwater resources and their management, the IPCC Fourth Assessment Report on impacts, adaptation and vulnerability (IPCC, 2007) 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 (IPCC, 2007) include the following:

- changes in volume, intensity, type and timing of precipitation will alter river flows and resultant wetland and lake levels;
- temperature, radiation, humidity and wind speed changes will affect the hydrological cycle and further exaggerate impacts of decreased precipitation;
- groundwater is less directly affected but can become more strongly relied upon to provide secure access to freshwater;

- increased variability and intensity of precipitation is projected to increase flood risk and drought;

- water quality will be significantly affected by multiple stressors such as higher temperatures, increased low flows and 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, 2008), which 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 by the authors of the upcoming AR5 report, 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 ongoing, 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:

- exposure and vulnerability are key factors determining risk to hazards and associated impacts;

- extreme and non-extreme weather or climate events affect vulnerability to future extremes by modifying resilience, adaptive capacity and coping capacity;

- the severity of climate extremes impacts depends on the level of exposure and vulnerability to extremes;

- 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);

- 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;

- exposure and vulnerability are dynamic, varying across spatial and temporal scales;

- 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;

- there is medium confidence that droughts will intensify in the 21st century, particularly in southern Europe, the Mediterranean and central Europe;

- extreme events will have the greatest impacts on sectors with close links to climate, such as water, agriculture and food security;

- 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 2.8 Climate change impact on freshwater ecosystems

Freshwater ecosystems are not only impacted by altered river flows but also by changing temperatures. Increasing temperatures stimulate earlier spring onset of biological phenomena like phytoplankton spring bloom, first flying days of insects or spawning of fish. An increased water temperature is also favourable for warm-water species while cold-water species have to move northwards or to higher altitudes, with an example being the brown trout in Alpine rivers.

Higher temperatures also make it easier for invasions of species that originate in warmer regions. The sub-tropic cyanobacterium Cylindrospermopsis raciborskii is highly toxic. Its recent appearance but rapid spread in temperate European drinking and recreational water supplies has given rise to international public health concerns.

Source: EEA, 2012c, Section 3.3.8.

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. A whole range of eco-hydrological impacts can be expected to affect ecosystems and species: increased low-flow episodes and water stress; shifts in timing of floods; increased evaporative losses from shallow waters; more frequent and intense storm flows; shifts in seasonality and frequency in thermal stratification of lakes and wetlands; salt-water intrusion; more intense run-off with increased sediment and pollution loads; and water temperature changes with shifts in concentrations of dissolved oxygen (Le Quesne et al., 2010). Such impacts will reduce the resilience of freshwater ecosystems to disturbance and subsequently increase their vulnerability to further climate change.

3 Pressures, state and outlook

As highlighted in Chapter 2, 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 demand for water 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 policymaking. The acknowledgement of variability as an inherent part of the water resources system necessitates the introduction of a more risk-based management framework, where concepts such as resilience and vulnerability form the basis of future indicators rather than fixed target figures for water demand and flood defence levels.

Given the close link between water and ecosystems, and mindful of 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. It is especially important to understand water demand, as well as the of magnitude and frequency of extreme events (see also (EEA, 2012c), Section 3.3 on inland waters). Of special concern is the impact of anthropogenic changes (like climate change, land use management, or urbanisation) on the environment and on the hydrological cycle, and how these might affect economic, 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 resource management and the resulting pressures exerted on Europe's water resources. Europe must manage its water resources sustainably if we are to ensure that a sufficient quantity of good quality water is available for people's needs and for the environment, and if we are to provide 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 occur in a matter of hours, while regional drought can develop over years, even decades.

3.1 Status of droughts and floods in the context of land use and climate change

Droughts, water scarcity, floods and inundations are all complex hydrological processes where future conditions are influenced by climate change and land use changes. One cannot underestimate the policy relevance of water scarcity given the many European directives, communications, etc. complemented by EU policy in other sectors, like the Common Agricultural Policy (CAP), the 2020 Territorial Agenda on regional development, or the White Paper *Adapting to climate change: Towards a European framework for action* and national initiatives. Many of these are mentioned in this report, and their relevance to the vulnerability of European waters explained. The three most important ones are as follows:

- the WFD (EC, 2000b);
- the Communication *Addressing the challenge of water scarcity and droughts in the European Union* (EC, 2007c);
- the Floods Directive (EC, 2007b).

It is important to make the right assessment for the right purpose, be it implementing these policy processes; compiling efficient and/or effective programmes of measures; or effecting transnational communication on the scale of the river basin district (RBD). Alongside the main pressures acting on Europe's water resources and the resulting impact of those uses, the following sections focus on the current state and situation with regard to water scarcity and droughts, as well as flooding, and on how these building blocks constitute a knowledge source for EEA's forward-looking analyses.

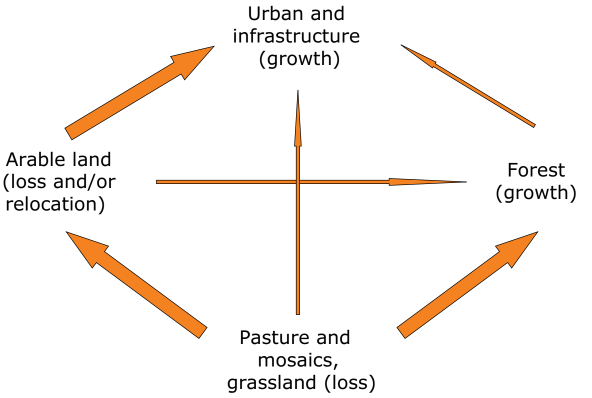
These status assessments of hydrological elements must be analysed, as the current state of Europe's water resources is perceived to be under increasing pressure from a range of external drivers, primarily driven by increased population and associated resource requirements; climate change (Weiß and Alcamo,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

3.1.1 *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, 2010d). This takes place in the context of an overall slow-down in the rate of land change observed in the period from 2000 to 2006 and the substitution of residential area expansion with dominant growth of commercial and industrial sites (EEA, 2010d). Figure 3.1 shows the predominant net land conversion in Europe.

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 areas in the EU-27 is in Cyprus (1.7 %) and the lowest in Malta (0.0 %) (Map 3.1). 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 up by the housing sector, followed by construction sites (in the graph, these are included in the mines and waste dumping sites) and the industrial and commercial sector (EEA, 2012d) (Figure 3.2).

Figure 3.1 Predominant net land conversions in Europe (1990–2006)



Note: Based on Corine Land Cover Analysis.

Source: EEA, 2010d.

Water, wetlands and forests constantly interact to produce healthy and productive ecosystems. The role of forests is pivotal in the hydrological cycle: they affect evapotranspiration rates and influence how water is routed, stored or retained in an ecosystem (Stella Consulting, 2012). Forests also regulate soil erosion and pollution, prevent salinisation (Blumenfeld et al., 2009) and can mitigate small and local floods (IUFRO, 2007). Forest soils readily absorb and retain water and, as a result, surface run-off rarely occurs outside of stream channels in these areas (Pike, 2003; Stella Consulting, 2012).

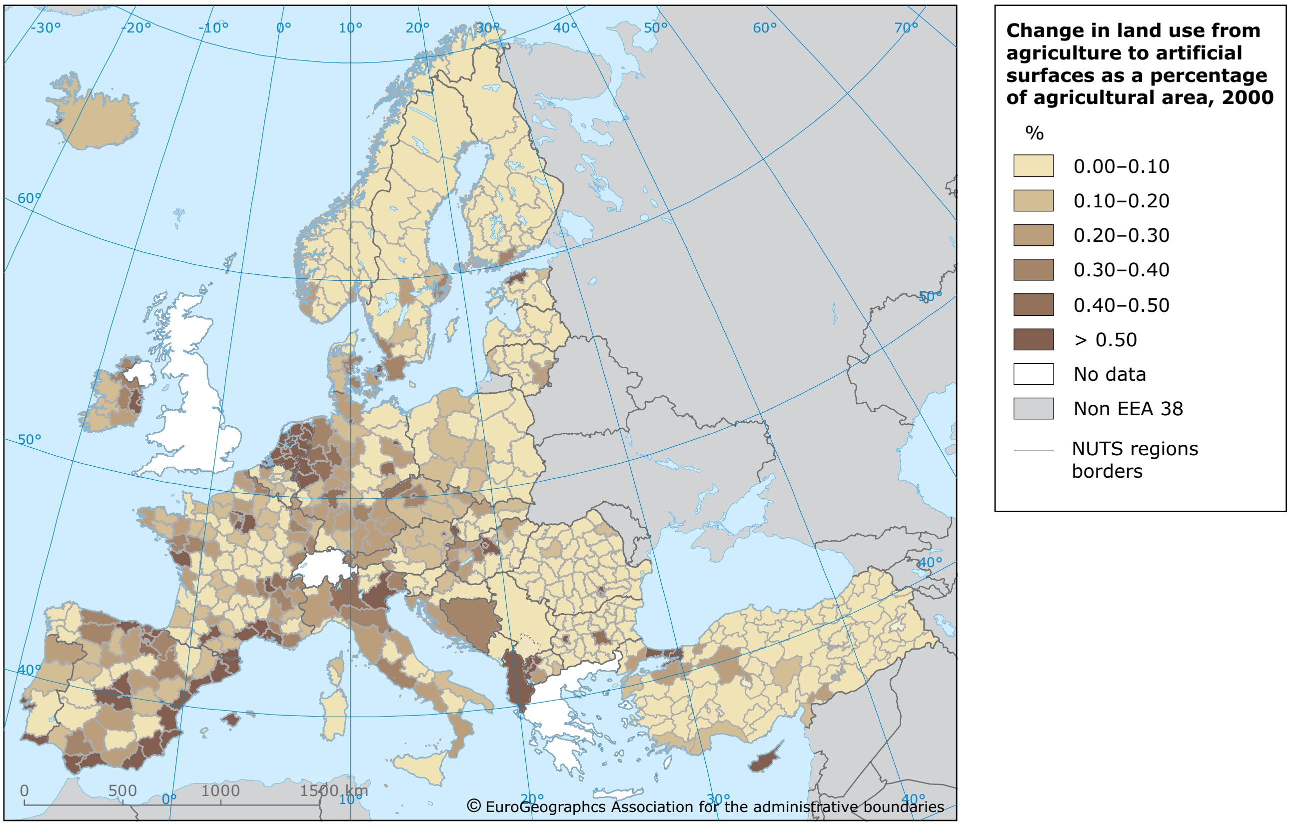
The preservation of wetlands is crucially important: they act as natural reservoirs and are extremely rich in terms of both biodiversity. They also help provide ecological services, for example within the realms of agriculture, sanitation, and energy. Forested riparian wetlands play a vital buffering role to ameliorate flood impacts (Blumenfeld et al., 2009).

Land cover conversions have an influence on the hydrological cycle. When agricultural land is converted to artificial surfaces, it is often accompanied by sealing of the soil. This can have several environmental impacts on water (fluxes), soil and biodiversity resources. The surface is made impermeable and links with the subsurface are disconnected, meaning a loss of any functionality for the hydrological cycle.

Due to their permeability, arable land and grasslands play an important role in the recharge of groundwater. However, the intensive use of agricultural land can cause soil compaction, which may increase the risks of soil erosion and water pollution. It also disturbs agricultural habitats, impacts animal migration patterns and affects the hydrological cycle (increased water run-off and decreased water retention) leading to an increased risk of floods. Intensive agricultural practices can also influence the hydromorphology of rivers, and lead to increased water use and pollution of groundwater when fertilisers and pesticides wash out, if water is not used efficiently (EEA, 2012e).

Local-scale and short-term afforestation can lead to increased water use by evapotranspiration. But on a regional and long-term scale forests and afforestation are beneficial for the water balance. Millán (2012) concluded that for most (vegetated) parts of the world, it is untrue that water resources

Map 3.1 Change in land use from agriculture to artificial surfaces, as a percentage of agricultural area, 2000



Note: For administrative regions NUTS 0, 2 and 3.

Source: EEA, 2012d.

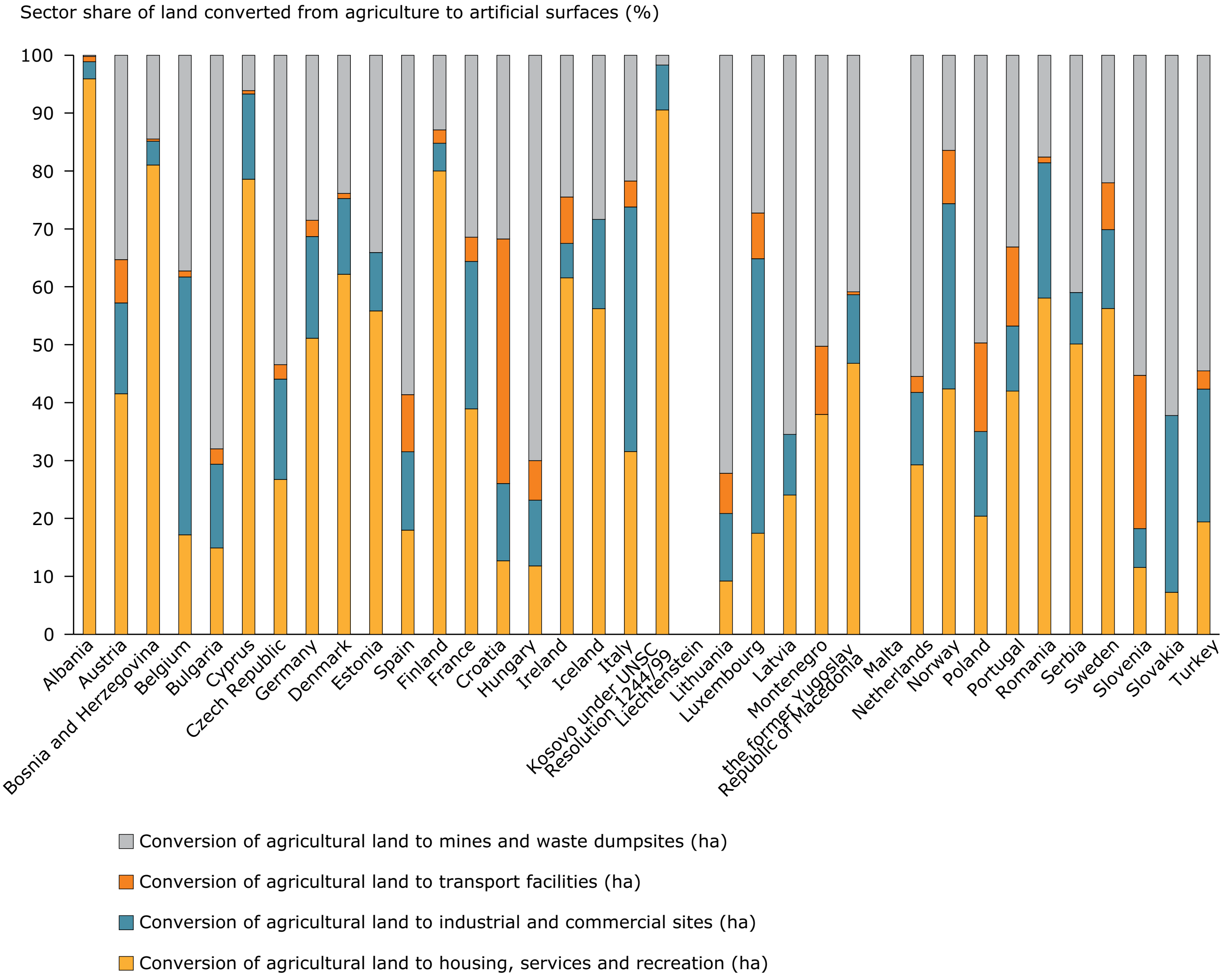
are provided by precipitation from a large weather system. On the contrary, a large part of the water is recycled (recirculated) between the forested soil and the atmosphere. In the Mediterranean region of Valencia, with mountains between 60 km and 100 km from the seashore, the moisture added to the atmosphere by evapotranspiration acts as a 'trigger component' for the next rainfall event. This means that removing the forest causes a decrease in the amount of rainfall in a region. While there was an increase in precipitation in stations close to the coast, at more than 40 km inland, the precipitation 5-year average regression showed a decrease in precipitation (Millán et al., 2005). So at the local to regional scale, the hydrological cycle (precipitation patterns and soil moisture) is affected by land use, especially when high contributors to air moisture like wetlands and forests are destroyed (Miao et al., 2003; Millán et al., 2005; Millán, 2012).

This complex feedback in the western Mediterranean between rainfall (or drought) and land use can lead to unexpected results: a holistic approach is needed before measures are taken. Like forests and wetlands, irrigated agriculture also contributes an indispensable service to water recycling. Reallocation of irrigation water to other uses may have a reduced effect on precipitation and increase the occurrence and severity of droughts (Millán, 2012).

As for climate change, scenarios for land use changes are developed based on socio-economic and biophysical processes at different spatial and temporal scales. Some of the EU-wide modelling exercises are 'Land-use scenarios for Europe: Qualitative and quantitative analysis on a European scale'(PRELUDE) (EEA, 2007), EURURALIS (Rienks et al., 2008), and 'Dynamic Land Use change Modelling for CAP impact assessment on the rural landscape' (LUCOMAP) (van Delden et al., 2010).

The impact of agricultural land use on the hydrology and water balance in a river basin depends on the type of management and the intensity and technique of irrigated land use

Figure 3.2 Sector share of land converted from agriculture to artificial surfaces (%)



Note: Changes for the 2000-to-2006 period.

Source: EEA, 2012d.

and management over rain-fed agriculture. The efficiency of irrigation and ways to achieve efficient water use in agricultural land use have been discussed in the EEA report *Towards efficient use of water resources in Europe* (EEA, 2012e). This report concludes with a call for irrigation management regimes that are better adapted to the available freshwater resources in river basins, and focuses on an integrated approach to balance the water use that occurs with different land use and management types.

3.1.2 *Changes in the climate component of the water cycle* (³)

Temperature and precipitation are two key climate variables (EEA, 2012c). Time series show long-term warming trends in European average annual temperature since the end of the 19th century, with the 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.

(³) This section is based on the indicator-based report *Climate change, impacts and vulnerability in Europe* (EEA, 2012c), to which the reader is referred for more detailed information and primary sources.

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 does. Annual precipitation trends since 1950 show an increase of up to 70 mm per decade in north-eastern and north-western Europe — most notably in winter — and a decrease of 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 forecast 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. One should bear in mind that trends in climatic variables like temperature or precipitation are not the only factors important for droughts and floods; the natural variability of the climate must also be considered in addition to long-term trends.

Besides the trends in average values, the extremes of temperature and precipitation are also 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 21st century. There are no widespread significant trends in 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 most pronounced in Scandinavia in winter, and in northern and eastern central Europe in summer.

In general, river flows have increased in winter and decreased in summer since the 1960s (EEA, 2012c). Climate change is projected to result in strong changes in the seasonality of river flows across Europe. River flows in summer are projected to decrease in most of Europe, including in regions where annual flows are projected to increase.

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 (Feyen and Dankers, 2009). Minimum river flows will not only decrease in southern and south-eastern Europe but will 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 snow accumulation during winter, the risk of early spring flooding would decrease.

3.2 Water scarcity and droughts

The working definitions used by the CIS WFD Expert Group for Water Scarcity and Droughts are the following (Schmidt et al., 2012):

Drought is a natural phenomenon. It is a temporary, negative and severe deviation along a significant time period , and over a large region from average precipitation values (a rainfall deficit), which might lead to meteorological, agricultural, hydrological and socio-economic drought, depending on its severity and duration.

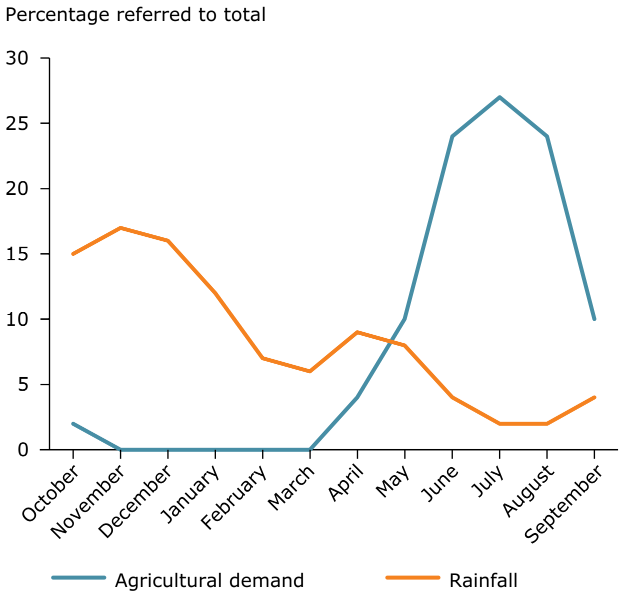
Water scarcity is a man-made phenomenon. It is a recurrent imbalance that arises from an overuse of water resources, caused by consumption being significantly higher than the natural renewable availability. Water scarcity can be aggravated by water pollution (reducing the suitability for different water uses), and during drought episodes.

The effects of over-abstraction upon water resources vary considerably depending upon the volume and seasonality of the abstraction; the volume and location of returned water; the sensitivity of the ecosystem; and specific local and regional conditions. Peak abstraction for both agriculture and tourism typically occurs in the summer months when water availability is generally at a minimum (EEA, 2011a). When considered on an annual basis only, the seasonal imbalances (see Figure 3.3) are not reflected in any indicators. This highlights a problem with the yearly timescale because itdisregards the current situation where seasonal problems occur. The economic and environmental costs of possible storages that could structurally 'compensate' for the seasonal unbalances may be high.

Drivers and pressures

Water scarcity and droughts have similar effects, but from a policy point of view — and in particular to define adequate responses — the distinction

Figure 3.3 Precipitation versus agricultural demand patterns



Source: Júcar Pilot River Basin Management Plan/Estrela et al., 2004.

made in the working definitions above is necessary. Table 3.1 gives an overview of the different causes and timescales of the related concepts.

The interconnections in the natural water cycle mean that changes in climate or land use conditions can also cause or exacerbate droughts. Climate change can affect the gradual change of average conditions, as well as the frequency and magnitude — and so the variability — of deviations from the average, thus affecting the occurrence of drought events. Climate change may also create or intensify water scarcity problems through a reduced supply or an increased demand (CIS WFD, 2009).

Many ecosystems are able to adapt to recurrent natural variations in precipitation and stream flow; freshwater ecosystems can even be totally dependent on these variations. Nonetheless, exceptionally severe droughts or droughts in combination with man-made over-abstractions can result in irreversible ecosystem changes. Contrary to natural variations, human-induced water scarcity usually affects ecological status in a negative way, depending on the duration and relevance of the water scarcity and the sensitivity of the ecosystem (Schmidt et al., 2012).

Data sources

Several information sources are important, and must be combined to define the water quantity status of both surface water and groundwater. The most important sources are the yearly WISE SoE water quantity reporting, the Eurostat data, and the reporting under the WFD. Even though the WFD focuses on qualitative aspects, the good status of groundwater levels is a crucial parameter in the health of the ecosystem and a key parameter in the good status assessment (see Section 3.2.1). Several partial indicators are available to predict droughts — and eventually water scarcity — when water use is taken into account as well. The most common one, the Standardised Precipitation Index (SPI), is a statistical indicator evaluating the lack or surplus of precipitation during a given period of time as a function of the long-term average precipitation and its distribution. It is calculated using a continuous, long-term (more than 30 years) series of historic precipitation records. Depending on the purpose of the analysis, the SPI can be calculated for different timescales (from less than 1 month to 48 months).

Although these indices are often used to evaluate the development of a drought, they can — when applied to historic time series — be used as a measurement for the severity of rainfall deficit (or surplus) and for trend analysis. Besides rainfall, biophysical indicators (see Section 3.2.2) exist that define how droughts affect the vegetation canopy. They can be handled as a forecasting tool for actual drought conditions: persistent droughts are clearly manifest in poor vegetation growth and vigour (Gobron et al., 2010). These drought assessment indicators are

Table 3.1 Timescale and causes of water scarcity, drought and related concepts

		Timescale		
		Short-term (days, weeks)	**Medium-term (months, seasons, years)**	**Long-term (decades)**
Causes	Natural	Dry spell	Drought	Aridity (ᵃ)
	Man-made	Water shortage	Water scarcity	Desertification (ᵃ)

Note: (ᵃ) Not discussed further in this document.

Source: Schmidt et al., 2012, based on Grigg and Vlachos, 1990.

relevant for the WFD in relation to the exemptions for temporary deterioration in status of a waterbody and as a justification for why additional measures are not practicable.

Although the rainfall and vegetation indicators above can be used retrospectively to analyse past periods of droughts, a short overview of the last 40 years is given in Section 3.2.3. This information is based on Member State reporting (e.g. in drought management plans or RBMPs), and supplementary information from scientific papers has been added. However, rhis exercise only provides a rough indication; it expresses the occurrence of a drought in a country in a specific year without further spatial and temporal scale details.

The WEI uses a more risk-oriented approach to examine hydrological balance in a river basin. The WEI is an indicator of the level of pressure that human activity exerts on the natural water resources. Contrary to the indicators described above for rainfall and vegetation anomalies, the WEI is not a drought indicator but a water scarcity indicator. National-level data is considered neither sufficiently accurate nor precise enough to assess the prevailing water stress conditions in a river basin. Only a full water balance at the right temporal and spatial scale provides the water manager with sufficient information to make correct decisions on water allocation between the different competing users, while still leaving enough water for the environment and for the maintenance of ecosystem functions.

The Expert Group on Water Scarcity and Drought

An Expert Network on Water Scarcity and Droughts was set up within the Common Implementation Strategy (CIS) of the WFD in December 2006. The network developed a drought management report (Water Scarcity and Droughts Expert Network, 2007) setting the basis for developing — when appropriate drought management plans complementary to the RBMPs, and aiming at minimising the socio-economic and environmental WS&D impacts. The Drought Management Plan (DMP) report recommends strategic, operative and administrative measures to be applied progressively, according to the drought status.

The Expert Group on Water Scarcity and Droughts (EG WS&D) — as a follow-up of the expert network — provides pragmatic and applicable indicators and maps for both water scarcity and drought, in order to provide a clear picture throughout the EU, capturing both natural phenomena and socio-economic aspects.

The EG WS&D also prepared working definitions of commonly accepted terms, and developed indicators for water scarcity and for droughts in Europe (as it is outlined here in the first paragraph of Section 3.2). Member States voluntarily provide data, and in close collaboration with the EEA and the JRC, evaluate the use of the developed European tools for the regional assessments regarding indicators for water scarcity (anthropogenic pressures) and for droughts (natural events).

3.2.1 Results from the first generation of River Basin Management Plans

The Water Framework Directive stated that the first generation of River Basin Management Plans had to be adopted by the EU Member States by 22 December 2009. Only for groundwater is good quantitative status explicitly part of good status in the WFD. In order to reach the WFD's environmental objectives, water quantity issues are implicitly included as environmental flow conditions in order to maintain sustainable ecosystems.

Groundwater quantitative status

Article 2(20) of the WFD (EC, 2000b) defines good groundwater status as 'the status achieved by a groundwater body when both its quantitative status and its chemical status are at least good'. So for groundwater, the quantitative status is explicitly mentioned in the criteria to achieve good status, along with chemical status as assessed by the (EEA, 2012a). The definition of good groundwater quantitative status according to the WFD requires that the level of groundwater in a groundwater body (GWB) is such that the available groundwater resource is not exceeded by the long-term annual average (LTAA) rate of abstraction. Thus, adequate groundwater levels are an inherent and important element of the good status assessment, which cannot be reached if groundwater-dependent ecosystems do not have enough water available. The achievement of good groundwater quantitative status and an abstraction regulation that enhances adequate levels led consequently to a water management approach where drought management plans were integrated as part of the RBMPs. The assessment of the overall good status of the EU groundwater bodies is described in more detail in a report drawn up for the Directorate-General (DG) for the Environment of the European Commission (Kossida et al., 2012) concerning the quantitative aspects, and the EEA report on status, pressures and ecosystems (EEA, 2012a) concerning the chemical aspects.

From the total number of groundwater bodies reported in the WFD RBMPs, 6.37 % (782 out of 12 268 classified groundwater bodies) were classified as being in poor quantitative status in 2009. These are distributed throughout several countries, namely Spain, the United Kingdom, Belgium, the Czech Republic, Denmark, Italy and Malta. Those countries all have groundwater quantitative problems, but these problems are mainly found in specific RBDs and not in the whole country. The exception to this is Cyprus, where approximately 70 % of its groundwater bodies hold poor status (Map 3.2). For Switzerland, none of the GWBs are in poor quantitative status (Sinreich et al., 2012).

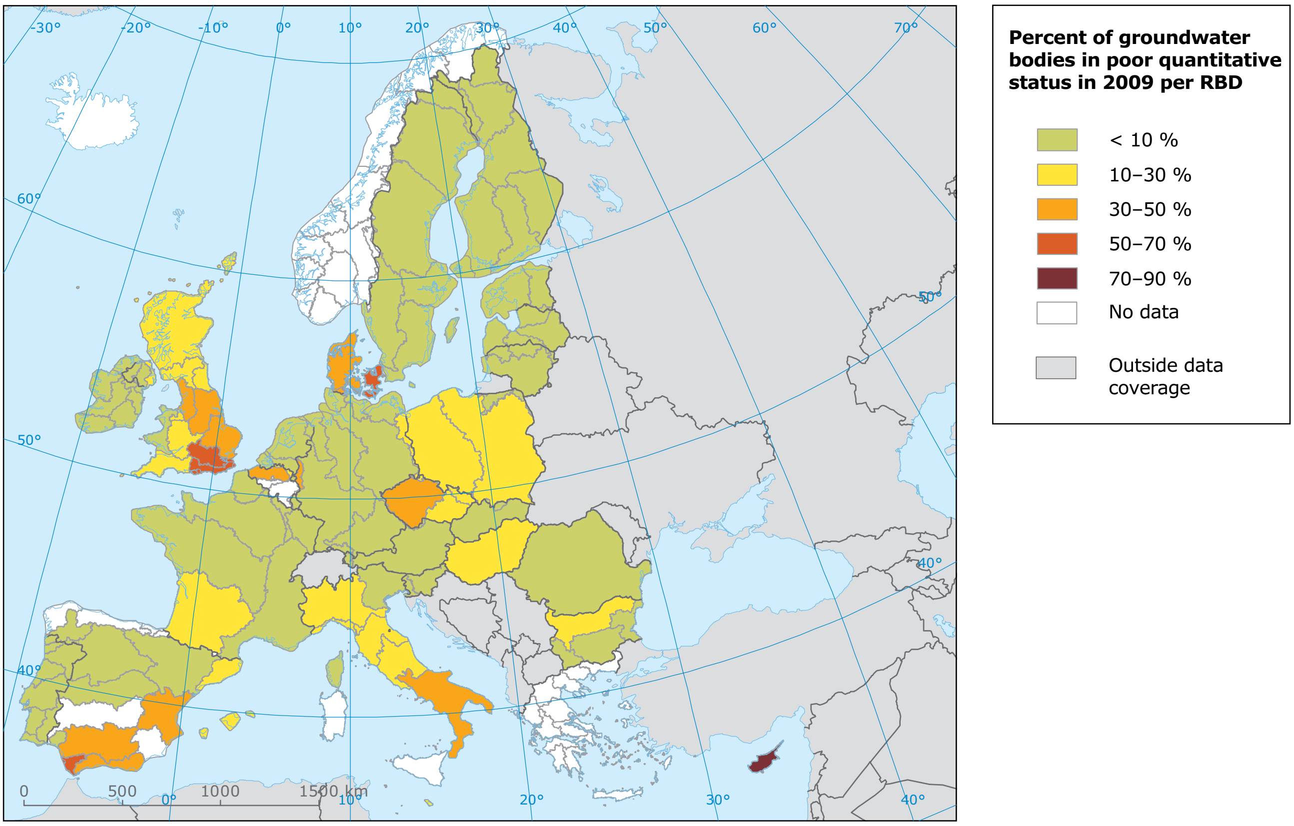
Part of the reporting under the WFD also dealt with the specification of significant pressures, which in relation to good groundwater status, are categorised into four groups. There are three groups of significant pressures affecting groundwater quantitative status. The most commonly reported pressures are water abstraction (present in 11 % of classified GWBs and 66 % of GWBs that are in poor quantitative status), followed by salt-water intrusion (present in 12 % of GWBs in poor status). Finally, other pressures are responsible for about 5 % of the GWBs being in poor quantitative status (Figure 3.4).

It is open to discussion whether salt-water intrusion is a pressure or an impact. For the GWB quantitative status 2009, it was decided to report this as a groundwater pressure for the WFD.

Information on surface waters

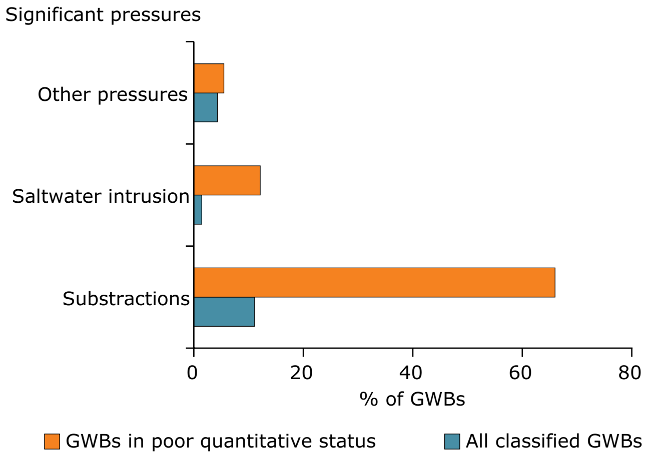
Although a good quantitative regime is not part of the good status requirements for surface waters, information on droughts and water scarcity can be found in the RBMPs as a necessary piece of knowledge to develop coherent and effective sets of measures to tackle WS&D in the programme of measures. Droughts are reported in several of the RBMPs (+/– 60 %) in different parts of Europe, ranging from RBMPs where droughts spells are RBD-wide up to local or sub-basin drought spells. However, it is not always possible to distinguish

Map 3.2 **Percent of groundwater bodies in poor quantitative status in 2009 per RBD**



Source: WISE-WFD master database, version of 13 June 2012.

Figure 3.4 Relevant pressures for GWBs



Source: WFD Master database, version of 13 June 2012.

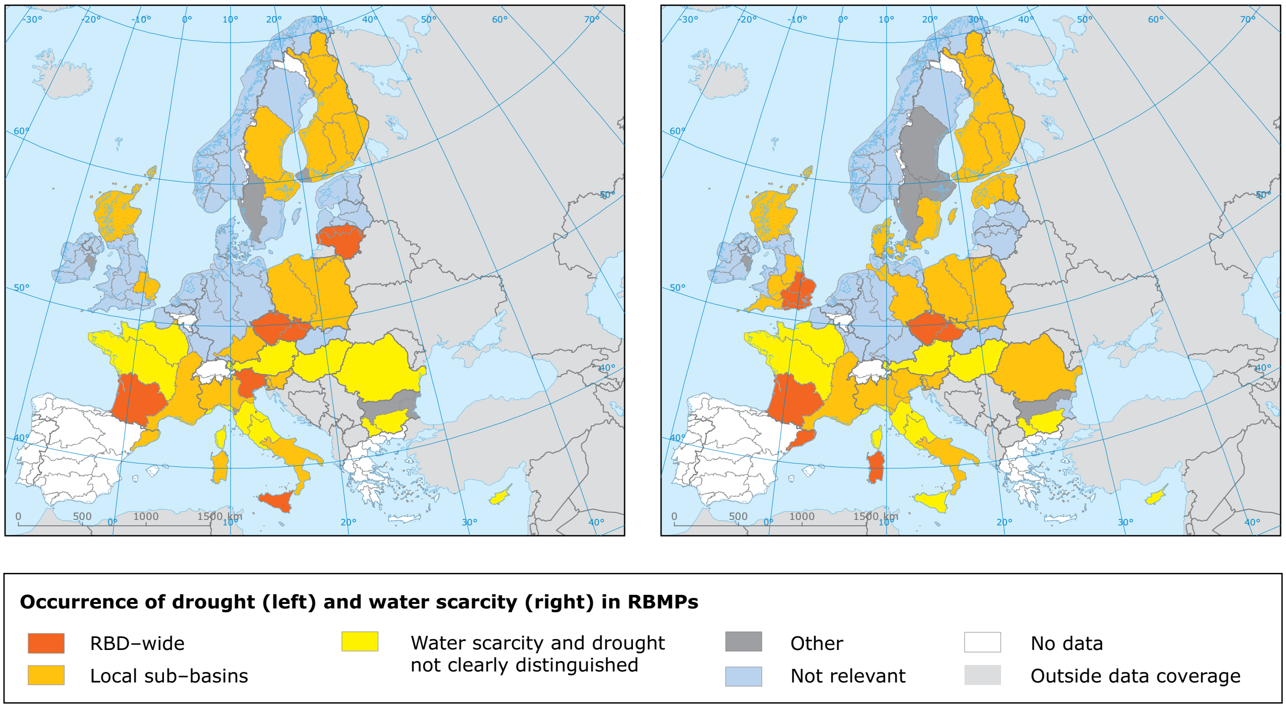
between droughts and water scarcity in the reporting (Schmidt and Benítez 2012) (Map 3.3). But the analysis of the RBMPs clearly indicates that droughts are not only characteristic for river basin districts in southern Europe, they also occur in many regions across the EU (Schmidt and Benítez, 2012).

3.2.2 *Drought assessments*

Over the past 30 years, the frequency of drought events and the areas and people affected have dramatically increased both in number and intensity within the EU (MED WS&D WG, 2007). Severe events have been identified that on an annual basis affected more than 800 000 km^2 of the EU territory (37 %) and 100 million inhabitants (20 %) in 1989, 1990, 1991, 2003 (with an exceptional cost of EUR 8.7 billion) 2007, and 2008 (EC, 2007a). More recently, western and south-western Europe were affected by severe summer and spring droughts in 2011 and 2012 (JRC, 2011a and 2012).

The EDO, developed and maintained by the JRC in collaboration with partners from Member States, provides up-to-date information on the occurrence and evolution of droughts through a suite of selected indicators. As the development of EDO progresses, more indicators and more analysis of historical time series will become available. JRC irregularly produces *Drought News* when severe drought events occur. This is available online through the EDO website. Currently, the following three indicators are provided through the EDO on an operational basis.

Map 3.3 Occurrence of drought (left) and water scarcity (right) in RBMPs



Note: 'Other' also includes the cases where there is no clear information about these issues in the RBMPs.

Source: Schmidt and Benítez, 2012.

The Standardised Precipitation Index

The SPI is an indicator to detect and quantify meteorological drought situations based on time series of rainfall. It is a statistical indicator to compare the total precipitation during a period of n months with the long-term average rainfall distribution for the same time period, based on historical data. The SPI can be calculated on different timescales, so meteorological drought evidence can be shown, e.g. for a past month (SPI-1), season (SPI-3) or year (SPI-12). In order to allow for statistical comparisons in between different climatic zones, the SPI is transformed into a standard normal variable with a mean of 0 and a variance of 1 (McKee et al., 1993 and 1995). The calculation over different rainfall accumulation periods allows for estimating different potential impacts of a meteorological drought (EG WSD, 2012; JRC, 2011b). The periods are:

- short accumulation periods (SPI-1 and SPI-3) are indicators for immediate impacts such as reduced soil moisture, snowpack or flow in small creeks;
- medium accumulation periods (SPI-3 and SPI-12) are indicators for reduced stream flow or reservoir storage;
- long accumulation periods (SPI-12 to SPI-48) are indicators for reduced reservoir or groundwater recharge.

While these relationships are valid on a general level, detailed impacts are dependent on the local environment (topography, geology, etc.) and human interference (e.g. existing irrigation schemes). A more complete interpretation is only possible when the SPI is calculated over several accumulation periods. Comparison with other drought indicators is needed to evaluate actual impact on vegetation (like fAPAR, see further) or on different economic sectors (EG WSD, 2012). EDO SPI data are calculated from point observations at rain gauge stations, blended with Global Precipitation Climatology Centre (GPCC) gridded data provided by the German Weather Service at a 1° spatial resolution to provide a complete picture over the entire European continent.

Soil moisture

Soil moisture is one of the important variables in hydrological, climatological, biological, and ecological processes, playing a crucial role in the interactions between the atmosphere and land surface. It represents a vital water reservoir for plants buffering water stocks, especially during periods of reduced rain water supplies. Drought manifests when soil moisture decreases considerably and crops and natural plant communities suffer due to insufficient water availability. Therefore, the spatial distribution of soil moisture is estimated on a 5 by 5 km^2 scale using a spatially distributed hydrological model (LISFLOOD) combined with precipitation and other atmospheric data (Vogt, 2012).

The soil water content can be used as an indicator for determining the start and duration of drought conditions. Soil moisture data are provided as 'water potential' (pF) and as anomalies compared with the long-term average (JRC, 2011c).

fraction of Absorbed Photosynthetically Active Radiation

The fraction of Absorbed Photosynthetically Active Radiation (fAPAR) is a biophysical variable directly related to primary production that can be used as an indicator of the state and productivity of vegetation. It is one of the 50 Essential Climate Variables recognised by the UN Global Climate Observing System (GCOS) as necessary to characterise the climate of the Earth (WMO et al., 2010). fAPAR is largely controlled by the Leaf Area Index and to a lesser extent by the absorption efficiency of the vegetation composing the canopy and the soil background. In the EDO, fAPAR grids are based on the VEGETATION sensor (replacing the Medium Resolution Imaging Spectrometer (MERIS) sensor after the failure of the Envisat satellite in April 2012). Data are provided every ten days with a spatial resolution of approximately 1 kilometre.

fAPAR and fAPAR anomalies are presented in the form of maps and graphs, providing information on both the spatial distribution of the vegetation activity and the temporal evolution over longer time periods. Gridded data can be aggregated over administrative or natural entities such as hydrological watersheds. This allows for the qualitative and quantitative comparison of the intensity and duration of the fAPAR anomalies with recorded impacts such as yield reductions.

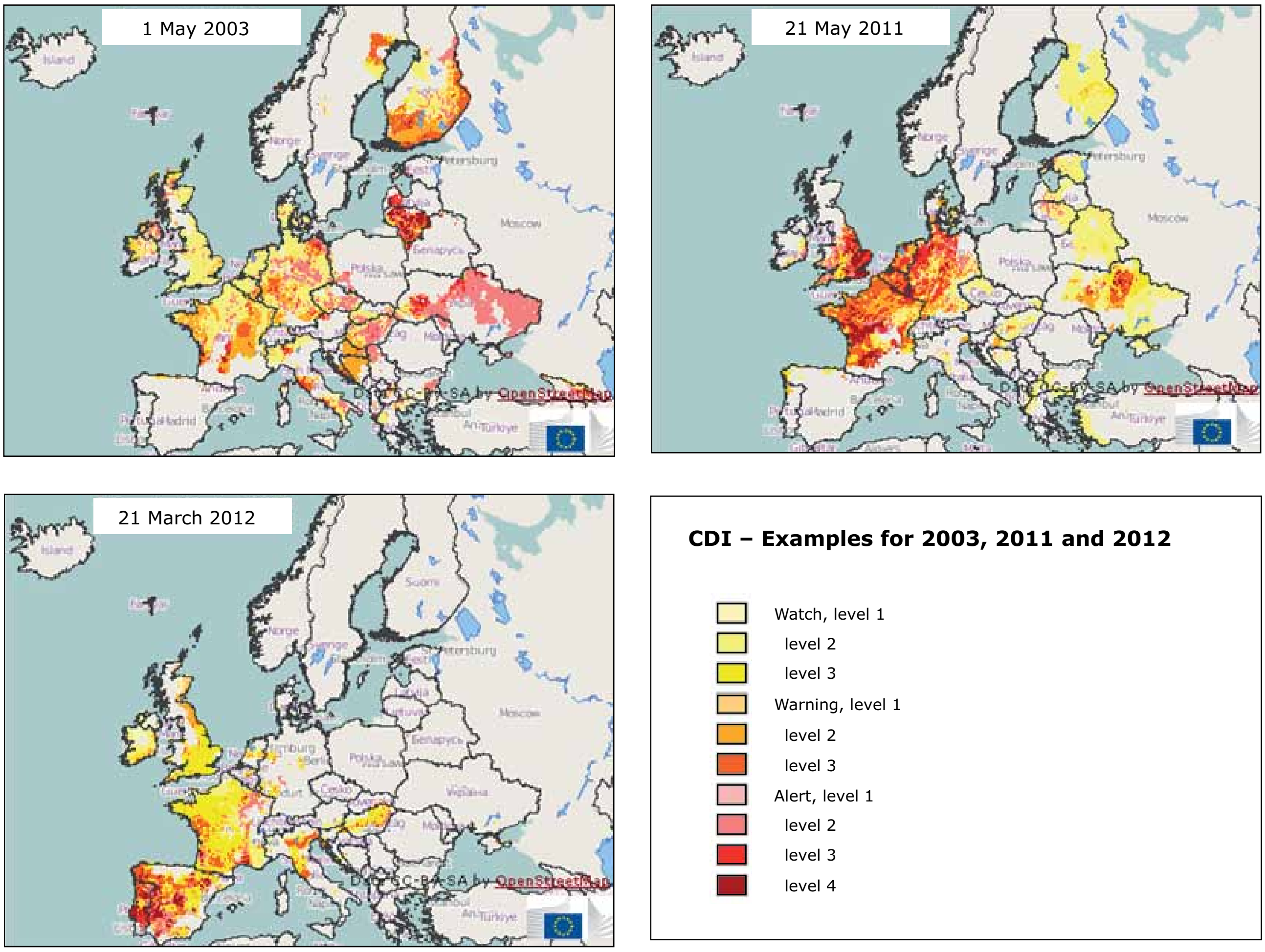
The EDO Mapserver presents fAPAR 10-day composite images and the fAPAR anomaly images calculated by comparing a given 10-day period in time to the historical series for the same 10-day period (JRC, 2011d).

The fAPAR is not directly measurable, but derived from models describing the transfer of solar radiation in plant canopies, using remote-sensing observations (WMO et al., 2010; Gobron et al., 2010). The fAPAR provides evidence of drought impacts as persistent droughts become manifest in poor vegetation growth and vigour (Gobron et al., 2010). GCOS has issued specific recommendations to monitor this variable systematically, both through a re-analysis of existing databases, and in the future, by means of instruments to allow for retrospective analysis of drought impacts as well as for the performance of trend analysis. More information can be found at the fAPAR project site of the Joint Research Centre (JRC, 2001d).

Combined Drought Indicator

In general, several methods and indicators are necessary to evaluate drought conditions and impacts. For example, one could use accumulated rainfall and rainfall deficits in the SPI over three months (SPI-3), and combine it with soil moisture and information on vegetation vigour (fAPAR). The EDO provides such assessments on an experimental basis and in close collaboration with the WS&D expert network (see Section 3.2). As a first approach, a Combined Drought Indicator (CDI) for agricultural drought has been developed recently that provides for a structured combination of three indicators based on the cause–effect relationships between rainfall deficit (SPI), soil moisture anomaly, and impact on the vegetation canopy (fAPAR anomaly) (Sepulcre et al., 2012) (see Map 3.4). According to the severity of the recorded impact, a watch, warning, or alert is issued. The CDI is targeted at agricultural drought impacts. A precipitation shortage is reflected in a watch. When the rainfall deficit translates into a soil moisture deficit, it is reflected

Map 3.4 Mapping of drought conditions in Europe



Note: Mapping of drought conditions in Europe as calculated by the CDI (based on SPI, soil moisture and fAPAR) for top left 21 March 2012, top right 21 May 2011, and bottom left 1 May 2003. 2003 was 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), and alert (when these two conditions are accompanied by an anomaly in the vegetation condition).

Source: JRC, 2012.

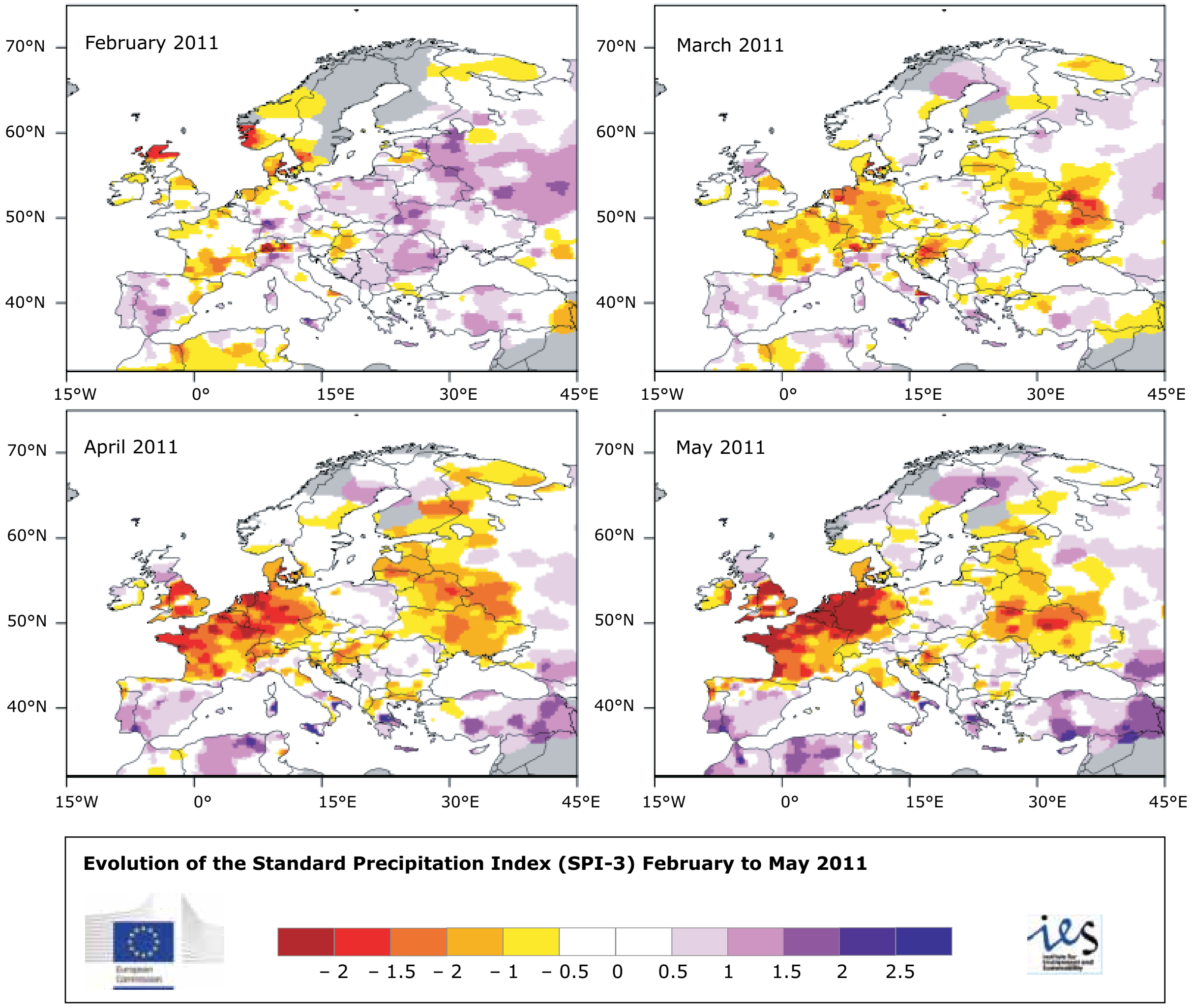
in a warning. Finally, when reduced vegetation production is identified, an alert is issued (Vogt, 2012; Sepulcre at al., 2012). The CDI is updated on a 10-day basis and presented in the EDO.

The EDO assessments of drought conditions on a European level provide overview information useful for monitoring the temporal and spatial evolution of drought events as well as for the assessment of drought hazard. For the critical areas, the situation should be followed up by more detailed local-level analysis based on locally available data. To do so, a multi-scale approach from continental to regional and local scales is required. In the EDO, this has been implemented through the interoperability of drought information systems at different scales.

Recent droughts in Europe, 2011

During 2011, in the period from January to May, severe cumulated rainfall deficits were recorded in the EU, which were comparable to the historic minima for many countries: in France (comparable to 1976), the United Kingdom (comparable to 1997), Belgium, the Netherlands (comparable to 1991, 1982 and 1976), Germany (comparable to 1996), Denmark, parts of the 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, 2011a). The evolution of the three-month SPI (SPI-3) from February to May 2011 is shown in Map 3.5. For e.g. Belgium, France, Germany, the Netherlands, Ukraine and the United Kingdom, the accumulated rainfall in

Map 3.5 Evolution of the SPI3 (February to May 2011)



Note: Values below − 1.5 indicate a severe meteorological drought. Grey shading indicates areas with insufficient reliable data to compute the SPI.

Source: JRC, 2011b.

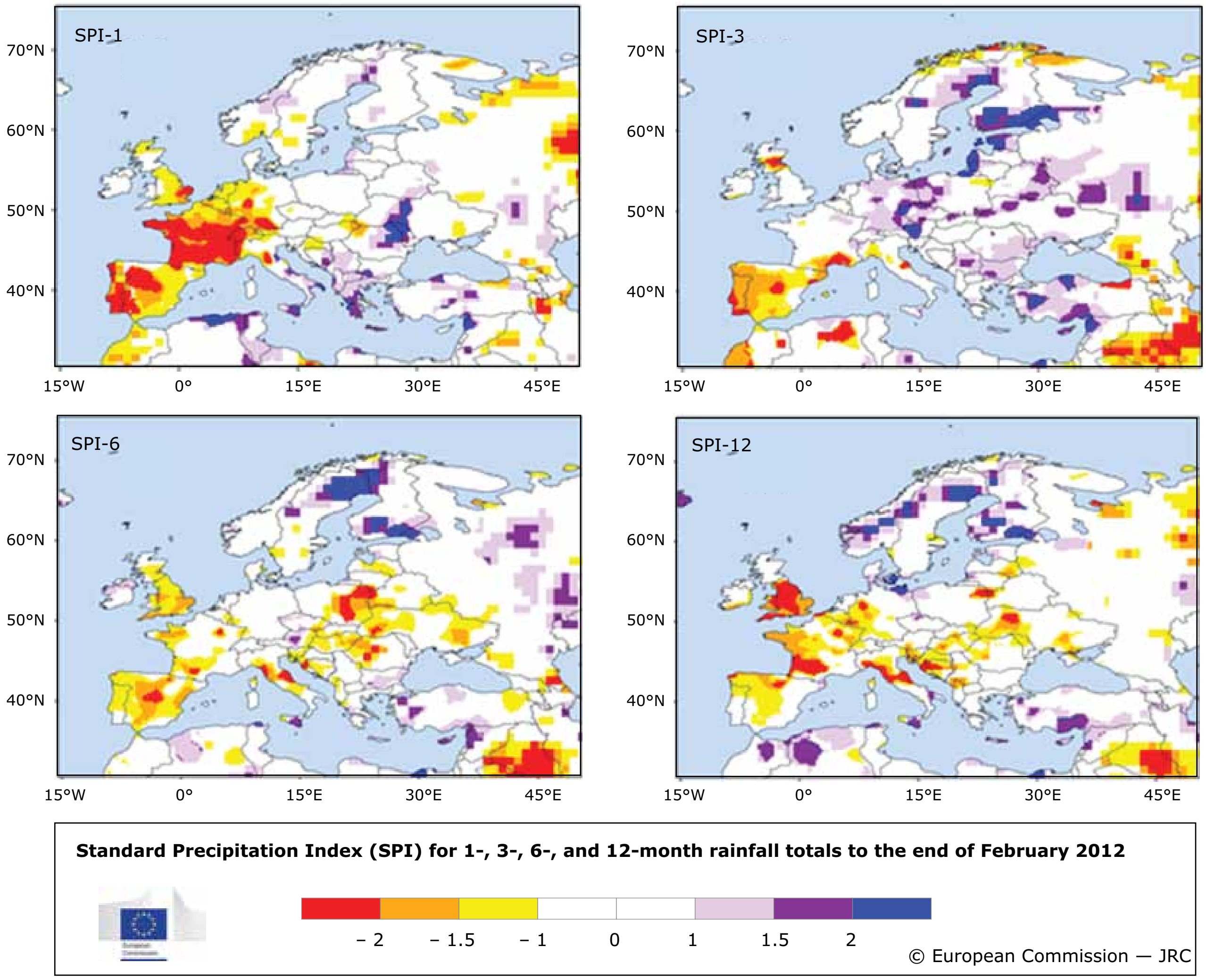
the first half of 2011 was lower than the long-term average rainfall minus one standard deviation for the first half of the year (JRC, 2011a). All rated in the top three of the years with lowest rainfall over the first 6 months of the year over more than 35 years.

Recent droughts in Europe, 2012

In 2012, a reduction in rainfall to below normal levels was recorded during the winter months, impacting the water resources of extended parts of southern and central Europe (JRC, 2012; see Map 3.6). Based on the Standard Precipitation Index (SPI-1) for February 2012, France, Spain, Portugal and England experienced extreme and severe drought conditions, even more pronounced in the low cumulative rainfall as expressed by the SPI-3 (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 also evident in Denmark, northern Italy (Po river) and the northern part of the United Kingdom (JRC, 2012).

In late August 2012 (10-day period from 21 to 31 August), the SPI-3 shows a precipitation deficit in parts of Spain, Italy and the Balkans that translates into a soil moisture deficit and reduced vegetation activity (see Map 3.7).

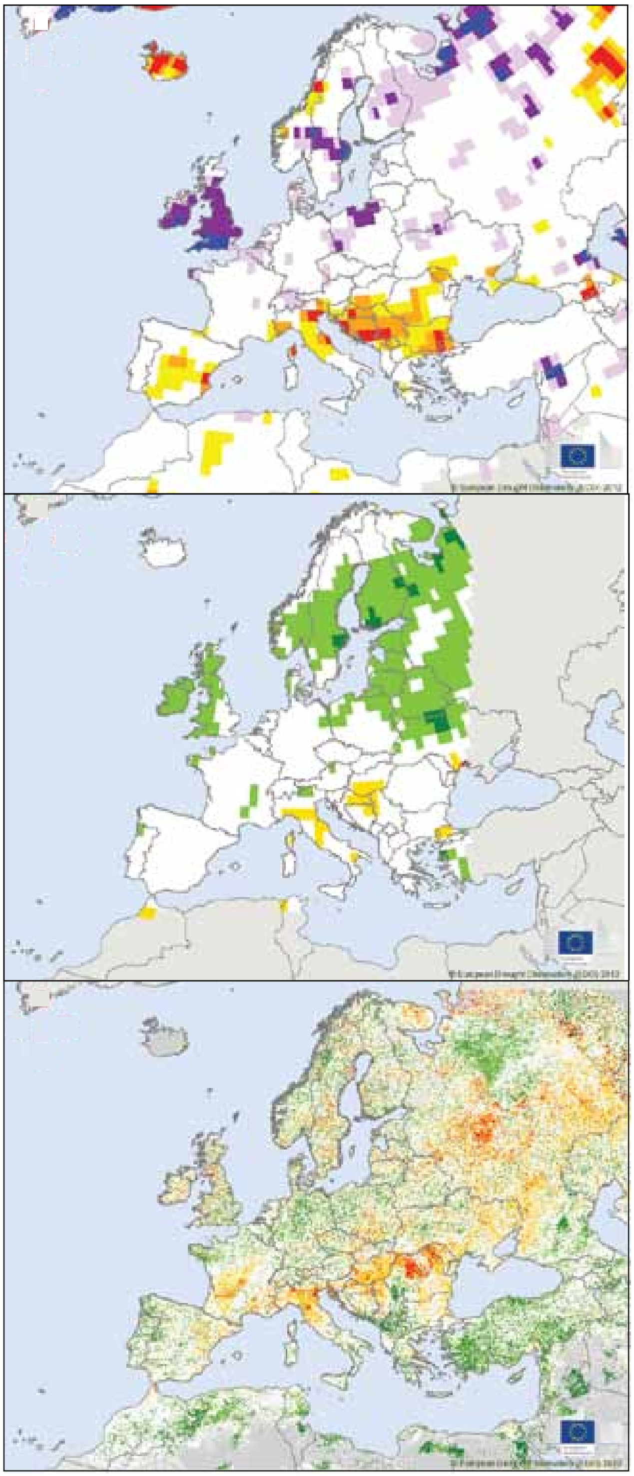
Map 3.6 SPI for 1-, 3-, 6-, and 12-month rainfall totals to the end of February 2012



Note: SPI gives an estimate of the severity of rainfall deficits for an accumulation period for a time of year and location. SPI between – 1 and – 1.5 (yellow) is categorised as moderately dry, SPI between – 1.5 and – 2 (orange) is categorised as severely dry and SPI less than – 2 (red) is categorised as extremely dry.

Source: JRC, 2012.

Map 3.7 SPI-3, Soil Moisture Anomaly and fAPAR Anomaly for the last 10 days of August 2012



Standard Precipitation Index (SPI-3), Soil Moisture Anomaly and Vegatation Productivity Anomaly (fAPAR Anomaly) for the last 10 days of August 2012

SPI blendet and interpolated

- 🟥 Extreme dry (SPI ≤ – 2)
- 🟧 Severe dry (– 2 < SPI ≤ – 1.5)
- 🟨 Moderate dry (– 1.5 < SPI ≤ – 1)
- ⬜ Near normal (– 1 < SPI ≤ 1)
- 🟪 Moderate wet (1 < SPI ≤ 1.5)
- 🟪 Severe wet (1.5 < SPI ≤ 2)
- 🟦 Extreme wet (SPI ≥ 2)

Soil Moisture Anomaly

Drier	🟥	> 2
	🟨	1–2
Normal	⬜	– 1 to 1
	🟩	– 2 to – 1
Wetter	🟩	< – 2

Vegetation Productivity Anomaly (fAPAR Anomaly)

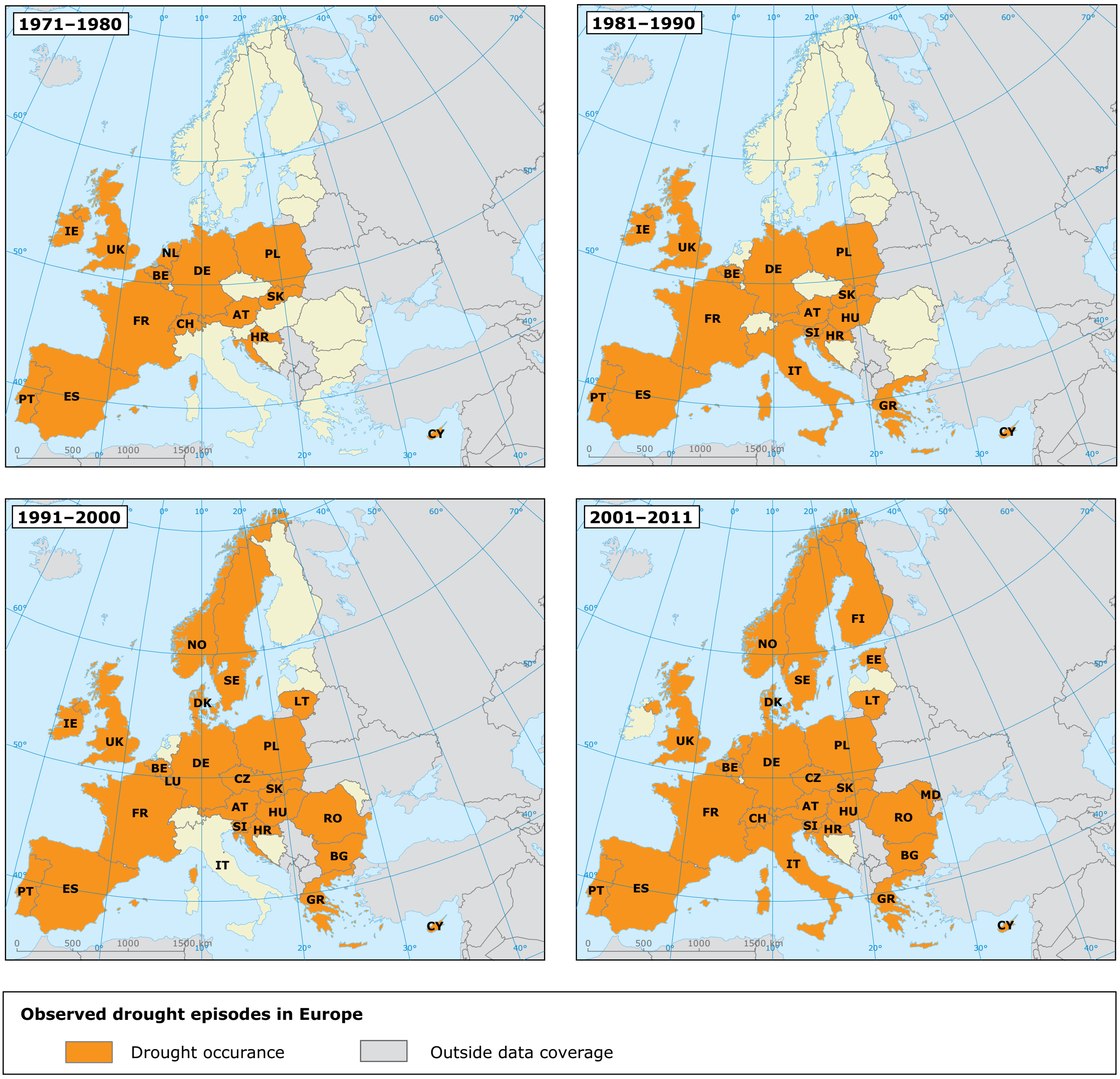
Lower than normal	🟥	< - 2
	🟨	- 2 to -1
Near-normal	⬜	-1 to 1
Higher than normal	🟩	1 to 2
	🟩	> 2

Source: EDO, Joint Research Centre, European Commission, http://edo.jrc.ec.europa.eu.

3.2.3 *Historic drought events*

Many European areas have experienced drought episodes of varying significance, duration (from a few months to years) and extent (from local to regional and from national to international) over the past 40 years. Drought has often grown from a meteorological hazard to an agricultural, hydrological and socio-economic one, subject to the regional characteristics. In so doing, drought has adversely impacted both environment and society. Map 3.8 illustrates the geographical extent of observed drought episodes in Europe per decade from 1971 to 2011. It must be emphasised that these maps demonstrate drought episodes that occurred in a country during a decade regardless of their temporal (few months, or years) and spatial (local, or nationwide) scale. We can observe an increase in the number of countries affected by drought per decade, rising from 15 in the period from 1971 to 1980, to 28 in the period from 2001 to 2011 (17 in the 1981-to-1990 decade and 24 in the 1991-to-2000 decade). A further comparison between the first and last decade in the exercise clearly shows that drought occurrence not only increased in the southern and central regions of the EU, but is also

Map 3.8 Observed drought episodes in Europe (1971–2011)



Note: A country is coloured with orange if drought episodes have occurred in that country during the reference decade, regardless of their temporal and spatial (local or nationwide) scale. No distinction between the severity, the frequency and the extent of the events is made.

Source: The background information has been collected from numerous sources (e.g. country reports, scientific papers, SoE assessments, Environment DG questionnaires to Member States for the purpose of the in-depth assessment on WS&D 2007, etc.).

of relevance for the northern and eastern parts of the EU.

3.2.4 *Assessing water scarcity*

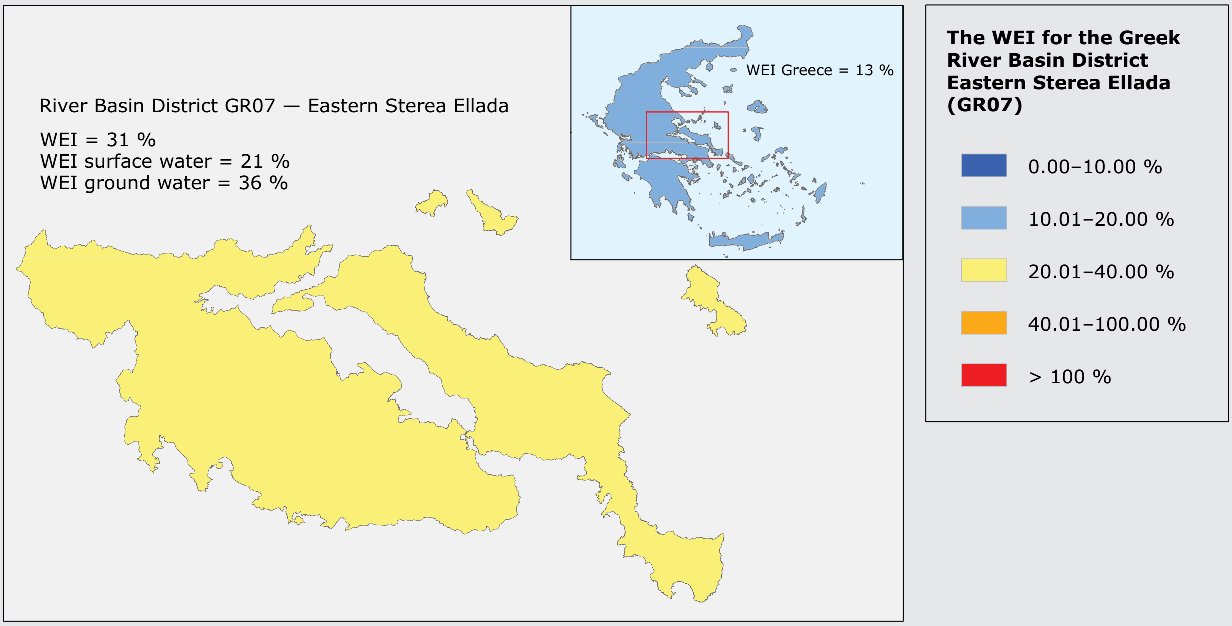
Water scarcity indicators express the level of pressure that human activities exert on the natural water resources (EG WSD 2012). One of the widely-used indicators is the Water Exploitation Index (WEI), defined as the ratio of all annual abstractions over (inter-)annual resources (⁴). The indicator expresses the exploitation of water (i.e. all water abstracted), and not only the use or final use of water. This distinction is important as the possibility to abstract sufficient water is a prerequisite to human activities, even if a large share of these abstracted volumes are returned to the natural system as happens with cooling water used in industry or electricity generation or water used for hydropower production.

Box 3.1 The importance of scaling and decoupling in the estimation of water exploitation and water stress

Choosing the spatial scale of analysis is essential to give an accurate representation of water scarcity conditions. Highly aggregated scales like country level fail to depict the full problem, as deficits between water resource availability and demand in one area can be hidden by surpluses in other areas. Similarly, separating surface water 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 an aggregate and the appropriate measures to counter the water stress may therefore be missing.

The Greek case of the RBD of eastern Sterea Ellada (GR07) is a relevant illustrative example. The WEI calculated based on long-term average availability of water describes 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 3.9). A further analysis conducted at river basin scale and sub-catchment scale, separating surface water (WEI_SW) and groundwater (WEI_GW) exploitation (Map 3.10) shows great variability within the RBD, with some basins and catchments being overexploited while others are not stressed. It also reveals a large range in the exploitation rates of the surface water and groundwater. This scale of analysis can better support the identification of the problem (together with additional management indicators) and guide targeted actions.

Map 3.9 The WEI for the RBD eastern Sterea Ellada (GR07) (Greece)

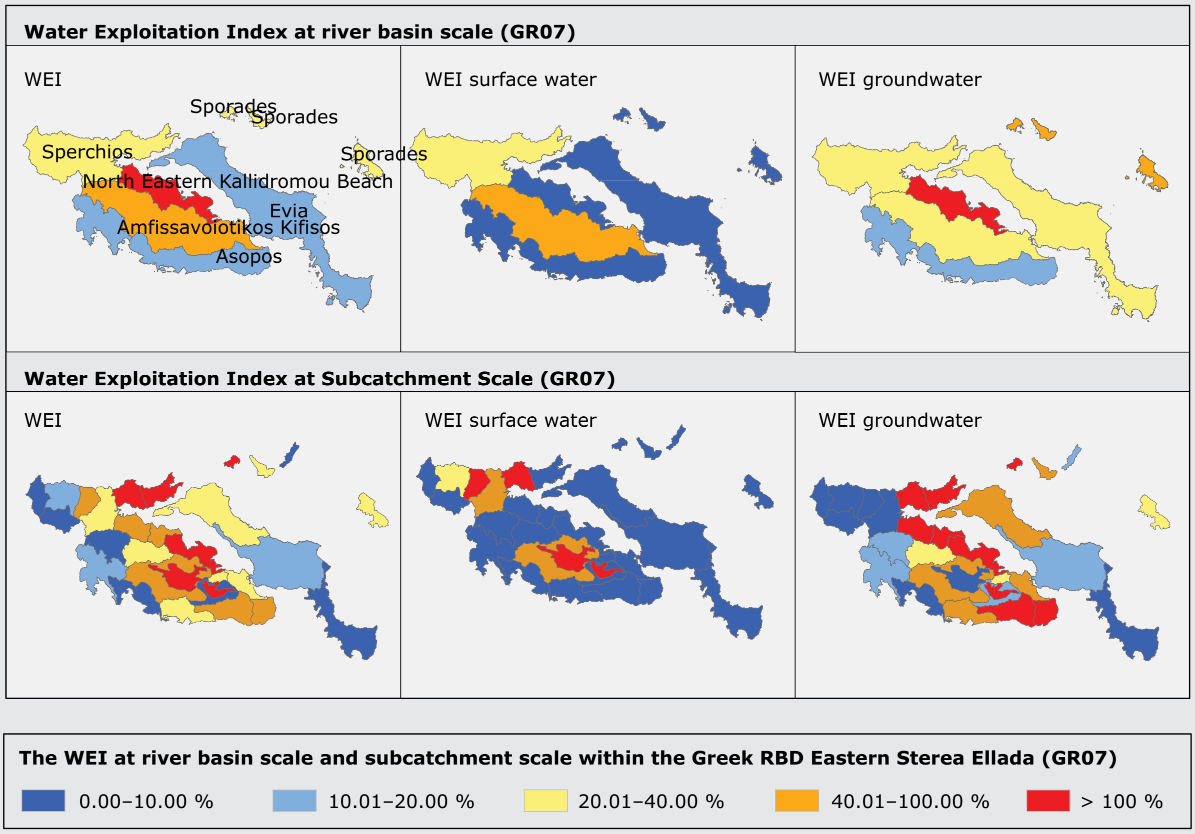


Source: Compiled by the ETC/ICM based on data provided in the Drought and Water Scarcity Management Plan of GR07 (Hellenic Ministry of Environment, Energy and Climate Change and NAMA S.A., 2012).

(⁴) All different categories of abstractions (from different sectors like agriculture, process water, energy production, public water supply etc.) are lumped together. To define downstream the resource availability it is important to know how much of this volume of water is consumed, returned (in the same water body or elsewhere) or how quality is influenced.

Box 3.1 The importance of scaling and decoupling in the estimation of water exploitation and water stress (cont.)

Map 3.10 **The WEI at river basin and sub-catchment scale within the RBD eastern Sterea Ellada (GR07) (Greece)**



Note: WEI total (left), for surface water (middle) and groundwater resources (right) at river basin (top) and sub-catchment scale (bottom) 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).

Historically this indicator was developed and applied at country and yearly level, as in the definition used by Eurostat (2011). It was designed as a tool for raising awareness of the state of water resources. The water exploitation index is an important indicator of the sustainability of use of freshwater resources and is one of the EEA's core set indicators (CSI 018 (5)). It shows in very general terms how total water abstraction puts pressure on water resources, identifying those countries prone to water stress. Changes over time (e.g. comparing values from 1990s with recent values) in the indicator help to analyse the impact of changes in abstraction, which can be caused either by increasing pressure on water or by more sustainable use of water.

The countries in the Mediterranean climate zone obviously have a rather high water exploitation index compared to northern Europe, but also in comparison with other areas across Europe. This is due to different reasons. For example, the Mediterranean climate zone is densely populated, and has large abstractions of water for agriculture.

Almost everywhere in Europe there are large seasonal differences in the water exploitation index, with

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(5) http://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources/use-of-freshwater-resources-assessment-2

temporal water stress occurring during summer months (when minimal availability is confronted with maximal agricultural demand). Hence, when the indicator is computed on an annual level, it only addresses the structural issues of water scarcity and is unable to depict any seasonal issues. Furthermore River basins within a country can be placed in rather different climate zones and the regional differences within a country are significant. A national indicator can obscure these regional differences, 'smoothing' out the values from different areas and thus making it unsuitable for water management interventions.

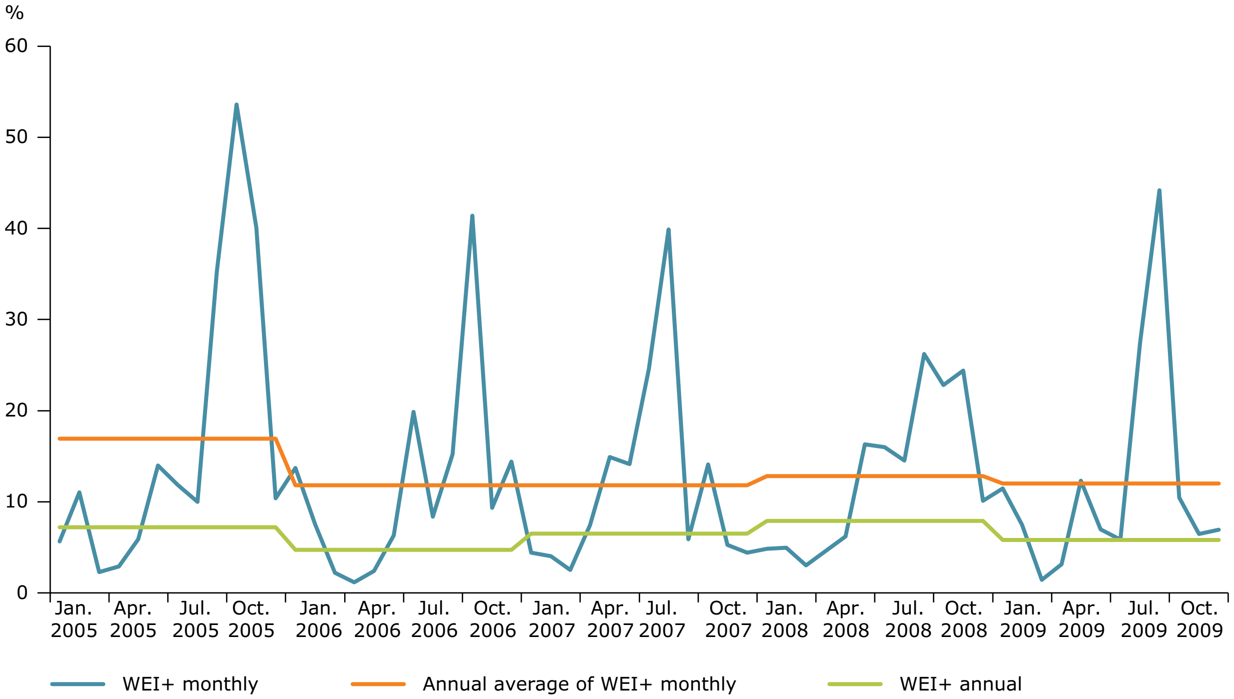
The need for spatial and temporal variability

The limitations of a national WEI are shown in the Greek example (Box 3.1). The national WEI does not reflect the large variety between sub-catchments. This variety is relevant for water management as resource deficits in one area cannot easily be compensated for by surpluses elsewhere. Reference areas that are too large (e.g. country, or even RBD) risk having their internal hydrological diversity neglected. Similar, sample data for the Czech Republic show the monthly variability of the Water exploitation index (see Figure 3.5). This variability is totally the result of seasonal hydrological variation and its expression is significantly related to seasonal buffer capacities (such as by large lakes) or transfer between areas.

Recognising the fact that a yearly time scale for a WEI on the national level has important limitations, the EEA works together with the European Commission on the development of Water Accounts (EEA, 2012h, see also Section 3.2.6) for monthly calculations on sub-basin level. EEA also works with the CIS WFD Expert Group on Water Scarcity and Droughts (EG WSD) to further test refine and improve the development of the traditional WEI into a WEI+ to reflect the above mentioned limitations and to better reflect the actual water scarcity situation as perceived and reported now in the first RBMP (see Section 3.2.1).

In terms of the assessment for the 'Blueprint to safeguard Europe's water resources', the WEI — improved by the WEI+ and the water accounts — provides an overview of water scarcity in Europe, and is able to communicate the problem of overexploitation to other EU policy areas. On the regional level — to develop the adequate management strategies — there is a need for more thorough analysis of the occurrence and causes of water scarcity as a phenomenon that is distinct from droughts. The first round of RBMP reporting

Figure 3.5 Variability of the WEI+ at Morava river basin (Czech Republic)



Note: Provisional data for the period 2005–2009 at monthly and yearly scale.

Source: Czech Republic Department of Hydrology (draft results, not published).

showed a deficit in precisely this area (Schmidt and Benítez, 2012, see also Map 3.3 in Section 3.2.1). Regional water balances feeding into indicators of WS&D (including the seasonality aspects) will improve the coherency and efficiency of water resource management measures in the RBMP Programme of Measures. Adequate knowledge of ecological flows as a regime over time helps target these measures to reach the good status in the water body and sustainably maintain the ecosystem services provided. The need for this knowledge is also expressed in Programmes of Measures in the 2009 RBMPs where improving knowledge and governance is the most mentioned group of measures (mentioned in 85 % of RBMPs, Schmidt and Benítez 2012).

3.2.5 *Future projections for droughts and water scarcity*

A summary of possible future evolutions of droughts is described by the EEA (2012c) based on the 'Climate Adaptation — modelling water scenarios and sectoral impacts' ClimWatAdapt project (Flörke et al. 2011). Hydrological droughts (as depicted by stream flow indicators) are projected to increase in frequency and severity in southern and south-eastern Europe, the United Kingdom, France, Belgium, the Netherlands and Luxembourg, southern Scandinavia and western parts of Germany over the coming decades (Feyen and Dankers, 2009). Especially in summer, a decrease in low flows is projected for many places in Europe, and these low flows are set to occur earlier in the season (Stahl et al., 2012). These low-flow analyses of observed (Stahl et al., 2010) and projected low flows (Stahl et al., 2012) are consistent with a Europe-wide selection of catchments where droughts are analysed in the 'Fostering European drought research and science-policy interfacing' (DROUGHT-R&SPI) project (Alderlieste and van Lanen, 2012).

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, and climate change exacerbates the problem. Water resources are expected to decrease in Europe as a result of an increasing imbalance between water demand and water availability. Water scarcity, mainly due to increased projections for irrigation, is projected to increase in many regions in Europe. How water demand might evolve and how this could impact water scarcity figures is described by the (EEA, 2012e). 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 by the EEA (2012f). Many cities in southern and eastern Europe, as well as some in western Europe, are already experiencing water stress during the summer. Projections indicate a deterioration and also a northwards extension of the problem in future. When cities need to overcome regional water scarcity through imported water, they become more dependent on other regions, with implications for water pricing.

3.2.6 *Improving knowledge: spatial and temporal refined needs for data*

Water scarcity and droughts are nowadays relevant for the majority of RBDs in Europe (Schmidt and Benítez, 2012), a situation that will most probably only be exacerbated by climate change. This means that improved knowledge of the water balances on the sub-basin level is a necessity for proper low flow management. There is also a need for spatial and time disaggregation to soundly represent the fact that water scarcity is in Europe mainly (apart from those areas exhibiting a permanent and hence structural deficit) an issue during summer season, and the corresponding data have to be collected.

The water asset accounts developed by the EEA and carried out with extensive data collection schemes, provide this comprehensive data set. This set is based on collection at the smallest physical level and aggregated at the sub-basin level and at monthly resolution over eight years on average. This data collection is based on much wider scope and detail than the current EEA Eionet priority data flow; the reporting under the WFD and Water Scarcity and droughts communication; or the Eurostat/OECD joint questionnaire. An important difference between this and the original WEI is the use of the use of a directly measurable parameter in the form of monthly river discharge that enables the monthly disaggregation of the water assets accounts.

There are three important features in the water asset account data and assessment scheme. First the assessment is based on a geographical reference system (Ecrins) to spatially organise data and define selection procedures. Second, the systematic reference to the LEAC kilometric grid for data organised as continuous fields (e.g. rainfall) enables to connect field related data to many other spatial features. And finally, for point data, the stratified approach allows the largest or most important objects to be accurately documented, whereas the smallest are addressed with the most effective method to minimise data collection burden while still incorporating their relevant values in the data sets. Several questions have to be answered including how to deal with parameters that are not directly measurable or what to do when the spatial or temporal distribution is uncertain. Another open question is how to consider multiple uses of water, with special regard to the successive non-consumptive uses that have eventually a significant impact on the aquatic system.

For the abstractions by the different sectors and categories a stratified approach is applied. The lack of data available hampers the proposed stratified approach in which the largest categories (e.g. metropolis, big power plants, major chemical industry sites) are individually surveyed. For the medium category, individual modelling is applied in order to insist on the pre-eminence of accurate positioning rather than on the precision of data If no individual data is available, information can be derived from regional or national technical coefficients or activity volumes. In the smallest category, lumped modelling is justified based on technical coefficients. This stratification in the treatment of scarce data can be justified by the extremely odd distribution of water abstractions, where for example a few hundreds of cities in Europe host close to 80 % of the population and likely more than 80 % of the total urban abstractions.

While the tools for the water accounts are being implemented and are already available, there are in practice large differences in data availability and completeness for different European countries for all categories of data (reference systems, river discharge, domestic uses, cooling water, process water and irrigation water). Future implementation needs to discuss and develop how the information needs for the water accounts on different scales can be moved into a more coherent and regular exercise.

When it comes to the international RBMPs, there is a clear approach on how WSD is dealt with in only about one third of the assessed 2009 RBMPs (Schmidt and Benítez 2012). This may be due to a lack of knowledge but it is more likely due to an absence of a common methodology and comparable set of indicators. Creating this common methodology and set of indicators should now be a priority. Based on the locally available datasets, the right indicator set has to be created for detailed water balances at the sub-basin level, explicitly taking into account seasonal variability. From the assessment of water scarcity and drought aspects in the 2009 RBMP (Schmidt and Benítez 2012), it became clear that more data are needed to distinguish between water scarcity and droughts. The quantitative data in several RBMPs are actually insufficient for a pro-active planning (Schmidt and Benítez 2012) and management based on prevention measures.

The WEI+ so far collected data on RBD level and — as a main limiting factor — on yearly level. The results so far do not reflect sufficiently the current situation of water scarcity in a number of Member States. Especially for summer situations the yearly average in the WEI+ is often seen as misleading and underestimating the water scarcity problem, thus ignoring its impacts. Here the water accounts can provide more detailed information, reflecting the variability in water exploitation index in sub-basins in the same RBD (similar to the situation expressed in Box 3.1). The water accounts can also provide a WEI reflecting the seasonal variability. With monthly data available, the variability of the flow regime and the seasonality effect can be expressed. They clearly show the areas with large variations in WEI and the situation regarding the variability of the flow regime.

For the second round of RBMPs, improved water scarcity assessments are also needed on a European level to reflect in the best way possible the water scarcity situation as seen in a river basin.

The still rather simple expression of the WEI+ and the more sophisticated calculations of the water asset accounts both have their advantages. In this CIS process, a methodological development would be needed to harmonise the WEI+ and the water accounts and to give the assessments both on RBD level (by member states) and on EU level on a comparable basis. It needs to bring together thematic and regional experts to fine-tune the indicator formulas from a conceptual point of view, as well as from a data-availability and calculability perspective.

This process began in parallel to the publication of this report with the consultation over the first results of the water accounts. This is a work in progress and draft results are expected in early 2013. With a technical report on water accounts, the EEA is providing input to the CIS process to develop guidance on water accounting at the sub-basin level, and to provide tools that can help water managers in the development of their programme of measures.

3.3 Floods and inundations

Throughout 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 (Brázdil et al., 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 flood hazard has changed in recent decades. When discussing changes and trends in flooding, it is important to distinguish between, on the one hand, changes in the occurrence of periods of intense river flooding (Section 3.3) and on the other hand, changes in economic damage resulting from inundation and destruction of infrastructure (Section 4.2).

Several severe flooding events have occurred in Europe over recent decades, causing loss of life, displacement of people, and heavy economic losses (EEA, 2011a). From 1980 to 2011, more than 325 major river floods were reported for all EEA member countries and co-operating countries, of which more than 200 were reported after 2000. The rise in the reported number of flood events over recent decades results mainly from better reporting and from land use changes.

Data sources

Any discussion of trends in flood occurrence highlights the current lack of a coherent European programme for collecting data and information on past floods. This may sound contradictory, as there are many national databases and research projects dealing with the physical event of flooding as well as with the impacts and responses (see Chapter 4). However, most of these deal with case studies, and the sum of all these cases is not easily combined into one European overview.

As a result of the Floods Directive, flood hazard maps will become available on an appropriate scale and for various scenarios. Information on past floods was part of the Preliminary Flood Risk Assessments (PFRAs). A great deal of information became available, but the PFRAs were based on readily- or easily-derivable information. This meant that many details are lacking concerning the physical aspects of the event (like the extent of the flood, the mechanism of flooding or its duration); their impacts (e.g. for few events, environmental and social impacts are given in a (semi-)quantitative way); and common thresholds to define which events to include as significant on a European scale.

The Working Group on Floods (see below) prepared a template for the reporting under the EU Floods Directive based on the source, mechanism and characteristics of floods (WG F Drafting Group, 2011b). This structure provides a good starting point for a standardised European database on past flooding. The main flood 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;
- seawater (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 of banks;
- defence exceedance (overtopping defences);
- defence or infrastructural failure (could include breaching or collapse of a flood defence or retention structure, but also includes the 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 distinguishing characteristics of floods are:

- flash floods (quite rapid 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.

The Working Group on Floods
The Working Group on Floods (WGF) is one of the working groups under the CIS for the WFD. Its purpose is to provide a forum for support in the implementation of the Floods Directive. It also acts as an information exchange between Member States and stakeholders on good practices with a view to reaching a common understanding on the requirements for the implementation of the Floods Directive. The WGF's final purpose is to link other related activities in the CIS, and support implementation at EU level.

Besides its work on the finalisation of the reporting formats for the Floods Directive, the WGF holds thematic workshops each year on themes related to the implementation of the Floods Directive. In the past, workshops were dedicated to the different stages of implementation (PFRA, flood hazard and risk mapping, Flood Risk Management Plan (FRMP)) as well as on overarching themes like climate change adaptation, catchment approach, and also on more specific types of flooding (flash floods). There is also information exchange to link and coordinate the Floods Directive with other relevant EU-level activities, including civil protection, accident prevention, integrated coastal zone management, agriculture, critical infrastructure, regional and structural development, as well as the JRC's activities on floods including the European Flood Alert System. Relevant research initiatives are presented to the WGF in coordination with the Research and Innovation DG.

3.3.1 Changes in flood flow

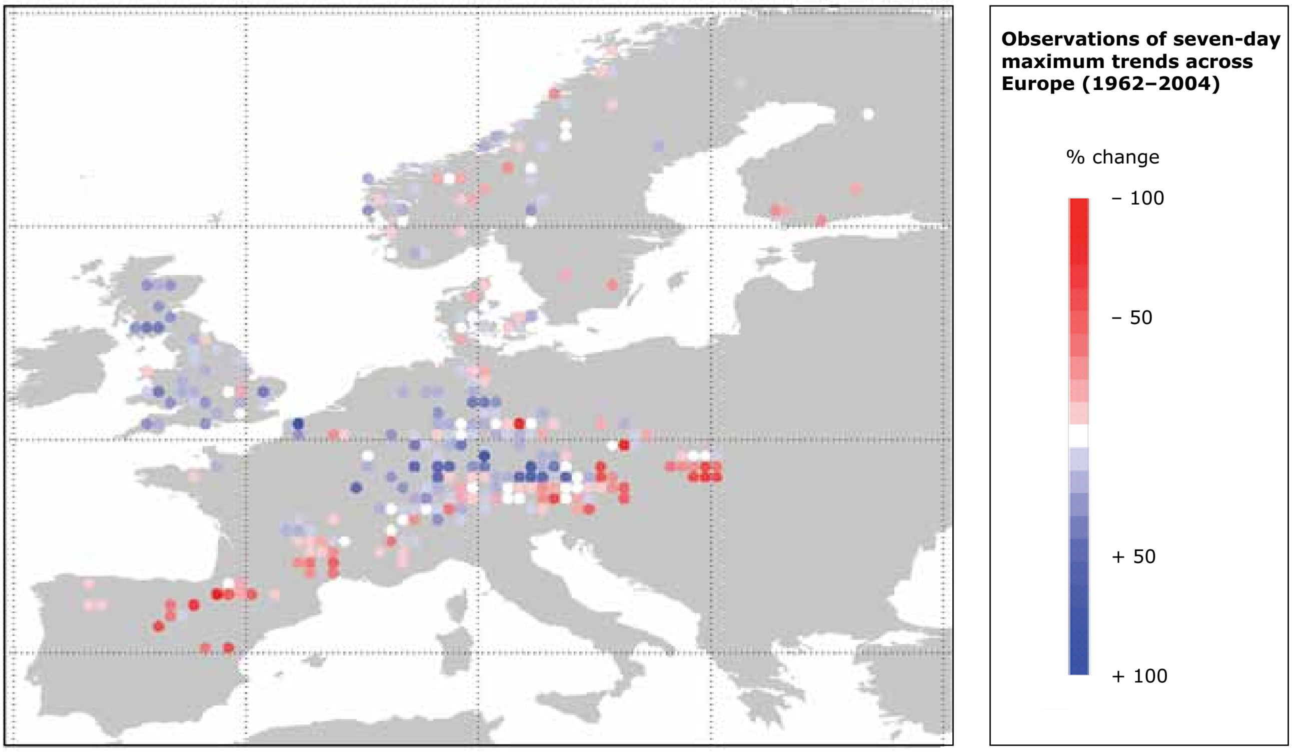
Available evidence suggests different patterns of flood flow across Europe, with increasing high flows in northern Europe, especially in western Britain and coastal Scandinavia. However, regional patterns are diverse, with many weak negative trends occurring in northern Europe as well, and a very mixed 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, and the relatively short period of observation in most rivers. Stahl et al. (2012) analysed trends in seven-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 the steepest trends in western Britain and coastal Scandinavia, but regional patterns are very mixed (Map 3.11). Conclusions from such evidence-based studies are limited in spatial scope to the areas where observed long-term flow data exist and are made available. For example, no observation data from south-eastern Europe were included in the study (Stahl et al., 2012).

Significant trends in river inundations have been identified in some regional and national studies. For example, significant increases in flood intensities have been identified between 1951 and 2002 in western, southern and central Germany (Petrow and Merz, 2009) as well as in upland catchments in the northern and western United Kingdom (Hannaford and Marsh, 2008). A new analysis of the strong British floods of 2000 suggests that anthropogenic climate change was a contributing factor (Pall et al., 2011). In the Alps (Renard et al., 2008) and Nordic region (Wilson et al., 2010), snowmelt floods have occurred earlier because of warmer winters. In contrast, no conclusive evidence was found in an analysis of flood trends in Austria (Villarini et al. 2012), and an increasing flood trend in Catalonia is attributed to socio-economic factors (Barnolas and Llasat, 2007).

3.3.2 Future evolution of 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. They should also include environmental evolutions. Recent studies (e.g. Dankers and Feyen, 2009; Feyen et al., 2011) suggest that climate change can add significantly to expected flood damage 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).

Map 3.11 Observations of seven-day maximum trends across Europe (1962–2004)



Source: Stahl et al., 2012.

The ClimWatAdapt project (Flörke et al., 2011) focused on floods with an annual exceedance probability of 1 % (equivalent to the predicted 100-year flood). The future scenarios showed that the likelihood of 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 produced very different results. Using the aggregated 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, 2012c). Flash floods and urban floods, which are triggered by intense local precipitation events, are also likely to become more frequent throughout Europe (Christensen and Christensen, 2002; Kundzewicz et al., 2006). Also, the trends in the annual run-off demonstrate a pronounced divergence in the pattern for Europe, with positive trends in western and northern Europe, and a negative one in southern parts of eastern Europe, mainly due to greater wetness during winter months (Stahl et al., 2012).

Contrary to the increasing trend of high flows in many rain-dominated regions in Europe, an inconsistent or decreasing trend in the high flows was found for snow-dominated regions (Stahl et al., 2012). 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. This will compensate for the increase in summer flood damage in these regions.

4 Impacts and responses

Water managers in Europe and beyond are faced with a catalogue of challenges of hitherto unseen proportions. Increased vulnerability to climate change in relation to social and economic changes and vulnerabilities in our society constitutes a challenge that is similar for different water management issues, be it too much or too little water. The first commonality is that both droughts/scarcity and floods have their starting point in a climatic or weather event; hence both are important impacts to be discussed in the context of climate change. Secondly, both scarcity/droughts and floods can be partly attributed to the spatial aspects of water management and planning. However, in this respect, there are wide differences in terms of impacts, while some of the responses in terms of risk management or importance of transboundary cooperation are similar. Also drought/scarcity and floods share the fact that the most sustainable measures to address them focus on long-term functionality of eco-systems and on increasing the resilience of ecosystems (rivers, groundwater bodies, and adjacent wetlands), so as they will be able to cope with and buffer sudden anomalies in precipitation and temperature resulting in floods or droughts. A consequent response to both is therefore the move from a traditional sectoral approach towards a more holistic consideration of water within the broader concept of ecosystem services. This should be combined with an appreciation for the increasing uncertainty of the future direction and magnitude of the drivers and pressures, for example climate or land use changes.

Despite this common ground, water scarcity and droughts do present some differences with flooding, for example in terms of their spatial and temporal scales. The existing water legislation provides a robust starting point for these distinct yet integrated policies. The 'Blueprint to safeguard Europe's water resources' (EC, 2012) can further elaborate these synergies between the goals and objectives of the different forms of water legislation by improving their implementation and fostering integration with other policies where desirable.

Droughts, water scarcity and floods all need a regional approach tailored to the respective natural and socio-economic conditions in the river basin. The impacts of these phenomena are distinct and are therefore described below in separated sections for water scarcity and drought, and for floods. Regarding the responses and the management planning, there is considerable added value in looking for synergies. Where the previous chapter focused mainly on the description of status, events and indicators for water scarcity and drought, this chapter promotes integrated management for water quantity. In addition to the effectiveness of measures as defined by the WFD, spatial planning; the consideration of ecosystem functionality; and efficiency are all key terms for the management of both floods and water scarcity.

4.1 Impacts

The impacts of both floods and droughts can widely affect our environment and society. This can be seen in economic, social and environmental impacts. Besides these three categories, the Floods Directive also explicitly mentions impacts on cultural heritage. Moreover, droughts can impact cultural assets by affecting the stability or conservation of buildings and landscapes. On the social side, both floods and droughts also affect human health and safety. In the following section, these impacts are linked to their economic and environmental impact, rather than treated as a separate category.

4.1.1 Water scarcity and droughts

To understand the impacts of water scarcity and droughts, Table 3.1 explains the terms as they relate to cause and timescale. The more long-term the effect, the more likely it becomes that environmental impacts will be accompanied by socio-economic impacts. In a risk assessment approach (trying to avoid the hazard or to limit its impacts), management have to avoid making by adverse climatic effects worse by additional strains like over-abstraction or flawed flood plain or reservoir management (see also Section 4.2 for responses).

The impacts of WS&D 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 et al., 2007). Economic losses and social disruption are examples of indirect impacts. Another classification of impacts is the division between economic, environmental and social impacts, each of which is treated in detail below.

Economic impacts

Economic impacts relate to the different economic sectors such as agriculture, industry, energy, navigation, and tourism. Mitigation measures and short-term solutions (e.g. water transfers) to overcome water scarcity have to be included in any assessment of the costs of scarcity or drought. These economic impacts are not exclusive to the Mediterranean; they occur throughout Europe, either directly or as a consequence of rising prices.

Agricultural economic damage includes losses in production of crops and livestock. The drought of 2003 mainly affected agricultural production in Romania where wheat production was just one third of production in a normal year (2 500 t/ha compared to 7 000 t/ha of a normal year) (DMCSEE, 2009). In Portugal, during the summer of 2005, large amounts of crops were destroyed because of drought (leading to a 60 % loss of wheat and an 80 % loss of maize production) (Isendahl and Schmidt, 2006). The costs exceeded EUR 500 million. 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 (resulting in a later harvesting period, and 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 region. Due to reduced production, feed prices rose and costs related to imports increased.

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

During nine summer periods between 1979 and 2007, the German government had to reduce the production of nuclear power due to high temperatures of water and/or low water flow rates (Müller et al., 2007). The reduction of power output of the Unterweser nuclear power plant was reported at 90 % (i.e. the plant was running at 10 % of its capacity) 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). Due to the 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 and Vögele, 2011). During the 2009 summer heat wave, shortages of cooling water resulted in a shortage of about 8 gigawatt (GW) in France, the largest European electricity exporter, resulting in imports of electricity from Great Britain (Pagnamenta, 2009, in Rübbelke and Vögele, 2011).

Hydropower is directly affected by drought and low flows. The drought of 2002 and 2003 affected most of Norway, Sweden and Finland leading to a considerable decrease in hydropower production and a consequent increase in the price of electricity (Kuusisto, 2004). 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,energy, and agriculture exceeded EUR 300 million (EC, 2007a).

Low river discharges and low water levels cause restrictions in the inland navigation sector, leading to an important increase in 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 EUR 70 million, while the total cost can increase to up EUR 800 million in a year with extremely low discharge conditions. In May 2011, river Rhine and river Meuse discharge 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 % to 50 % of their capacity (Vidal, 2011). Also, the need to switch transportation method increases the price of products, affecting almost the entire industrial sector.

Social impacts
Several of the social or socio-economic impacts of water scarcity and droughts are related to public water supply. A deficiency in water supply negatively affects the quality of life of individuals and communities. Depending on the frequency, duration and extent of the interruptions in water supply, public health and safety issues can arise. The 2008 extreme drought event left Spain's reservoirs half-empty. In particular, some reservoirs in Catalonia that supplied almost 6 million inhabitants reached 20 % of their capacity, resulting in restrictions on domestic water use, such as for swimming pools and gardening, as well as on public water use, such as for fountains (Collins, 2009). These measures reduce quality of life to a certain extent but do not have direct economic impacts — except for on tourism and recreation — as long as public health and safety are secured.

The price of maintaining supply can be considerable: in Portugal during the 2004-to-2006 drought, the cost for public water supply was over EUR 20 million, while 22 850 water supply operations using tankers supported urban water supply in 66 municipalities with more than 100 000 inhabitants. The cost of the inconvenience to the inhabitants affected was considered to be significantly higher than the direct costs reported (MAOTDR, 2007).

The impacts of water shortages are not equally distributed and can be a source of conflict between different water users. In Greece, water consumers are affected by serious water shortage problems, particularly interruptions, during irrigation season, when about 87 % of total freshwater abstraction is used for agriculture (Isendahl and Schmidt, 2006). This conflict occurs not only at the local level between users, but can acquire regional importance when water transfers are made and flow regimes are changed. 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).

Environmental impacts
As explained in the introduction of Section 3.2 and in Table 3.1, there is a difference between droughts (which have a natural cause) and water scarcity (which has human-induced causes) The impact of droughts on the environment is often rather limited, as most ecosystems are dependent on fluctuations in water level, moisture, etc. Severe droughts will have a negative impact on the services these ecosystems can deliver, but when water scarcity (as a man-made over-abstraction of the available resources) strengthens the effects of a drought, environmental management is no longer sustainable, and there will be structural negative environmental impacts.

Both water quantity and water quality have an important influence on the environmental impacts. A decrease in available water resources jeopardises environmental flows as a minimum requirement for a healthy ecosystem. A degradation of water quality — for example by eutrophication or seawater intrusion — further increases the pressures on the freshwater-dependent ecosystems. These are not only the riverine ecosystems but also terrestrial ones that depend on fresh surface water or groundwater resources. There are many examples of the already measurable effects of water scarcity on ecosystems and their services.

For over the last 40 years, groundwater overexploitation in the southern part of Spain has had an enormous ecological 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 salt-water intrusion. The problem of salt-water intrusion due to overexploitation is also very common in several coastal aquifers of Italy (Antonellini et al., 2008). In coastal areas in Sardinia, the Catanian Plain of Sicily, the Tiber Delta, Versilia, and the Po Plain, freshwater resources are becoming scarcer due to drought, overexploitation and salinisation. In the special case of Malta, where no large rivers can provide freshwater, high water demand results in over-abstraction, and the main groundwater bodies risk failing to achieve the environmental objectives of the WFD (MEPA and MRA, 2010).

Other impacts include the loss of biodiversity and the degradation of landscape quality. In Section 3.1.1 the important role of wetlands and forests is explained at local and a regional scale. Throughout Europe, it is possible to find several other examples of biodiversity loss caused by extreme drought events in combination with water scarcity affecting water quantity and quality. According to research conducted from June 2003 to March 2008 in the Mondego estuary in Portugal, drought conditions have had a significant impact on fish communities, causing disturbances in their behaviour and functions (Baptista et al. 2010).

During drought periods, brackish habitats moved to more upstream areas due to increased salinity inside the estuary and low freshwater flows further upriver. This also resulted in new marine adventitious species being found downstream. Freshwater species no longer existed inside the Montego estuary during drought, and lower densities were observed for most of the species. The drought resulted also in water levels falling in many reservoirs in several parts of Portugal. Two major reservoirs (Funcho and Arade) completely dried out. The reduced river flows, together with a degradation in water quality consequently affect migrating species (e.g. lamprey in Minho river), caused a water table decline in aquifers; salt-water intrusion in transboundary waterbodies (e.g. Tagus Estuary); forest fires; and 220 tonnes of dead fish (MAOTDR, 2007).

In Romania, severe drought events (such as in 2007 and 2009) are reported to have negatively affected forest areas, causing changes in the area occupied by several tree species and the boundaries of vegetation zones (which moved north and west of the silvo-steppe), while also encouraging the appearance of certain Saharan species in southern Romania (Lupu et al., 2010). Hills and plains covered with forests in south and east Romania, such as Dolj, Olt, Galati, Braila and Ialomita, have been proved to be very vulnerable to drought. This vulnerability not only affects environmental balance, but it also has a negative socio-economic impact on the population. Also, in the Czech Republic during the dry years (2003–2004), an increased defoliation of tree species was noticed. It especially affected the dieback of unoriginal spruce forests and *Pinus nigra*. Forests weakened by drought were more vulnerable and consequently were attacked by *Armillaria ostoyae* and bark-beetles (Czech Republic National SD Reports, 2008).

The indirect environmental impacts of droughts and water scarcity are also important. Once vegetation becomes scarcer, increased soil erosion can take place. Dry vegetation is also more vulnerable to forest and range fires. 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).

4.1.2 Floods

Article 1 of the Floods Directive (EC, 2007b) states its purpose as being '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'.

Worldwide databases for natural disasters in general, like the International Disaster Database (EM-DAT) (2012) or the Downloadcenter for statistics on natural catastrophes (NatCatService) (2012), or more specifically for floods, e.g. Dartmouth Flood Observatory (2012) are nowadays the main data sources available for Europe-wide studies. Details on damage have been compiled in the EM-DAT database, which contains data on floods fulfilling at least one of the following criteria:

- 10 or more people reported killed;
- 100 or more people reported affected;
- declaration of a state of emergency;
- call for international assistance.

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).

The thresholds used to include an event in the database make them less accurate for smaller events that still have a significant impact. In the reporting of the preliminary flood risk assessment for the European Floods Directive (EC, 2007b), 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 across Europe, exploring possibilities for a common European database.

ClimateCost (Watkiss, 2011) — a European project — made an assessment of future changes in the cost of floods in Europe. To achieve this, river flow changes affecting the frequency of floods were combined with information on exposed assets, depth-damage relations and population density, to estimate economic losses 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 EUR 5.5 billion for the EU-27.

On average, the study projected higher flood damages for all countries within the EU (Map 4.1). Taking into account both climate and socio-economic changes under the A1B scenario (6), the EAD was projected to increase to EUR 20 billion by the 2020s, to over EUR 45 billion by the 2050s, and almost EUR 100 billion by the 2080s for the aggregated 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 EUR 10 billion by the 2020s, almost EUR 20 billion by the 2050s, and EUR 50 billion by the 2080s. Map 4.1 only shows the relative changes in EAD, assuming that no adaptations are made to limit possible future risks. In reality, several of these adaptation programmes for flood protection already exist. They include 'Room for the river' or 'Making space for water' programmes and many local measures.

A cost–benefit analysis and multicriteria analysis with criteria for all four types of negative consequences were applied on the different scenarios of measures. A basic result of this test case can be found in Figure 4.1 but the final ranking should depend on stakeholders' involvement, their visions and the importance they assign to each of the criteria.

4.2 Responses

Water scarcity and drought on the one hand, and flood on the other seem to be contrasting phenomena. But in terms of the best responses to these phenomena, there are in fact many commonalities.

These commonalities refer to:

- the risk management that is needed. Both droughts/water scarcity and floods require a cycle of long-term preparedness and short-term hazard management, as both are dependent on climatic and weather abnormalities, and too much or too little precipitation;
- the management plans for dealing with both droughts/water scarcity and floods both link to the RBMPs under the WFD;
- both phenomena can be mitigated by ecosystem functions and a well-balanced hydrological cycle in the river basin. Water retention measures can thus have a double function: in floods as well as in drought management;
- the need for transboundary and sectoral cooperation in the water management processes that deal with these phenomena.

There are, of course, distinct measures for both of these challenges. However, these distinct challenges can be addressed under one of the above wider categories.

In some respects, often the risk management cycle for floods is further developed than for droughts, and will serve as an example against which to compare drought and water scarcity management.

The policy framework

The assessment and management of floods in the EU Floods Directive uses a risk-based framework to effectively cope with the random and uncertain nature of flood phenomena. A risk management framework for floods should include: preventive and protection measures including spatial planning and land use planning to obviate damages and infrastructure works; preparedness measures including early warning systems; and response measures for effective crisis management during floods. Response measures must also include recovery actions for an efficient return to normality for people, economies and ecosystems, as well as a process to ensure that important lessons are learned. More details on the integrated risk management cycle are described below.

In the area of water scarcity and drought, no distinct directive provides a management framework, but the European Commission Communication *Addressing the challenge of water scarcity and droughts in the European Union* (EC, 2007c) is the primary policy document guiding EU Member States' efforts to combat water scarcity and drought. The communication defines overarching policy options, several of which are related to water economics and resource efficiency (see also Section 1.2). Resource efficiency is seen as an important measure to reduce vulnerability and increase long-term preparedness. The EEA report on efficient use of water resources (EEA, 2012a) deals with this aspect in detail. Other policy options deal with water allocation, drought risk management, and improved knowledge and data collection. Droughts and water scarcity are

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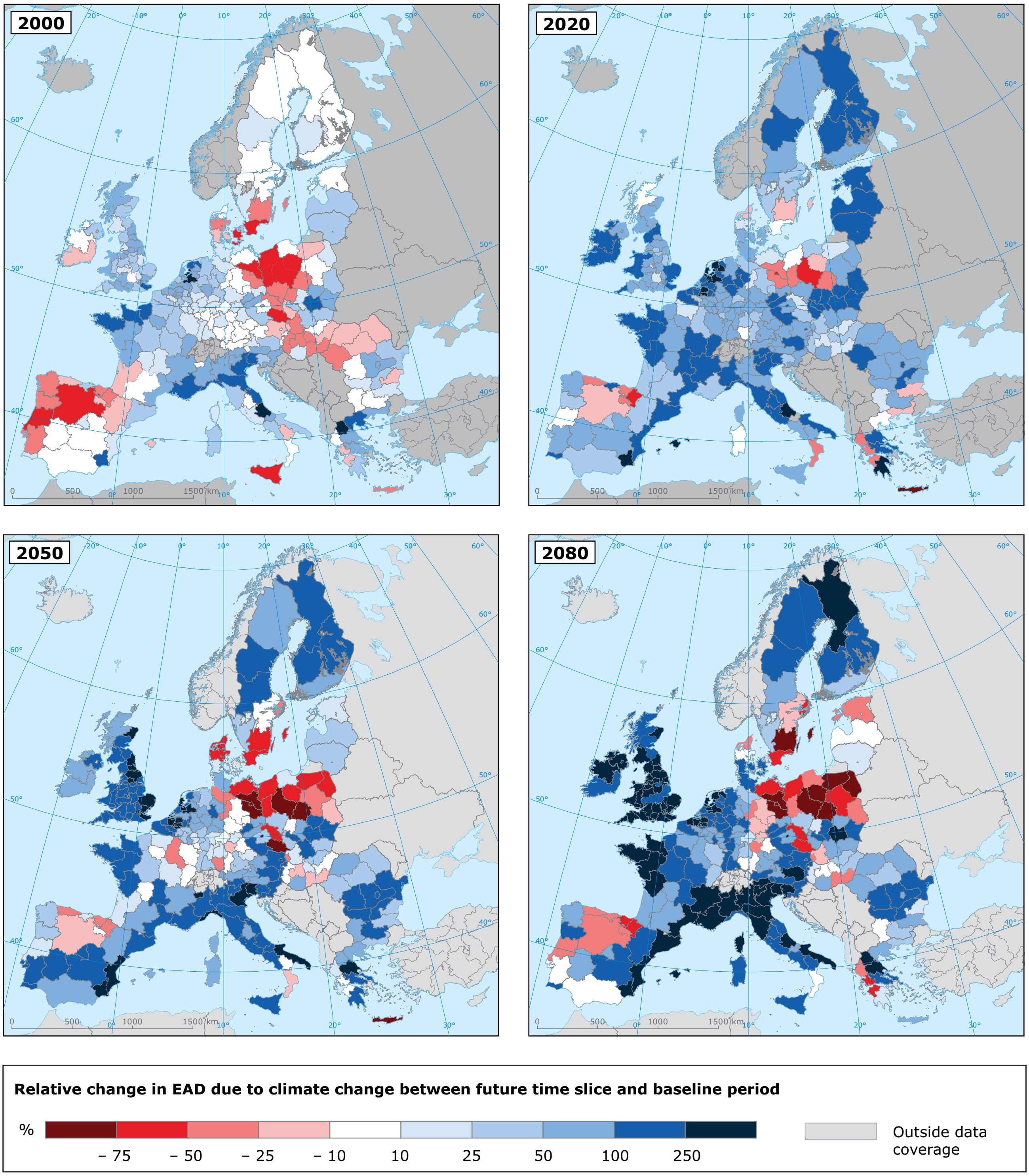
(6) The IPCC A1B scenario (IPCC, Bernstein et al., 2008) is a member of the group of A1 scenarios (a more integrated world). They are characterised by rapid economic growth, a global population that reaches 9 billion in 2050 and then gradually declines, the quick spread of new and efficient technologies, and a convergent world (income and way of life converge between regions), with extensive social and cultural interactions worldwide. There are subsets to the A1 family based on their technological emphasis, with A1B having a balanced emphasis on all energy sources. More details about these scenarios can be found in (EEA, 2012c). More about the project ClimateCost can be found in Section 5.7.1 of the same report.

Map 4.1 Relative change in EAD



Note: Relative change in 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).

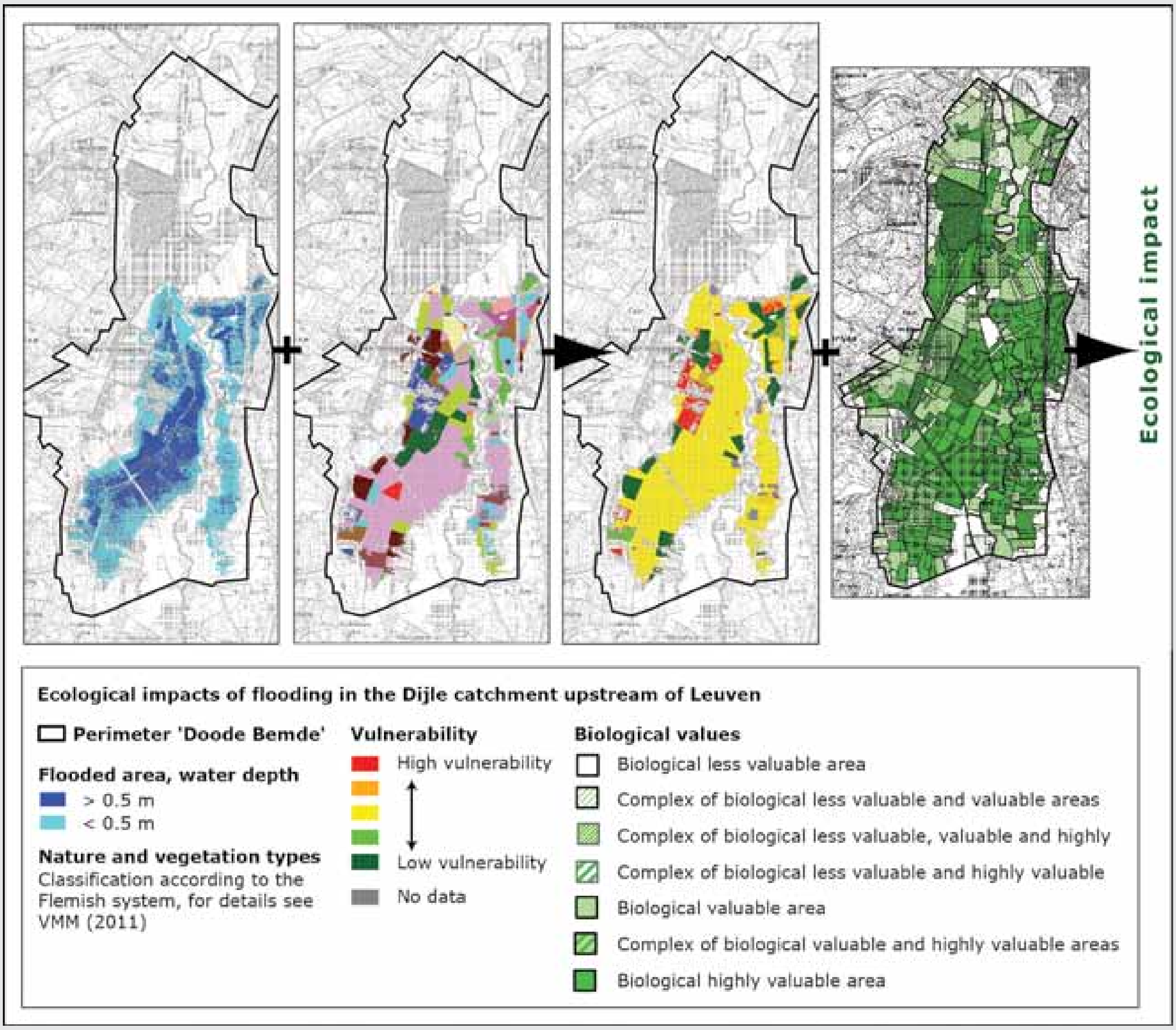
Source: ClimateCost, reported in Flörke et al., 2011.

Box 4.1 Example of impact of flooding on human health, ecology, cultural heritage and economic activity

In the FloodResilienCity project different techniques of mapping and combining the different categories of negative consequences were prepared as an exercise during a WGF workshop on floods and economics in Ghent, Belgium. The study area is the Dijle catchment (Belgium) at the city of Leuven and upstream.

The most important economic effects were material damages to agriculture, houses, buildings, industries, infrastructure, and cars. Social and health impacts were evaluated by a proxy using the 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 the United Nations Educational, Scientific and Cultural Organization (UNESCO) world cultural heritage sites. The ecological impacts were mainly upstream of the city and were based on a combination of vulnerability and biological values (see Map 4.2).

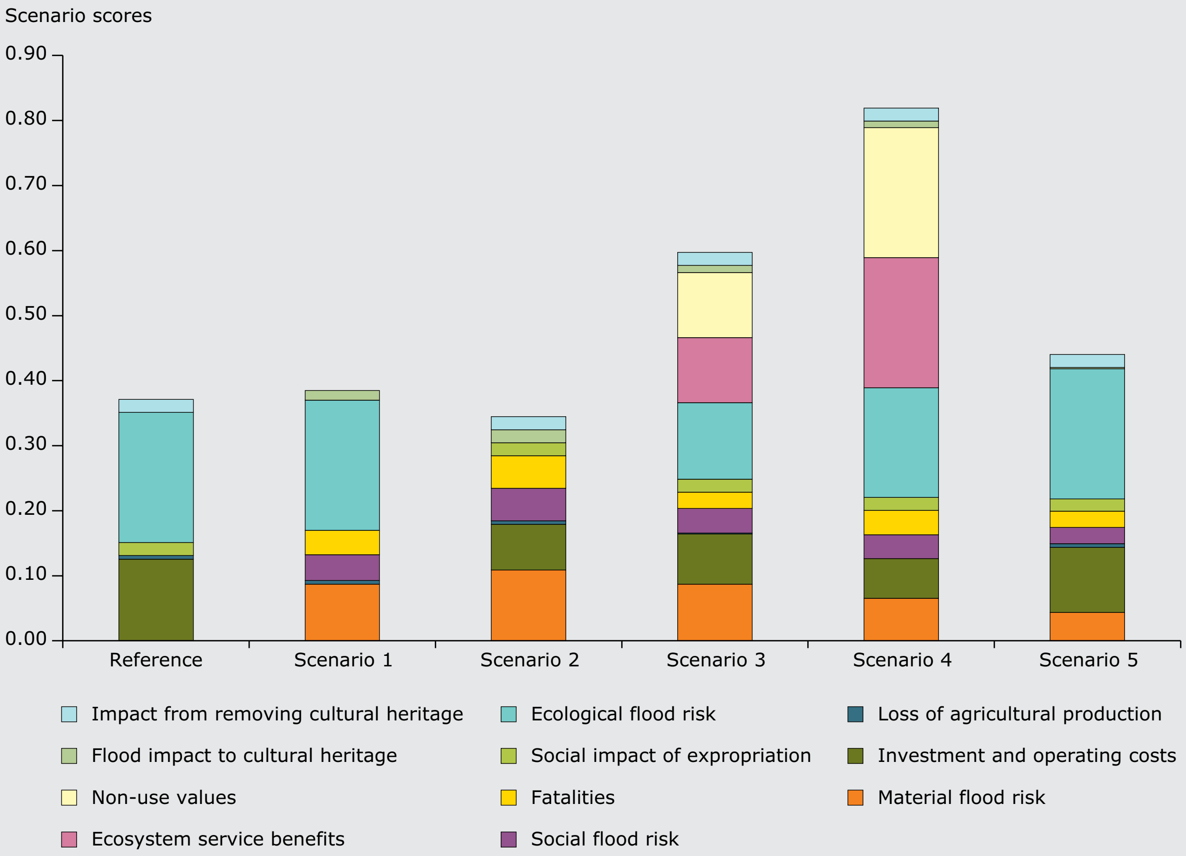
Map 4.2 Ecological impacts of flooding in the Dijle catchment upstream of Leuven (Belgium)



Source: VMM 2011 and CIS WG Floods Workshop on Floods and Economics, Ghent, October 2010.

Box 4.1 Example of impact of flooding on human health, ecology, cultural heritage and economic activity (cont.)

Figure 4.1 Score of the different scenarios of measures in the MCA for the Dijle around Leuven (Belgium)



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). Note that in this exercise, a combined scenario of structural and non-structural measures was not included.

Source: VMM 2011 and CIS WG Floods Workshop on Floods and Economics, Ghent, October 2010.

different phenomena (see Table 3.1), but they can overlap when an already water-scarce area faces an additional drought. In water management practice, both situations are often dealt with in a similar way, although their policy and management options differ and are particular to each (Schmidt and Benítez, 2012).

The WFD is not directly designed to address issues of water quantity, although its goal includes mitigation of drought effects, and its environmental objectives include finding a balance between abstraction and recharge of groundwater. The RBMPs include more detailed programmes of measures for issues relating to particular aspects of water management such as water scarcity and droughts. Over 20 measures for managing WS&D are found in the RBMPs; the top 5 (Schmidt and Benítez, 2012) are as follows:

1 reduction/management of groundwater abstraction;

2 studies, research and pilot projects;

3 training, education and capacity building;

4 reduction of urban network losses;

5 development of drought management plans (DMPs).

Some countries, especially those faced with water scarcity and drought more frequently, have already implemented DMPs at river basin scale.

4.2.1 *Integrated risk management*

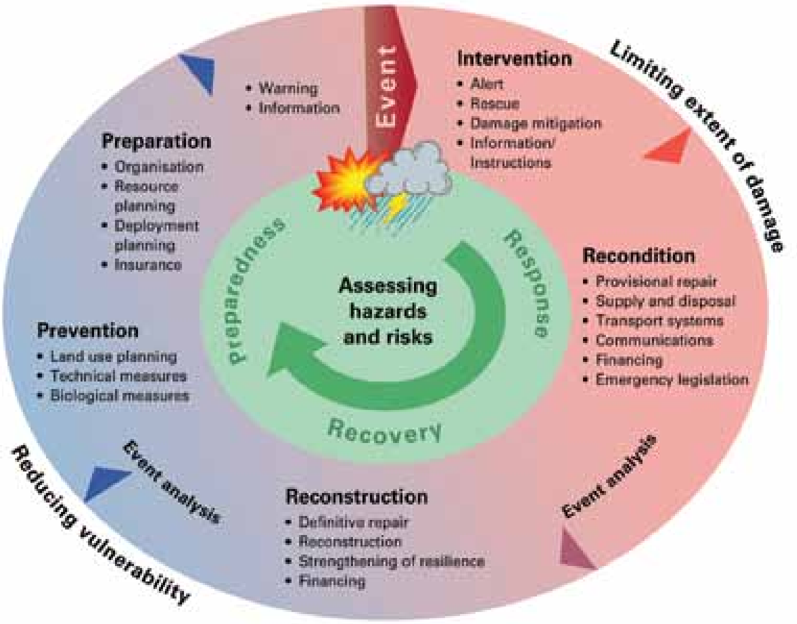
In recent years, policies for disaster risk reduction and management have shifted from defence against hazards (mostly by structural measures) to a more comprehensive, integrated risk approach (see Figure 4.2). Within integrated risk management (IRM), the full disaster cycle — prevention, preparedness, response and recovery — should be taken into consideration when dealing with any type of hazard, be it natural or technological (EEA, 2011a). From an environmental perspective, the focus is on prevention and preparation, as the main synergies with environmental protection and integration with ecosystem-based management are found here.

The Floods Directive deals with all aspects of this cycle, although it focuses on prevention, protection and preparation (the 'reducing vulnerability' part of the cycle, or the pre-event in Figure 4.2). The Communication *Addressing the challenge of water scarcity and droughts in the European Union* (EC, 2007c) aims at preventing and mitigating water scarcity and drought situations. The follow-up report from 2009 (EC, 2010b) points out, among other things, a number of areas to be tackled (land-use planning, water pricing, water metering, etc.). The cycle in Figure 4.2 has not been explicitly developed for management of drought and water scarcity, but most planning aspects and measures discussed in the development of the water scarcity and drought policy fit well into its framework, as shown further down in Section 4.2.2 on plans and measures.

Water scarcity in this sense occurs where preventive and preparatory measures have not been set in place in time, and where the risk assessment and adaptation of the water management has failed to account for the vulnerability of the system and for the possibility of a drought occurring naturally in the given climatic conditions or as part of climate change–driven shifts.

With regard to limiting the extent of damage, the European Commission released the complementary Communication *A Community approach on the prevention of natural and man-made disasters* (EC, 2009a). This communication proposes that EU-level actions should focus on three areas: (a) developing knowledge-based prevention policies; (b) linking actors and policies throughout the disaster management cycle; and (c) improving

Figure 4.2 Cycle of IRM



Source: Swiss Federal Office for Civil Protection (FOCP, 2012).

the effectiveness of existing financial and legislative instruments (EEA, 2011a).

Hazard and risk analyses are the starting point for (as well as a crucial element of) integral risk management. This concept is understood to mean the systematic identification, assessment, and prioritisation of hazards and the associated risks, as well as the management of measures for risk mitigation. The individual phases of prevention, coping, and recovery are weighted equally within the integral risk-management model and are mutually interactive. The demarcation between these phases is not always clear-cut (FOCP, 2012).

In the Spanish drought management plans for river basins, there are three consecutive stages, each requiring different actions. In the pre-alert stage, measures are restricted to low-cost and voluntary actions such as information dissemination. In the alert stage, a drought is occurring and structural measures are taken (e.g. restrictions on recreational water use). In the emergency stage, the impacts of drought are visible and water supply is in danger. Infrastructure changes are applied and urban supply must be sourced through different means (Garrote et al., 2006).

Urban flood risk management and measures

Many cities and towns are situated in locations such as deltas and flood plains that are prone to fluvial flooding. Cities at a distance from water bodies can also experience 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 watercourses into which storm water and floodwater drain.

There is a general consensus that urban areas need to be made more resilient to flooding. Flood proofing of buildings and sustainable urban drainage are two measures that can address this issue. Green infrastructure can also provide opportunities for addressing problems caused by land sealing in urban areas (EEA, 2010c; EEA, 2012f). Reducing the vulnerability of urban areas to floods requires detailed knowledge of local conditions. Measures have to deal with water supply, wastewater treatment, rainwater run-off 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 must 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 alter conditions for current practices related to urban drainage, water management and treatment. More details on urban adaptation and water can be found in a related EEA report (2012b).

4.2.2 Plans and measures

Structural measures for floods, i.e. technical flood protection like dams, dikes, canalisation, flood polders, are usually associated with the highest costs. On the drought-management side, this can be compared to supply-side measures focusing on technical solutions to increase water supply by water transfers, large reservoirs or desalination.

A central element in effective flood risk management is the identification of measures, as categorised in Table 4.1, for instance. Another way to structure measures is proposed by the WGF (WGF Drafting Group, 2011a) and links the different measures to the stages in the risk management cycle (Table 4.2). When floods occur, the focus is on crisis management. Contingency plans should 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 infrastructure and its maintenance. Flood event management includes forecasting and the provision of warnings, deployment of temporary flood-protection structures and emergency response.

The timescales for the development of a drought are different to those of floods, but a similar list of actions can be defined. Drought management includes forecasting and warning, temporary measures and an emergency response to limit the negative consequences. Drought event management must involve all the relevant sectors, such as water supply, agriculture, energy, industry, tourism, navigation, etc.

However, in an environmental context, the focus in both flood and drought management is put on measures that also relate to the quality of the environment and ecosystem, and that use the ecosystem functionalities in a long-term abatement strategy.

Table 4.1 Potential measures for flood risk management, by functional group

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	
		Channelisation	
	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, in Schanze et al., 2008.

Table 4.2 Potential measures for flood risk management, related to the stages of the risk management cycle

Aspects of flood risk management	Type	Description
No action	No action	No measure is proposed to reduce the flood risk
Prevention	Avoidance	Measure to prevent the location of new or additional receptors in flood-prone areas, such as land use planning policies or regulation
	Removal or relocation	Measure to remove receptors from flood-prone areas, or to relocate receptors to areas of lower probability of flooding and/or of lower hazard
	Reduction	Measure to adapt receptors to reduce adverse consequences in the event of a flood, actions on buildings, public networks, etc.
	Other prevention	Other measure to enhance flood risk prevention (may include flood risk modelling and assessment, for instance)
Protection	Natural flood management/run-off and catchment management	Measure to reduce the flow into natural or artificial drainage systems, such as overland flow interceptors and/or storage, enhancement of infiltration, etc. and including in channels, floodplain works, and the reforestation of banks that restore natural systems to help slow flow and store water
	Water flow regulation	Measure involving physical interventions to regulate flows, such as the construction, modification or removal of water-retaining structures (e.g. dams or other online storage areas, or development of existing flow regulation rules), which have a significant impact on the hydrological regime
	Channel, coastal and floodplain works	Measure involving physical interventions in freshwater channels, estuaries, coastal waters and flood-prone areas of land, such as the construction, modification or removal of structures or the alteration of channels
	Surface water management	Measure involving physical interventions to reduce surface water flooding, typically in an urban environment, such as enhancing artificial drainage capacities or though sustainable urban drainage systems (SUDSs)
	Other protection	Other measure to enhance protection against flooding, which may include flood defence asset maintenance programmes or policies
Preparedness	Flood forecasting and warning	Measure to establish or enhance a flood forecasting or warning system
	Emergency event response planning	Measure to establish or enhance flood event institutional emergency response planning
	Public awareness and preparedness	Measure to establish or enhance public awareness or preparedness for flood events
	Other preparedness	Other measure to establish or enhance preparedness for flood events to reduce adverse consequences
Recovery and review ([a])	Individual and societal recovery	Clean-up and restoration activities (buildings, infrastructure, etc.) Health and mental health supporting actions, including managing stress. Disaster financial assistance (grants, tax), including disaster legal assistance and disaster unemployment assistance. Temporary or permanent relocation.
	Environmental recovery	Clean-up and restoration activities (with several sub-topics like mould protection, well-water safety, and securing hazardous materials containers)
	Other recovery and review	Lessons learnt from flood events Insurance policies

Note: ([a]) Planning for the recovery and review phase constitutes part of preparedness in principle.

Source: WG F Drafting Group, 2011a (with minor changes).

As an example, Switzerland strives to make use of synergies between flood risk management and river rehabilitation projects. They aim at securing enough space for surface waters to be able to accommodate more frequent flooding as part of the recently adopted climate change mitigation and adaptation strategy (BAFU, 2012).

While some of the measures in the tables above are typical measures to reduce river flow or abate flooding consequences, others (e.g. run-off management or forecasting and warning) can also be directly applied to water scarcity and drought. In any case, a complete set of measures has to include all stages, from prevention to recovery and review. The prevention measures and the majority of protection measures will reduce water scarcity. These should not be applied in times of low precipitation, but well in advance. By reducing the vulnerable assets or by modelling to locate the needed environmental flows, the water stress can be reduced. In the case of a drought, the economic, social and environmental effects will likewise be reduced. The preparedness, recovery and review measures are in place to further reduce the effects of a drought when it occurs.

For flood management, 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 between effective and efficient flood measures. Effectiveness is a result-based measure and describes the degree of goal achievement in terms of risk reduction or effects towards risk reduction. Efficiency is a yield-based measure 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 Flooding ERA-Net, 2009).

Ensuring the knowledge base

A real-time early-warning system can be an effective non-structural management tool. It enables authorities to start implementing contingency plans, such as (in the case of floods) 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 4.2 for more details).

Early warning and forecasts are also vital in the case of drought management. Some of the results showing the development of droughts over Europe using precipitation-related indicators are shown in Section 3.2.2. But in addition to preparedness regarding the development of the climatic conditions it is absolutely vital for the water manager to have a clear view on the long-term water balances and water consumption in the river basin, so as to be able to react early in scarcity situations. There are several approaches for keeping track of the parameters indicating water scarcity. All take their starting point in the balance between water availability and water use (UNEP, 2012). To include seasonal variability, it is vital to work with information at a monthly resolution level, at least. Water accounts as presented in Section 3.2.4 provide water balance information on a macroeconomic level. Management-oriented water account calculations (like life cycle analysis or the water footprint approach) can be used for corporate reporting, awareness raising, or to link water balance information to economic activities in single sectors.

But knowledge of the hydrological reality is vital for all the planning steps in sustainable water resource management, in order to prevent water scarcity and to deal with drought risks in a sustainable, well-prepared way.

Natural water retention measures: working with the ecosystem

Some of the measures listed in Table 4.1 and Table 4.2 are specifically related to the functionality of the ecosystem, and make use of the natural ability of water-related ecosystems and wetlands to retain water.

Natural water retention measures (NWRMs) aim to safeguard natural storage capacities by restoring or enhancing the natural features and characteristics of wetlands, rivers, floodplains, etc., and by increasing soil and landscape water retention and groundwater recharge (Stella Consulting, 2012). As the implementation of a measure is always a human intervention, 'natural' in this case refers to measures designed and implemented to reuse natural features, such as using trees to mitigate surface run-off or intercept rainwater. Most of these measures are beneficial in decreasing floods and droughts. For the Impact Assessment, 21 NWRMs were divided into four

Box 4.2 Ecologically acceptable flows in Slovenia

The importance of minimum flows to aquatic ecosystems has been recognised in Slovenia for a number of decades, being first defined in a decree back in 1976. With the implementation of the Water Framework Directive, the Slovenian Water Act was updated in 2002. The act now requires that an ecologically acceptable flow (EAF) be determined and maintained where water abstraction causes a decrease in river flow or level. The EAF is established to ensure that aquatic and riparian ecosystems are protected and to support the achievement of good ecological and chemical status.

Building upon the 2002 act, a decree on the 'criteria for determination and mode of monitoring and reporting of EAF' was adopted in 2009. This prescribes the use of one of the hydrological approach for the determination of an EAF. According to the hydrological approach, the EAF is the product of mean low flow — defined as the arithmetic average of the lowest annual values of mean daily flow at a site over an extended monitoring period, usually the last 30 years — and a coefficient 'f'. Values of f are based on the characteristics of abstraction including; the quantity and duration of water abstracted and the amount and location of water returned after use; the ecological type of the watercourse; and the ratio between the mean flow and mean low flow.

The hydrological approach is not the only approach that can be used to estimate EAF. For example, a lower value of EAF may be determined on the basis of a holistic approach at the request of the applicant for the water right. This holistic approach involves evaluation of the hydro-morphological, biological and chemical characteristics of the river reach where the water abstraction or diversion is to occur. The final determination of the EAF also includes protection arrangements and requires that the holder of the right to abstract water must monitor river flow and show that the EAF has been met throughout the year. Water protection inspections are also carried out by authorities with the possibility for financial penalties to be imposed when necessary.

Source: Smolar-Žvanut et al., 2008; Uradni list RS 2009.

Photo: The Soca River, Slovenia © Natasa Smolar-Zvanut/Institute for Water of the Republic of Slovenia (IZVRS)

Box 4.3 Flood risk forecasting in Finland

Flood risk assessment and flood control in Finland has been developed in a series of research projects and continual development work. This has led to the creation of a flood forecasting and warning system and specific projects for floodwater management.

The basis is a hydrological watershed and forecasting 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.

Photo: Flooding at Vöyrinjoki River (Finland) in summer 2004 © YHAphoto/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 publicly available on the internet.

Interactive maps allow users to zoom in on their area of interest. The WSFS includes information on hazards by providing, for example, flood and water level warnings and precipitation warnings, both for the last 24 hours and with 3-day forecasts. Warnings are graded and expressed with colour symbols.

In addition to the warnings, the system provides continually updated information on, for example, run-off; precipitation; snow cover; water equivalent of snow; snowmelt; soil moisture deficit; and water level. Nutrient loads are also simulated.

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

groups (Stella Consulting, 2012). As can be seen in Table 4.3, most NWRMs have a positive effect in diminishing both floods and droughts.

Not all NWRMs are automatically applicable everywhere. Important criteria in assessing the applicability of a measure are the climate zone; the principle land use; the soil permeability and depth; and the topography. In addition to these criteria, the Stella Consulting report (2012) assessed the relevance of these measures to the wider EU context, an important consideration when developing policy recommendations for promoting the uptake of NWRMs at EU level.

Measures where the benefits equal or exceed the costs regardless of whether predicted climate changes occur are called 'no-regret' measures (IPCC, 2008; CIS WFD, 2009). Based on the effectiveness and cost–benefit analysis, the study concludes that wetland restoration and creation is a no-regret measure, as are all agricultural measures (see Table 4.3), in particular crop practices, since they have the widest applicability and can therefore have a larger impact than wetlands. Although forests provide multiple benefits, location and future climate change scenarios are a key parameter in determining the no-regret nature of these measures. And based on the available information, it seems unlikely that re-meandering and bank stabilisation are no-regret measures.

NWRMs fit in the ecosystem services (ESS) approach (see Section 2.1). NWRMs aim to simultaneously: contribute to the regulation of water flows and storage; increase the resilience of ecosystems to climate change; improve biodiversity and connectivity; and improve many other ecosystem services (Stella Consulting, 2012). Many of the NWRMs also constitute so-called green infrastructure (GI): they help to maintain healthy ecosystems that can continue to deliver valuable ecosystem services; are in general cheaper than artificial measures not designed to provide multiple services: and thus reduce the costs of implementing the WFD and the FD. GI assists in water retention, one of the key components in mitigating the effect of extreme events like floods and seasonal water scarcity. It also contributes to achieving the GES of water bodies. GI will make these ecosystems less vulnerable to the effects of climate change. These benefits are closely linked to an integrated approach for land management and to careful strategic planning as well (Stella Consulting, 2012).

Water scarcity and droughts: demand-side adaptation strategies

Next to increasing the functionality of the ecosystem to prevent water scarcity, improving efficiency is the main priority for reducing water consumption and keeping it in balance with water availability. Improvements in infrastructure and practices, especially in the agricultural sector, are key. Agricultural water demand may also be decreased through the promotion of better crops and cultivars with lower water requirements (EEA, 2012e). 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 perverse 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, 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 in regions with greater water stress. Detecting illegal abstractions is also a challenge. 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, 2012e).

Many demand-side strategies have the potential to create conflicts between competing demands from economic sectors or geographical regions. 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 local level. Cooperation among water users is a primary goal and requires appropriate institutional frameworks in order to guarantee that water users 'play by the rules'. This does not mean that enforcement policies are the only tools that should be used. Public participation and

Table 4.3 Groups of NWRMs

Forest measures	Continuous Cover Forestry (CCF)
	Maintaining and developing riparian forests
	Afforestation of agricultural land
Urban measures	Filter strips and swales
	Permeable surfaces and filter drains
	Infiltration devices
	Green roofs
Agricultural measures	Restoring and maintaining meadows and pastures
	Buffer strips
	Soil conservation crop practices
	No or reduced tillage
	Green cover
	Early sowing
	Traditional terracing
Water storage measures	Basins and ponds
	Wetland restoration and creation
	Floodplain restoration
	Re-meandering
	Restoration of lakes
	Natural bank stabilisation
	Artificial groundwater recharge (AGR)

Source: Stella Consulting, 2012 (annex Impact Assessment).

awareness are even greater priorities to ensure that the threats to water resources are understood and appreciated.

Many of the measures to reduce water demand are so-called 'soft' measures, as they do not require large infrastructure works. Often they are innovative, either in their technology or in the way they are applied. In this way, demand-reducing measures are a flexible toolkit to reduce water stress under current climate conditions and as an adaptation measure to climate change.

Water scarcity and droughts: supply-side strategies
As described in the previous section, policies for dealing with and adapting to water scarcity and drought should primarily concentrate on efficiency improvements and reducing demand. However, in some circumstances and despite having exhausted all possibilities to reduce the water demand, it may be necessary to balance demand-side policies with the exploration of supply-side measures (EC, 2010b). 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 fresh water. 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 (United Kingdom), desalination plants have been included in plans to adapt to growing water demand and reduced supply of water resources.

Alternative water sources include municipal wastewater, 'grey water' (water disposed of in household sinks and washing machines but not water disposed of in toilets) and rainwater. It often requires investments in infrastructure, and information and campaigns to overcome public stigma. In some cases it requires 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.

One of the fundamentals of a green economy has to be that investments in infrastructure for overexploitation are not subsidised. In the past,

Box 4.4 'Room for the river', or retaining water in the landscape

'Room for the river', also known as 'space for water' or 'Ruimte voor de rivier' is a group of measures taken within the floodplain and involving natural and artificial flooding areas. 'Room for the river' allows rivers to flood over their banks in periods of high water flow, and flow out uninterrupted over flood plains. These flood plains therefore become repositories for this excess water, keeping the water in the landscape. 'Room for the river' contrasts with traditional methods of flood management, which often involves building levees and dikes to prevent rivers spilling over their banks.

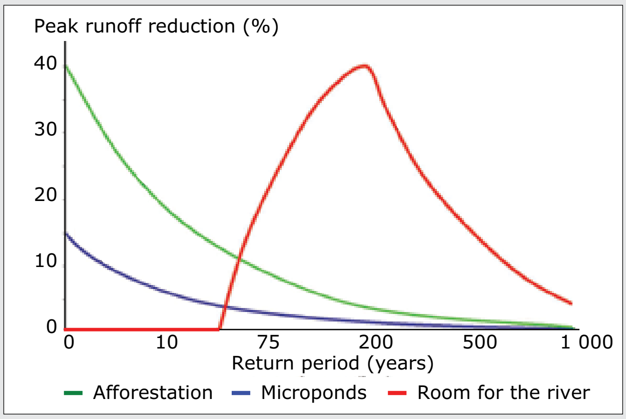
For the Kamp catchment in Austria, the effectiveness and efficiency of 'room for the river' as a measure was compared with so-called 'retaining water in the landscape' measures that retain water in the landscape by micro-ponds or afforestation (Francés et al., 2008).

In general, the potential additional water storage capacity resulting from afforestation and micro-ponds will have a physical limit and this additional storage capacity is greatest when dealing with small floods. For larger flood events, afforestation and micro-ponds have to be complemented with structural measures such as dykes to prevent large-scale damage. If the potentially damaged infrastructure and economic goods 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. As a result, the risk reduction for measures such as micro ponds and afforestation can be higher than expected from the hazard reduction.

In the Kamp catchment, significant reductions in the flood peaks can be obtained when the river is allowed to flood out into 'retention basins' according to the principles of 'room for the river'. However, a lot of space is needed to apply this measure. The main advantage of the 'room for the river' methodology is that the polders/retention basins can be designed in such a way that there is no flooding over of river banks during small flood discharges, leaving the full storage capacity for larger floods at peak time.

The benefits of 'retaining water in the landscape' measures like microponds or afforestation are a function of so-called 'flood return periods' a measure of the statistical likelihood of a flood occurring. This means that 'retaining water in the landscape' measures are most effective in mitigating the smaller floods that occur reasonably frequently, and have 'return periods' of up to 25 years. 'Room for the river' seems in this example more effective for medium-return periods (100–500 years return period, see Figure 4.3).

Figure 4.3 **Estimated flood peak reductions for different measures in the Kamp catchment (Austria)**



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: Room for the river, in Francés et al., 2008; CRUE Flooding ERA-Net, 2009.

several supply-side measures were taken that increased the total available amount of water in the short term. But as many of these measures were not sustainable, they needed a lot of energy and had impacts on water quality. These measures normally need large infrastructure works and technical expertise. They cannot be changed without large costs and don't really contribute to adaptation strategies dealing with the effects of climate change.

Measures actually taken under the WFD

Most of the measures outlined above and fostered under the WS&D policy or the Floods Directive are actually taken up in one way or another in the first round of RBM planning.

The development of drought management plans that move from a crisis-response approach to a risk-management approach is a way to improve society's resilience to water scarcity and droughts (EC, 2010b). The most common measures to deal with water scarcity and droughts in the RBMP programmes of measures are measures to improve knowledge and governance (used in 85 % of RBMPs) and measures to improve efficiency (used in 75 % of RBMPs). An overview of the use of measures can be found in Table 4.4 (Schmidt and Benítez, 2012).

Some of the measures in these groups are voluntary, such as awareness-raising or education, while others are regulatory, such as the creation of registers of abstraction. Some are technical measures (e.g. monitoring or artificial recharge), while others are legislative (e.g. the requirement for prior authorisation) or financial (financial incentives and investments).

Deviations from the general numbers in Table 4.4 can be found for RBDs where water scarcity and drought spells are a RBD-wide phenomenon, a local problem, or not significant. Efficiency measures and measures to improve knowledge and governance are included in 100 % of the RBMPs where RBD-wide water scarcity and drought spells are reported. It is remarkable that restrictions on land use are more likely to be included in the RBMPs of RBDs with local problems of water scarcity and droughts (27 % of RBDs with local WS&D problems restrict land use) than in those where the problems are RBD wide (13 % of RBDs with RBD-wide problems of WS&D restrict land use). There are even more RBDs without any significant WS&D problems that implement restrictions on land use than there are RBDs with have RBD-wide problems of WS&D that implement restrictions on land use (Schmidt and Benítez 2012).

Table 4.4 Groups of measures and popularity

Water scarcity and droughts measures	in % of RBMPs
Restrictions to land-use	20 %
Efficiency	75 %
Pricing and economic measures	45 %
Knowledge and governance	85 %
Increase water supply	58 %
Other measures	34 %

Note: Based on 123 RBMPs.

Source: Schmidt and Benítez, 2012.

Schmidt and Benítez (2012) looked at 22 measures related to water scarcity and droughts in the RBMPs in more detail and linked them to the headings in the Communication *Addressing the challenge of water scarcity and droughts in the European Union* (EC, 2007c) (see Section 1.2). The categories with the most measures (5) are 'water supply infrastructure' and 'efficiency'. The different measures can address the drivers or the pressures, or directly decrease the negative impacts (7). In the RBMPs, nearly two out of three water scarcity and droughts measures address the pressures of the 'Driving forces, Pressures, State, Impact and Responses' (DPSIR) scheme; 40 % of them address the impact, and approximately 25 % address the drivers (Schmidt and Benítez, 2012). The more integrated measures place the groundwater status into a direct context of risk assessment and vulnerability to droughts and water scarcity. These more integrated measures have some potential to be further developed. Economic instruments, which require an even more integrated approach going throughout several sectors, have been least applied.

Box 4.5 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 abstractor of water. The impacts of water scarcity and drought on this sector are not only felt at farm and regional levels: in the case of widespread or longer term droughts, they 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 scarcity and drought 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 suitable crops, and efficiency improvements.

Agricultural adaptation options can be divided into autonomous adaptations (such as changes in varieties, sowing dates, fertilisers and pesticide use) and planned adaptations, referring to major structural changes such as land allocation, farming systems and the development of new crop varieties (Bindi and Olesen, 2010; Moriondo et al., 2010). The most appropriate adaptation strategy is likely to be a combination of these, and the final strategy adopted will depend on the impact that each option will have, and on the particular vulnerability of the system being considered. It is important to take into account local conditions, including farm intensity, size, and type. These factors 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, feasibility and impacts. In some cases, certain cultivations or agricultural activities may become unviable.

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

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(7) One measure can address one or more than one aspects of the DPSIR chain.

4.2.3 *Cooperation*

Considering the above system of management and planning to deal with floods or water scarcity and drought, it is obvious that cooperation across boundaries and between the different sectors involved plays a paramount role.

The Floods Directive (EC, 2007b) seeks to improve international cooperation between regions and Member States, using a structured three-step approach to flood 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 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 (APSFRs) is made, where more in-depth analyses are carried out.

2 For the APSFRs, a more detailed analysis is made, starting with two series of flood maps, which are to be ready by the end of 2013 at the latest. The flood hazard maps describe the physical aspects of the anticipated flood: the extent of the flood, water depth, flow velocity, etc. The maps describe events with a high, medium (at least 1 % annual probability) and low probability of occurrence. For each of these events, flood risk maps are developed, indicating the impact and consequences of these floods. People (victims, evacuated and affected persons, etc.) and economic consequences are taken into account, but the EU Floods Directive also 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 APSFRs 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 must 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. This must be done by addressing all phases of the flood risk management cycle, particularly focusing on prevention, protection, and preparedness. FRMPs will take into account relevant aspects such as costs and benefits; flood conveyance routes and areas with the potential to retain floodwater such as natural floodplains; and the environmental objectives of the WFD. Explicitly mentioned issues linking the Floods Directive and the environmental objectives of the WFD include soil and water management; spatial planning; land use; nature conservation; navigation; and port infrastructure. The importance of land use (changes) for the hydrological cycle has already been mentioned in Section 3.1.2. Besides the geographical coordination at the level of the RBD, there is also a need to involve other sectors, with spatial planning and land use being one of the most important.

Due to the nature of flooding, notwithstanding the enumeration of elements to take into account, much flexibility on objectives and measures is left to the Member States in view of subsidiarity. Not only must FRMPs be made available to the public (as in PFRAs, APSFRs and the flood hazard maps and flood risk maps), but an active involvement of interested parties shall be encouraged. After 2015, a new six-year cycle is to start, consisting of the same three steps.

Transboundary cooperation and defining joint challenges and measures are of relevance for droughts, as they affect large areas. In a preliminary analysis of 38 RBMPs, less than 50 % provide information on transboundary coordination, and in less than 5 % do plans include coordinated measures for the entire RBD (Schmidt and Benítez, 2012).

4.2.4 *Lessons learned*

After a flood disaster relief effort, reconstruction actions and financial compensation 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 experience. General flood impact databases such as EM-DAT (2012) or the Dartmouth Flood Observatory (2012) exist to give a general overview, but for more in-depth learning, more detailed documentation is needed. The development of detailed databases on flood events and impacts is ongoing in several EU Member States and at the European level.

To summarise, increased use of natural retention measures, the build-up of flood plains, and 'making room for the river' make up the most sustainable approach for dealing with floods. These measures take into account all aspects of vulnerability and complement the flood risk management cycle at the point of prevention.

The same effort is needed for droughts and water scarcity. In the case of droughts and water scarcity, the extent of the physical event is more difficult to delineate, as are the start and end dates. However, much useful information can be derived when a consistent information base on water balances exists, particularly at regional level, for the water manager. The effectiveness and efficiency of measures can be evaluated after drought and water scarcity events and new plans can be based on these insights. The aggregation of this data at European level as overview information is addressed in Section 3.2.4, and should inform further policy developments and hotspot analysis at European level. Moreover, for water scarcity and droughts, and for floods, a good overview of the phenomena helps educate and raise awareness, and this is fundamental for long-term sustainable water management.

In the context of vulnerability, it is clear for both situations (of too much or too little water), that only long-term planning and preparedness can improve the sustainability of water management. The development of a more ecosystem-based approach that focuses on retention measures is necessary to provide a stable and resilient hydrological cycle in the river basin as a guarantee for most effective adaptation. For the same reason, to stabilise the natural water balance and adapt to the challenges possibly posed by climate change, it is absolutely vital to commit to and focus on demand-side management as a sustainable answer to water scarcity and droughts.

Box 4.6 Flooding in the United Kingdom in 2007: lessons to be learned

The flood events experienced in the United Kingdom in the summer of 2007 were in large part caused by three storms of record-breaking magnitude and spatial extent. The storm of 19 and 20 July produced up to 140 mm of localised rainfall, estimated to have a return period (the statistical likelihood of its occurrence) 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 EUR 4.5 billion by late 2007. Many flooded and low-lying localities had to be evacuated

Following the summer 2007 floods, the British government asked Sir Michael Pitt to undertake a comprehensive review of the lessons to be learned from the events. During the fact-finding mission over a 10-month period, the review team examined over 1 000 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). Proposed actions included meeting 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 practice (Defra, 2009).

5 Conclusions

5.1 Vulnerability of Europe's waters on the increase

Droughts, water scarcity and floods influence our environment, and their impacts should not only be expressed in economic (often monetary) and social terms (e.g. how many people are affected) but also in terms of their effects on ecosystems. Concepts based on ecosystem goods and services as first defined by the Millennium Ecosystem Assessment are highly relevant to define the vulnerability of freshwater resources and to assess the services they provide to the society.

Our freshwater resources have to be managed carefully, as over-abstraction decreases the resilience of ecosystems and hampers long-term sustainability in economic activities. Over-abstraction affects not only Europe's rivers and lakes but also the people who depend on these river and lakes for living, for working, for recreation, for agriculture, for transport, and for energy.

Water can be vulnerable to shocks such as a pollution event, as polluted waters cannot provide the same services to economy, people and the ecosystem. But even when the water quality is good there is a potential vulnerability: flooding and water scarcity can impede certain human activities, like hydropower, agriculture, and recreational activities. It can also interrupt the ability of ecosystems to dissolve waste, distribute nutrients and act as breeding places for aquatic fauna.

The inherent uncertainty in these complex systems of how changes to timing and flow will affect ecosystems requires a risk-based approach to vulnerability. This risk-based approach is increasingly being adopted by climate change policy and adaptation strategies in disaster risk reduction. Such strategies require identification of the ecosystem's sensitivities and its vulnerability to pressures that could cause negative shifts in ecosystem structure.

This report investigates the consequences of risk-based approach to water management would have in particular in the areas of water scarcity, droughts and flood management.

5.2 Having a good water regime for the ecosystem

Freshwater ecosystems, as well as terrestrial ecosystems that depend on freshwater resources, are dynamic systems. Besides the water needed for all types of human activities, water is needed in different amounts at different times of the year to allow these ecosystems to maintain their functioning. This time-sensitive volume of water required for ecosystems is known as 'environmental flow' or ecological flow. This complex concept is evolving, but research developments suggest that ecological flows are not just a minimum volume of water but a necessary water regime which varies over time and with the right water quality.

This change in the need for water corresponds to the natural variability of water bodies. Over time, the damage to human activities caused by floods and droughts has led to changes in the form of engineering solutions to water courses. For example, dykes and channels have been built to limit flood damage, while reservoirs and weirs have been built to ensure there is sufficient water available during dry periods. More gradual changes in terms of human use of water have come in the form of overexploitation of groundwater resources. These evolutions, in combination with land use and climate changes, cause in most cases an increased vulnerability and reduce the services provided by the ecosystem.

Defining the water regimes needed to maintain the ecosystem and the environment cannot be done with a single rule or single number as there are different types of water bodies and different natural variability characteristics. But the evolving knowledge has to be collected and shared amongst European water managers — and also with spatial planners and risk managers — in order to develop a transparent common methodology to define the water needs of the ecosystem. Measures to work together with the environment, like natural water retention measures, can contribute to the improvement of the amounts of water available to maintain an ecosystem's functionality.

5.2.1 *Green infrastructure and natural water retention measures*

Many, if not all natural water retention measures (NWRM), and elements of green infrastructure (GI) have indirect benefits for humans and the environment. For example, a measure like 'room for the river' is beneficial as a flood protection measure and at the same time can improve habitat conditions for fauna and flora (which is not the case when a concrete dyke is build). This can also make the river more attractive for recreation. In times of budget cuts GI and NWRM can combine different compatible objectives and improve human well-being, economic activity, and environmental status at a lower cost than traditional engineering works when co-benefits are taken into account.

5.2.2 *Land use changes*

Land use changes are an important driver of water vulnerability. For a long time, water resource management and spatial planning have been separated topics for long time. In the Water Framework Directive, the connection between these two disciplines was addressed explicitly for the first time. Regional planning, agricultural policies and land use management drive land use change, which affects both water quantity and quality. With integrated water management on the scale of the river basin as a basic principle of the Water Framework Directive, the spatial interactions became much more important. Land use influences water management, especially when open areas are transformed into zones with a high degree of soil sealing, like urban areas or industrial sites. Even agriculture can present problems for soil sealing, when agricultural activities cause soil compaction.

By contrast, the preservation and restoration of wetlands helps to retain water as they act as natural reservoirs. The positive influence of wetlands and forests on the water system is unmistakable, and there is a permanent interaction between them. The role of forests is pivotal for both water quantity and water quality. Forests influence the hydrological cycle, the way water flows, and how it is stored and retained. Forests also regulate soil erosion and pollution. In addition, afforestation is beneficial for the water balance of Mediterranean areas: the evapotranspiration moisture of forests triggers rainfall events, and removing forests decreases the precipitation amount. These complex feedbacks between hydrology and land use show the need for a holistic approach: measures to reduce vulnerability must maintain ecosystem services and improve their functionality.

The main pressures on EU water bodies are diffuse pollution, over-abstraction and hydro-morphological pressures. When talking about mitigating the impacts of land use changes in agriculture, some measures can be taken on farm level, while others need a regional approach that includes other water users. In the on-going CAP reform, the European Commission proposed to introduce specific requirements from the WFD in the CAP compliance mechanism along with some other water-related provisions. If these proposals are implemented and strengthened, they can lead to a significant decrease in agricultural pressures caused by water abstractions and hydromorphological changes on farm and regional level.

5.2.3 *Climate change*

Climate change must be taken into account in addition to land-use changes and other interlinked drivers like demographic changes and economic activities. Climate change will influence the quality of water and its availability. The white paper on climate change adaptation (EC, 2009b) has a section related to both water quantity and quality on 'increasing the resilience of biodiversity, ecosystems and water'. However, equally important is the role of water in the other sections of the white paper, which mentions agriculture (CAP reform), industry, and households.

No-regret measures are those that are beneficial (cost-efficient) whether the predicted climate change scenario actually occurs or not. Many of the NWRMs are no-regret measures, in contrast to classic engineering ('grey infrastructure') measures, which often don't work in harmony with the ecosystem and are less able to evolve and adapt to subsequent changes. Promotion of NWRMs as a valuable alternative requires further knowledge-sharing and examples of good practice on different scales: from local measures that can be taken individually, all the way up to large river restoration projects.

Compared to the knowledge of trends in temperature and rainfall, much less is known about the evolution of river discharges. In climate projections, more is known on the annual trends of river flows than about the evolution of high flows (floods) and low flows (droughts), even though these extreme states are likely to have the largest impacts. Over the next decades, natural climatic variability makes the frequency and extent of extreme water events uncertain. Over the longer term, this uncertainty — combined with the uncertainty regarding the greenhouse gas emission scenarios — make it difficult to make any conclusions about the likelihood of the evolution of an extreme event. In general, under scenarios with an increased variability and intensity of rainfall, both flood and drought risks are projected to increase in Europe. This may not prevent the inclusion of additional measures in the RBMPs and FRMPs, as these programmes of measures are revised (at least) every six years. No-regret and flexible measures that can be adapted when new knowledge evidence becomes available are preferred. Those measures that irreversibly prevent the improvement of natural water retention have to be avoided.

Rising water temperatures will create new aquatic ecosystems — possibly with invasive species. But higher temperatures will also change regional weather patterns, and alter river flows, with knock-on effects on wetland and lake levels.

5.3 Sustainable water resource management

While drought is a natural phenomenon (a rainfall deficit), water scarcity is man-made and caused by an imbalance that arises from an overuse of water resources. As shown by several information sources over the recent years, (such as the water exploitation index or assessments on RBD level) many areas across Europe experience water stress. These areas are mostly in the Mediterranean region, but are not limited to this area. In most of these areas, water scarcity is seasonal; i.e. mainly occurring in summer, when water availability is generally low and demand is higher.

The widespread implementation of water accounting, both at a European level and at the sub-basin level based on good regional information, would be tremendously helpful. It would provide the knowledge needed to take measures to tackle water stress and to better achieve the objectives of the European Water Scarcity and Drought policy. Water accounting can also quantify non-abstracted water volumes and their variation on a monthly base. In this way it can support future work on ecological flow requirements. To be able to calculate and interpret the different indicators that can be based on the water accounts, more guidance on how to apply them in the different river basins is necessary.

This report summarised the problems with the Water Exploitation Index (WEI) as an indicator for water scarcity, and then examined some of the possible solutions to these problems. The original indicator was based on a yearly time scale and a national spatial scale making it unable to accurately represent regional and time variations. Not only are there large differences between different river basins within a country, there are also differences in a river basin depending on the time of year. Water scarcity is for most areas a seasonal problem, occurring during summer when water demand is highest (e.g. for agriculture) and availability is low. For this reason, the CIS WFD Expert Group on Water Scarcity and Droughts, where thematic and regional experts meet, worked on the concept of a new WEI+. Complementary to this, the European Commission and the EEA developed a water accounting methodology on monthly and sub-basin data scales based on more extensive data flows. The first results of these water accounts, which are currently being refined in consultation with Member States show significant improvements in comparison to the water scarcity assessments provided by the WEI or WEI+. Therefore in 2013, WEI+ and the Commission/EEA water accounts will be brought together to use the water accounts for the calculation of an improved water exploitation index.

5.3.1 Water resource management in the RBMP

In the 2009 RBMPs, the only direct water resource information (i.e. information related to water quantity as opposed to quality) related to the good status of on groundwater in the WFD. Groundwater is the only water type in the WFD where a good quantitative status is an explicit condition of good status. Water stress as a pressure is reported to be relevant for more than half of the RBDs in Europe. In two out of three groundwater bodies (GWB) not in good quantitative status, abstraction is mentioned as an important pressure. But abstractions are also the most common pressure even for those GWBs in good quantitative status. Sustainable water abstraction does not exceed the long-term recharge capacity of the groundwater body. Changes in land use towards less soil sealing or soil compaction can increase the recharge capacity and help to bring the GWB into good quantitative status.

In only one third of international RBDs do RBMPs clearly describe how to deal with WSD. This reflects a lack of knowledge and an absence of common indicators for international RBDs. The management of high waters — floods — will be reported in the 2015 flood risk management plans, which have to be coordinated with the 2015 RBMPs.

5.3.2 Implementation of water demand management

Sustainable water management in a green economy implies a more efficient use of water to ensure ecosystem services are maintained, because reducing water demand implies that there is more water left for the environment. As over-abstraction is one of the main pressures for many water bodies, water demand management techniques reduce vulnerability and the risk of water scarcity. These measures are explored in the EEA report 'Towards efficient use of water resources in Europe'. More water-efficient solutions can be found in technology such as the use of drip irrigation in agriculture, the treatment of wastewater to improve reuse, and water saving devices. The EU's Innovation Partnerships can also assist technology. Economic instruments like water pricing can also help improve efficiency, as can tackling illegal water use. These economic instruments are directly linked to other policy processes. For example, the funding of irrigation efficiency measures is under discussion in the reform of CAP Pillar II (see also Section 5.3).

While water resource efficiency is a prerequisite, on its own it is insufficient to guarantee a sustainable environmental water regime. This is because efficiency gains sometimes encourage an increase in the consumption of water, because each unit of water can now do more than before. This is called the 'rebound effect' and highlights the problem with resource efficiency. Even if improved resource-efficiency results in declining resource use, that use may still put excessive demands on the environment in absolute terms.

Many of the reported measures that are listed in the RBMPs and DMPs are water resource efficiency measures. Measures to combat flooding are only present in a limited number of first generation RBMPs, as the FRMPs are expected by the end of 2015, together with the second generation RBMPS.

5.4 Towards integrated water management

Integrated water management does not look into measures to mitigate or reduce an individual water problem. It works on holistic solutions taking into account water quality, low flows, floods, etc. Solutions that only address one problem, but are disadvantageous for others and solutions that replace upstream problems with downstream problems have to be avoided. Integrated management deals with the full risk-management cycle. However, from an environmental perspective, the main focus of integrated management is on prevention against — and preparation for — water scarcity and drought.

Integrated water management looks beyond individual sectors (industry, agriculture, energy etc) as it has a wider territorial dimension. Not only does it focus on the water available (or not-available) in the water courses themselves, it focuses also on the whole hydrological cycle and adjacent ecosystems. It seeks to understand in which areas is water retention being hampered; how much sediment is entering the rivers due to erosion; what are the assets to protect behind the water defences; how much water is needed for a sector: and what is the minimum water regime needed for the environment? These and many more questions can only be answered when the wider landscape is included in the analysis.

Although there are different policy documents dealing with water quality; floods; water scarcity; and droughts, coordination between the different management plans is necessary. The Floods Directive explicitly mentions coordination with the Water Framework Directive and so does the Communication on Water Scarcity and Droughts.

5.4.1 Risk management

Human water demand and the occurrence of excessive hydrological events (floods or droughts) create vulnerability in ecosystems as well as in economic and social systems. The goods and services that ecosystems provide are diminished through poor management of water resources. The inherent complexity of ecology, combined with the uncertainty about the impacts of climate change, means that a risk-based approach is the best way to manage this vulnerability.

In a risk-based approach, the range of different potential impacts is related to the probability of these impacts occurring. This differs from a crisis approach where measures are taken to mitigate the actual damage during a flood when a drought occurs, or when water quality sudden becomes worse. An integrated risk management cycle can be developed for all types of natural and technological hazards, although it is nowadays more likely to be applied for floods than for other water related events. Preventive measures can decrease the impact of floods, droughts, and water scarcity at a lower societal cost compared to a strategy that focuses on response (during an event) and recovery (after the event). During the preparedness phase, the needs of the different actors (including the ecosystem/environment) can be compared in different alternative combinations of measures. Measures that work together with nature are typically those that can best reduce vulnerability before an event occurs (see also green infrastructure and NWRM Section 5.2). Intervention when a water scarcity or flood event is already happening is mostly meant to limit the extent of the damage. The transition between response/recovery and prevention/preparation is typically a moment for analysis and reflection and for exploration of the lessons learned (see also Section 5.5).

5.4.2 *Integrated planning and action*

Integrated planning means that there is coordination between the different planning obligations for water quality; flood prevention and protection; droughts; and water scarcity. This includes coordination of objectives and programmes of measures. These coordinated plans are more likely to reduce social and economic vulnerability and increase ecosystem resilience in a cost-effective way than single ad hoc measures responding to single problems.

But integrated planning needs to go beyond the coordination in between water policy instruments. Promoting and implementing NWRMs in the coordinated RBMPs, FRMPs and DMPs will need to be done in cooperation with other EU policies like the CAP (pillar I) or the Structural and Cohesion Funds, as well as with other international and national funding schemes such as the lending policy of the EIB.

It is impossible to completely prevent floods, droughts and every risk to water quality. Even when the chances of these events happening are low, the probability is not zero. There will therefore always be a degree of vulnerability. But small probabilities with highly damaging potential consequences can still represent a large risk. 'Hard' engineering works on their own will not be the most efficient way to reduce these risks and improve the resilience of human activities and the environment. An efficient mix of measures, adapted for the local circumstances, will often be achieved through a combination of measures including those that do not involve heavy construction works. For example, the combination of measures could include spatial planning; behavioural adaptation; awareness raising; and catchment management. Here there is an important role for NWRMs to play.

5.4.3 *Coordination and cooperation*

Demography, economic activity, changes in land use, and climate change are all strongly interlinked drivers of floods, water scarcity and drought. There is therefore a need for a holistic view on water management that takes into account the pressures arising from these drivers. This holistic approach can be achieved by increased integration of water policy objectives (covering water quality, as well as policies dealing with floods, water scarcity and droughts) with energy policy, transport policy, the Common Agricultural Policy (CAP), and the Structural and Cohesion Funds (SCF). It is also essential to integrate spatial planning and climate change adaptation policy, a link explicitly referred to in the EU Floods Directive.

Besides integration across sectors policies, cross-boundary cooperation over the administrative boundaries is also a necessity as more than half of the EU territory is part of a transboundary river basin. A third form of cooperation, besides the thematic and spatial ones, is between research communities, water managers and policymakers. State-of-the-art knowledge is needed to decide on the most efficient (and effective) sets of measures to be taken to manage water resources.

5.5 Lessons for the future

Droughts and floods are partly natural phenomena, so they will continue to occur in the future. To reduce their negative consequences in the future, a comprehensive understanding of previous flooding and water scarcity events is needed. A good example of such an attempt to reach this understanding is the detailed analysis made in the Pitt review after the UK 2007 floods. It is also necessary to frame the conclusions of these studies of local or regional events within a wider European picture. To do this it is imperative to have the right data. More work needs to be done to ensure that water managers have this data at their fingertips. The European Flood Impact Database is currently under preparation. It must allow the comparison of data from different national and regional institutes and be more detailed than the currently existing worldwide databases. The Water Information System for Europe (WISE) is the logical entry point for the presentation of available European information available, including detailed reference data like ECRINS (river network) or the water accounts information.

The coordinated implementation of the different water legislation and policy documents has several advantages over a more separate, individual approach. Not only does it allow more cost-efficient sets of measures to be defined, coordination of objectives also gives more attention to environmental flow regimes and the sustained management of ecosystem services. But equally important is the challenge of coordinating — where necessary — with other sectoral policies, most notably the CAP and Cohesion Funds. Here the 'Blueprint for safeguarding Europe's water resources' gives an opportunity to place greater emphasis on a more coordinated implementation of sectoral policies. The Blueprint also gives guidance on which issues have to be developed in more detail for a better implementation.

Experience from the past (floods, droughts, pollution, erosion etc.) has to lead to measures that have co-benefits for the environment and the different water-using sectors. Environmental flow takes a central role when it comes to water quantity, as sustainable ecosystems are dependent on the existence of a water regime where abstractions are limited and sufficient water is left for the environment. Green infrastructure, NWRMs, awareness raising, and forecasting and evacuation tools (whether or not in combination with classic engineering solutions) are all part of this effort to work together with the ecosystem.

Acronyms and abbreviations

APSFR	Areas with potential significant flood risk
BHDs	Birds and habitats directives
CAP	Common Agricultural Policy
CDI	Combined Drought Indicator
CERS	Center for Environmental Systems Research
CIS	Common Implementation Strategy
DG	Directorate-General
DMP	Drought Management Plan
DPSIR	Driving Forces, Pressures, State, Impact and Responses
EAD	Expected annual damage
ECRINS	European Catchment and Rivers Network System
EDO	European Drought Observatory
EU	European Union
FAPAR	fraction of Absorbed Photosynthetically Active Radiation
FEC	Functional elementary catchment
FOEN	Federal Office for the Environment
FOWG	Federal Office for Water and Geology
FRMP	Flood Risk Management Plan
GCOS	Global Climate Observing System
GDP	Gross domestic product
GEP	Good ecological potential
GES	Good ecological status
GI	Green Infrastructures
GIS	Geographic information system
GMES	Global Monitoring for Environment and Security
GNP	Gross national product
GPCC	Global Precipitation Climatology Centre
GWB	Groundwater body

IES	Institute for Environment and Sustainability
IPCC	Intergovernmental Panel on Climate Change
IRM	Integrated risk management
JRC	Joint Research Centre
LCP	Large combustion plant
LTAA	Long-term annual average
MCA	Multicriteria analysis
MERIS	Medium Resolution Imaging Spectrometer
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne
NRC	National Reference Centre
NWRM	Natural water retention measures
OECD	Organisation for Economic Co-operation and Development
PFRA	Preliminary Flood Risk Assessment
RBD	River basin district
RBMP	River Basin Management Plan
RWR	Renewable Water Resources
SCOPE	Scientific Committee on Problems of the Environment
SEA	Strategic Environmental Assessment
SEEA	System of Economic and Environmental Accounts
SEIS	Shared Environmental Information System
SNA	System of National Accounts
SoER	State of the Environment Reporting
SPI	Standardized Precipitation Index
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistical Division
WEI	Water Exploitation Index
WFD	Water Framework Directive
WMO	World Meteorological Organisation
WS&D	Water scarcity and droughts
WSFS	Watershed and forecasting model system

References

Acreman, M. C. and Ferguson A. J. D., 2010, 'Environmental Flows and the European Water Framework Directive', *Freshwater Biology,* 55 (1) 32–48.

Adger, W.N., 2000, 'Social and Ecological Resilience: Are They Related?', *Progress in Human Geography,* 24 (3) 347–364.

Alderlieste, M.A.A. and van Lanen H.A.J., 2012, *Trends in low flow and drought in selected European areas derived from WATCH forcing data and simulated multi-model mean runoff*, Technical Report. Wageningen University, Wageningen, the Netherlands: DROUGHT-R&SPI.

Alessa, L., Kliskey A., Busey R., Hinzman L. and White D., 2008, 'Freshwater Vulnerabilities and Resilience on the Seward Peninsula: Integrating Multiple Dimensions of Landscape Change', *Global Environmental Change,* 18 (2) 256–270.

Antonellini, M., Mollema, P., Giambastiani, B., Bishop, K., Caruso, L., Minchio, A., Pellegrini, L., Sabia, M., Ulazzi, E. and Gabbianelli, G., 2008, 'Salt Water Intrusion in the Coastal Aquifer of the Southern Po Plain, Italy', *Hydrogeology Journal,* 16 (8) 1541–1556.

BAFU, 2012, *Anpassung an den Klimawandel in der Schweiz: Ziele, Herausforderungen und Handlungsfelder.* Erster Teil der Strategie des Bundesrates vom 2. März 2012. Bern: Bundesamt für Umwelt BAFU (http://www.bafu.admin.ch/publikationen/publikation/01673/index.html?lang=de) accessed 10 September 2012.

Baptista, J., Martinho, F., Dolbeth, M., Viegas, I., Cabral, H. and Pardal M., 2010, 'Effects of Freshwater Flow on the Fish Assemblage of the Mondego Estuary (Portugal): Comparison Between Drought and Non-drought Years', *Mar. Freshwater Res*., 61 (4) 490–501.

Barnolas, M., and Llasat M.C., 2007, 'A flood geodatabase and its climatological applications: the case of Catalonia for the last century', *Natural Hazards and Earth System Sciences,* 7 (2) 271–281.

Bates, B.C., Kundzewicz, Z., Wu, S. and Palutikof, J. (eds.), 2008a, Climate change and water Technical paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva (https://docs.google.com/file/d/0B1gFp6Ioo3akcFFFeGRRVFNYM0E/edit?pli=1) accessed 12 July 2012.

Bernhardt, E., Bunn, S.E., Hart, D.D., Malmqvist, B., Muotka, T., Naiman, R.J., Pringle, C., Reuss, M. and van Wilgen, B., 2006, 'Perspective: The Challenge of Ecologically Sustainable Water Management', *Water Policy,* 8 (5) 475.

Bindi, M. and Olesen, J.E., 2010, 'The Responses of Agriculture in Europe to Climate Change', *Regional Environmental Change,* 11 (S1) 151–158.

Blumenfeld, S., Lu, C., Christophersen, T. and Coates, D., 2009, *Water, wetlands and forest: a review of ecological, economic and policy linkages,* Secretariat on the Convention on Biological Diversity and Secretariat of the Ramsar Convention on Wetlands, Montreal and Gland (http://www.cbd.int/doc/publications/cbd-ts-47-en.pdf) accessed 16 August 2012.

Boelee, E., Chiramba, T. and Andreini, M., 2011, *An ecosystem services approach to water and food security*, UNEP, Nairobi (http://www.iwmi.cgiar.org/topics/ecosystems/PDF/Synthesis_Report-An_Ecosystem_Services_Approach_to_Water_and_Food_Security_2011_UNEP-IWMI.pdf) accessed 22 August 2012.

Bourdin, L., Stroffek, S., Bouni, C., Narcy, J.B. and Dufour, M., 2009, *Restaurer et préserver les cours d'eau Restauration Hydromorphologique et territoires: Concevoir pour négocier*, Guide Technique SDAGE, Comité de bassin Rhône méditerranée (http://www.documentation.eaufrance.fr/entrepotsOAI/AERMC/R156/66.pdf) accessed 26 October 2012.

Brázdil, R., Kundzewicz, Z.W. and Benito, G., 2006, 'Historical Hydrology for Studying Flood Risk in Europe', *Hydrological Sciences Journal,* 51 (5) 739–764.

Bunn, S.E. and Arthington, A.H., 2002, 'Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity', *Environmental Management* 30 (4) 492–507.

Bürger, K., Dostal, P., Seidel, J., Imbery, F., Barriendos, M., Mayer, H. and Glaser, R., 2006, 'Hydrometeorological Reconstruction of the 1824 Flood Event in the Neckar River Basin (southwest Germany)', *Hydrological Sciences Journal* 51 (5) 864–877.

BWG, 2001, *Flood Control at Rivers and Streams — Guidelines*, Federal Office for Water and Geology (FOWG) (http://www.eea.europa.eu/soer/countries/ch/soertopic_view?topic=freshwater) accessed 10 September 2012.

Christensen, J.H, and Christensen, O.B., 2002, 'Severe summertime flooding in Europe', *Nature,* 421 (20 February) 805–806.

CIS WFD, 2009, *Guidance document No. 24 — River basin management in a changing climate*, Technical report. Common Implementation Strategy for the Water Framework Directive (2000/60/EC) & European Communities, (http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/guidance_documents/management_finalpdf/_EN_1.0_&a=d) accessed 27 March 2012.

Collins, R., 2009, 'Water scarcity and drought in the Mediterranean', *EU Change,* 5 (3) 58–62.

Costanza, R., d' Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M., 1997, 'The Value of the World's Ecosystem Services and Natural Capita', *Nature,* 387 (6630) 253–260.

CRUE Flooding ERA-Net, 2009, *Syntesis Report adressing the key findings of research related to Risk Assessment and Risk Management: Effectiveness of Non-structural Flood Risk Management Measures* [Pichler, A., Deppe, T. and Jackson, V. (eds.),], CRUE Flood Risk Management Research Monograph Series, CRUE Flooding ERA-Net (http://www.crue-eranet.net/partner_area/documents/CRUE_1st_Research_Funding_Initiative_Synthesis_report.pdf) accessed 17 July 2012.

CRUE Flooding ERA-Net, 2012, *Syntesis Report adressing the key findings of research related to Flood Resilient Communities — managing the consequences of flooding* (Thieken, A. and Beurton, S. (eds.)), CRUE Flood Risk Management Research Monograph Series, CRUE Flooding ERA-Net (http://www.crue-eranet.net/partner_area/documents/CRUE_2nd_Research_Funding_Initiative_-_Synthesis_Report_2012.pdf) accessed 14 July 2012.

Czech Republic National SD Reports, 2008, *Drought Report. CSD 16/17 (2008–2009*), UN Department of Economic and Social Affairs, Division of Sustainable Development, National Information/National Report (http://www.un.org/esa/agenda21/natlinfo/countr/czech/drought.pdf) accessed 19 July 2012.

Dankers, R. and Feyen, L., 2009, 'Flood hazard in Europe in an ensemble of regional climate scenarios', *Journal of Geophysical Research,* 114 (D16).

Dartmouth Flood Observatory, 2012, *Space-based Measurement and Modeling of Surface Water — For Research, Humanitarian, and Water Management Applications*, University of Colorado (http://floodobservatory.colorado.edu/) accessed 17 July 2012.

Defra, 2009, *The Government's Response to Sir Michael Pitt's Review of the summer 2007 Floods*, Progress Report, Department for Environment, Food and Rural Affairs, (http://archive.defra.gov.uk/environment/flooding/documents/risk/pitt-progress091215.pdf) accessed 17 July 2012.

DMCSEE, 2009, *Drought Monitoring in Romania*, presented at the 1st Joint DMCSEE-JRC Workshop on Drought Monitoring, September 21, Ljubljana, Slovenia (http://www.dmcsee.org/uploads/file/84_drought_monitoring_in_romania.pdf) accessed 16 July 2012.

EC, 2000a, *Managing natura 2000 sites: the provisions of article 6 of the 'Habitats' Directive 92/43/CEE*, European Commission — Environment Directorate-General (http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/provision_of_art6_en.pdf) accessed 29 August 2012.

EC, 2000b, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive) (OJ L 327, 22.12.2000).

EC, 2001, Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (Strategic

Environmental Assessment Directive) (OJ L 197 21.07.2001).

EC, 2007a, *Water Scarcity and Droughts in-depth assessment*, 2nd Interim Report. European Commission — Environment Directorate-General (http://ec.europa.eu/environment/water/quantity/pdf/comm_droughts/2nd_int_report.pdf) accessed 18 July 2012.

EC, 2007b, Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Floods Directive) (OJ L 288 06.11.2007).

EC, 2007c, Communication from the Commission to the European Parliament and the Council addressing the challenge of water scarcity and droughts in the European Union (COM(2007)414 final of 18 July 2007).

EC, 2009a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the committee of the regions on A Community approach on the prevention of natural and man-made disasters (COM(2009)82 final of 23 February 2009).

EC, 2009b, White Paper 'Adapting to Climate Change: Towards a European Framework for Action' (COM(2009) 147 Final of 1 April 2009).

EC, 2009c, Final Report from the Commission to the Council and the European Parliament: Composite Report on the Conservation Status of Habitat Types and Species as required under Article 17 of the Habitats Directive (COM(2009)358 of 13 July 2009).

EC, 2010a, Directive 2009/147/EC of the Europen Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version of Directive 79/409/EEC as amended) (Birds Directive) (OJ L 20 26.01.2010).

EC, 2010b, Final Report from the Commission to the Council and the European Parliament: Second Follow-up Report to the Communication on water scarcity and droughts in the European Union COM(2007)414 final (COM(2010)228 of 18 May 2010).

EC, 2012, *A Blueprint to Safeguard Europe's water resources — Consultation Document*, European Commission — Directorate-General Environment (http://ec.europa.eu/environment/consultations/pdf/blueprint.pdf) accessed 12 July 2012.

EEA, 2007, *Land-use scenarios for Europe: qualitative and quantitative analysis on a European scale (PRELUDE),* EEA Technical report No 9/2007, European Environment Agency.

EEA, 2008, *Energy and environment report 2008*, EEA Report No 6/2008, European Environment Agency.

EEA, 2009, *Water resources across Europe — confronting water scarcity and drought,* EEA Report No 2/2009, European Environment Agency.

EEA, 2010a, *10 messages for 2010 — freshwater ecosystems,* European Environment Agency (http://www.eea.europa.eu/publications/10-messages-for-2010-2014-1) accessed 17 September 2012.

EEA, 2010b, *Water resources: Quantity and flows — SOER 2010 Thematic Assessment* , State of the environment report No 1/2010, European Environment Agency.

EEA, 2010c, *Urban Environment — SOER 2010 Thematic Assessment*, State of the environment report No 1/2010, European Environment Agency.

EEA, 2010d, *Land use — SOER 2010 Thematic Assessment,* State of the environment report No 1/2010, European Environment Agency.

EEA, 2011a, *Mapping the impacts of natural hazards and technological accidents in Europe*, EEA Technical report No 13/2010, European Environment Agency.

EEA, 2011b, *Europe's environment — An Assessment of Assessments*, European Environment Agency.

EEA, 2012a, *European waters — assessment of status and pressures*, EEA Report No 8/2012, European Environment Agency.

EEA, 2012b, *European waters — current status and future challenges — Synthesis*, EEA Report No 9/2012, European Environment Agency.

EEA, 2012c, *Climate change, impacts and vulnerability in Europe 2012 — An indicator-based report*, EEA Report No 12/2012, European Environment Agency.

EEA, 2012d, 'AEI 09 Land use change indicator (draft) — Agri-environmental Indicator Fact Sheet', European Environment Agency.

EEA, 2012e, *Towards efficient use of water resources in Europe*, EEA Report No 1/2012, European Environment Agency.

EEA, 2012f, *Urban adaptation to climate change in Europe — Challenges and opportunities for cities together with supportive national and European policies*, EEA Report No 2/2012, European Environment Agency.

EEA, 2012g, *Environmental indicator report 2012 — Ecosystem resilience and resource efficiency in a green economy in Europe*, European Environment Agency.

EEA, 2012h, *Territorial cohesion and water management in Europe: the spatial perspective*, EEA Technical report No 4/2012, European Environment Agency.

EEA ETC/CCA, 2012, *Floods — vulnerability, risks and management*, Technical Paper from the EEA European Topic Centre on Climate Change impacts, vulnerability and Adaptation and European Topic Centre on Inland, Coastal and Marine Waters (http://cca.eionet.europa.eu/reports/TP_2-2012) accessed 6 November 2012.

EEA ETC/ICM, 2012a, *Thematic Assessment on Vulnerability to Water Scarcity and Drought*, Report from the EEA European Topic Centre on Inland, Coastal and Marine Waters and European Topic Centre on Climate Change impacts, vulnerability and Adaptation (http://icm.eionet.europa.eu/ETC_Reports) accessed 6 November 2012.

EEA ETC/ICM, 2012b, 'Ecological and chemical status and pressures', Thematic assessment for EEA Water 2012 Report, Report from the EEA European Topic Centre on Inland, Coastal and Marine Waters (http://icm.eionet.europa.eu/ETC_Reports) accessed 6 November 2012.

EEA ETC/ICM, 2012c, 'Hydromorphology', Thematic assessment for EEA Water 2012 Report, Report from the EEA European Topic Centre on Inland, Coastal and Marine Waters (http://icm.eionet.europa.eu/ETC_Reports) accessed 6 November 2012.

EEC, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitat Directive), (OJ L 206 22.07.1992).

EG WSD, 2012, 'Update on Water Scarcity and Droughts indicator development', Water Scarcity and Droughts Expert Group of the Common Implementation Strategy for the Water Framework Directive.

EM-DAT, 2012, *The International Disaster Database*, Centre for Research on Epidemiology of Disasters — CRED (http://www.emdat.be) accessed 17 July 2012.

Estrela, T., Fidalgo, A., Fullana, J., Maestu, J., Pérez, M.A. and Pujante, A.M., 2004, *Júcar Pilot River Basin, Provisional Article 5 Report Pursuant to the Water Framework Directive*, Confederatión Hydrográfica del Júcar & Ministerio de Medio Ambiente, Valencia (http://www.chj.es/es-es/ciudadano/participacion_publica/Documents/Plan%20Hidrol%C3%B3gico%20de%20cuenca/Jucar_pilot_river_basin_Parte_2.pdf) accessed 23 August 2012.

Eurostat, 2011, *Water Statistics*, European Commission — Eurostat (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Water_statistics#Context) accessed 01 October 2012.

Evelpidou, N., Mamassis, N., Vassilopoulos, A., Makropoulos, C. and Koutsoyiannis, D., 2009, 'Flooding in Athens: The Kephisos River flood event of 21-22/10/1994', In *Proc. COST C22 and UNESCO-IHP Conference Road Map Towards a Flood Resilient Urban Environment 26/27.11.2009*, Unesco, Paris (http://itia.ntua.gr/getfile/1163/1/documents/Kifissos_Chapter_COST22_v3.pdf) accessed 15 September 2012.

Falkenmark, M., 2003, 'Freshwater as Shared Between Society and Ecosystems: From Divided Approaches to Integrated Challenges', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358 (1440) 2 037–2 049.

Falloon, P. and Betts, R., 2010, 'Climate Impacts on European Agriculture and Water Management in the Context of Adaptation and mitigation—The Importance of an Integrated Approach', *Science of the Total Environment*, 408 (23) 5 667–5 687.

Feyen, L. and Dankers, R., 2009, 'Impact of global warming on streamflow drought in Europe', *Journal of Geophysical Research,* 114 (15 September) 17 pp.

Feyen, L., Dankers, R., Bódis, K., Salamon, P. and Barredo, J.I., 2011, 'Fluvial Flood Risk in Europe in Present and Future Climates', *Climatic Change,* 112 (1) 47–62.

Flörke, M., Wimmer, F., Laaser, C., Vidaurre, R., Tröltzsch, J., Dworak, T., Marinova, N., Jaspers, G., Ludwig, F., Swart, R., Giupponi, C., Bosello, F. and Mysiak, J., 2011, *Climate Adaptation — modelling water scenarios and sectoral impacts*, Final Report. Center for Environmental Systems Research (CERS) in cooperation with Ecologic, Alterra and CMCC.

FOCP, 2012, Swiss Federal Office for Civil Protection, (http://www.bevoelkerungsschutz.admin.ch/

internet/bs/en/home/themen/gefaehrdungen-risiken.html) accessed 5 September 2012.

FOEN, 2011, *Core indicator Structure of watercourses*, Federal Office for the Environment (FOEN), (http://www.bafu.admin.ch/umwelt/indikatoren/08525/08586/index.html?lang=en) accessed 10 September 2012.

Foley, B., Jones, I.D., Maberly, S.C. and Rippey, B., 2012, 'Long-term Changes in Oxygen Depletion in a Small Temperate Lake: Effects of Climate Change and Eutrophication', *Freshwater Biology,* 57 (2) 278–289.

Folke, C., 2003, 'Freshwater for Resilience: a Shift in Thinking', *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 358 (1440) 2 027–2 036.

Folke, C., 2006, 'Resilience: The Emergence of a Perspective for Social-ecological Systems Analyses', *Global Environmental Change,* 16 (3) 253–267.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S. and Walker, B., 2002, 'Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations', *AMBIO: A Journal of the Human Environment,* 31 (5) 437–440.

Förster, H. and Lilliestam, J., 2010, 'Modeling Thermoelectric Power Generation in View of Climate Change: a Reply', *Regional Environmental Change,* 11 (1) 211–212.

Francés, F., García-Bartual, R., Ortiz, E., Salazar, S., Miralles, J.L., Blöschl, G., Komma, J., Habereder, C., Bronstert, A. and Blume, T., 2008, *Efficiency of non-structural flood mitigation measures: 'room for the river' and 'retaining water in the landscape'*. Final report. First CRUE ERA-Net Common Call Effectiveness and Efficiency of Non-structural Flood Risk Management Measures. CRUE Flooding ERA-Net (http://www.crue-eranet.net/partner_area/documents/Room_for_the_River_final_report.pdf) accessed 24 July 2012.

Füssel, H.-M. and Klein, R., 2006, Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking', *Climatic Change,* 75 (3) 301–329.

Gaffield, S. J., Goo, R.L., Richards, L.A. and Jackson, R.J., 2003, 'Public Health Effects of Inadequately Managed Stormwater Runoff', *American Journal of Public Health,* 93 (9) 1 527–1 533.

Gallopín, G.C., 2006, 'Linkages Between Vulnerability, Resilience, and Adaptive Capacity', *Global Environmental Change,* 16 (3) 293–303.

Garrote, L., Martin-Carrasco, F., Flores-Montoya, F. and Iglesias, A., 2006, 'Linking Drought Indicators to Policy Actions in the Tagus Basin Drought Management Plan', *Water Resources Management,* 21 (5) 873–882.

Glaser, R., Riemann, D., Schönbein, J., Barriendos, M., Brázdil, R., Bertolin, C., Camuffo, D., Deutsch, M., Dobrovolný, P., Engelen, A., Enzi, S., Halíčková, M., Koenig, S.J., Kotyza, O., Limanówka, D., Macková, J., Sghedoni, M., Martin, B. and Himmelsbach, I., 2010, 'The Variability of European Floods Since AD 1500', *Climatic Change,* 101 (1–2) 235–256.

Gobron, N., Knorr, W., Belward, A.S. and Pinty, B., 2010, 'Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)', in Arndt, D.S., Baringer, M.O. and Johnson, M.R. (eds), *State of the Climate in 2009,* 91 (7), Bulletin of the American Meteorological Society s50–s51.

Gordon, L.J., Finlayson, C.M. and Falkenmark, M., 2010, 'Managing Water in Agriculture for Food Production and Other Ecosystem Services', *Agricultural Water Management,* 97 (4) 512–519.

Gordon, L.J., Peterson, G.D. and Bennett, E.M., 2008, 'Agricultural Modifications of Hydrological Flows Create Ecological Surprises', *Trends in Ecology & Evolution,* 23 (4) 211–219.

Grigg, N.S. and Vlachos, E.C., 1990, *Drought Water Management*, In Proceedings of a National Workshop Held in Washington, D. C. on 1–2 November 1988. Colorado State University.

Gunderson, L.H., 2000, 'Ecological Resilience — in Theory and Application', *Annual Review of Ecology and Systematics,* 31 (1) 425–439.

Hannaford, J. and Marsh, T.J., 2008, 'High-flow and Flood Trends in a Network of Undisturbed Catchments in the UK', *International Journal of Climatology,* 28 (10) 1 325–1 338.

Haygarth, Ph.M. and Ritz, K., 2009, 'The Future of Soils and Land Use in the UK: Soil Systems for the Provision of Land-based Ecosystem Services', *Land Use Policy,* 26 S187–S197.

Hellenic Ministry of Environment, Energy and Climate Change and NAMA S.A., 2012, 'River Basin

Management Plan of the River Basin District of Eastern Sterea Ellada (GR07). Phase B, Deliverable 4, Drought and Water Scarcity Management Plan (in Greek)'. Hellenic Ministry of Environment, Energy and Climate Change.

Hightower, M. and Pierce, S.A., 2008, 'The Energy Challenge', *Nature,* 452 (7185) 285–286.

Hilton, J., O'Hare, M., Bowes, M.J. and Jones, J.I., 2006, 'How Green Is My River? A New Paradigm of Eutrophication in Rivers', *Science of The Total Environment,* 365 (1–3) 66–83.

Hinkel, J., 2011, 'Indicators of Vulnerability and Adaptive Capacity: Towards a Clarification of the Science–policy Interface', *Global Environmental Change,* 21 (1) 198–208.

Hirji, R. and Davis, R., 2009, *Environmental flows in water resources policies, plans, and projects findings and recommendations*, World Bank, Washington, D.C. (http://public.eblib.com/EBLPublic/PublicView.do?ptiID=459509) accessed 29 August 2012.

Holling, C.S., 1973, 'Resilience and Stability of Ecological Systems', *Annual Review of Ecology and Systematics,* 4 (1) 1–23.

Ibáñez, C. and Carola, N., 2010, *Impacts of Water Scarcity and Drought on Iberian Aquatic Ecosystems — Policy Note 04-0910,* Water Science and Policy Centre, University of California, Riverside.

ICPDR, 1994, *Convention on Cooperation for the Protection and Sustainable use of the Danube River (Danube River Protection Convention*), International Commission for the Protection of the Danube River (http://www.icpdr.org/main/icpdr/danube-river-protection-convention) accessed 26 October 2012.

IPCC, 2007, *Climate Change 2007: impacts, adaptation and vulnerability: working group I contribution to the Fourth Assessment Report of the IPCC,* Cambridge University Press, Cambridge.

IPCC, 2008, *Climate change 2007: synthesis report* (Bernstein, L., Pachauri, R.K. and Reisinger, A.,(eds.)), Intergovernmental Panel on Climate Change, Geneva, Switzerland.

IPCC, 2012, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J.,. Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M. (eds.)), Intergovernmental Panel on Climate Change, Cambridge (UK) and New York (USA) (http://ipcc-wg2.gov/SREX/report/) accessed 12 July 2012.

Isendahl, N. and Schmidt, G., 2006, *Drought in the Mediterranean: WWF Policy Proposals*. WWF-World Wide Fund for Nature (http://assets.panda.org/downloads/wwf_drought_med_report_2006.pdf) accessed 16 July 2012.

IUFRO, 2007, *How do Forests Influence Water? — IUFRO Fact Sheet No 2,* IUFRO — the International Union of Forest Research Organizations (http://www.iufro.org/download/file/4384/4475/fact-sheet-07-water_pdf/) accessed 22 August 2012.

JRC, 2011a, *Drought news in Europe: Situation in May 2011 — Short Analysis of data from the European Drought Observatory (EDO),* Joint Research Centre (JRC), Institute for Environment and Sustainability (IES) (http://desert.jrc.ec.europa.eu/action/php/index.php?id=118) accessed 18 July 2012.

JRC, 2011b, *Product Factsheet: Standardized Precipitation Index (SPI), version 1,* Joint Research Centre (JRC), Institute for Environment and Sustainability (IES) (http://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_spi.pdf) accessed 13 November 2012.

JRC, 2011c, *Product Factsheet: Soil Moisture, version 1*. Joint Research Centre (JRC), Institute for Environment and Sustainability (IES) (http://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_soilmoisture.pdf) accessed 13 November 2012.

JRC, 2011d, *Product Factsheet: Fraction of Absorbed Photosynthetically Active Radiation (fAPAR), version 1,* Joint Research Centre (JRC), Institute for Environment and Sustainability (IES) (http://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_fapar.pdf) accessed 13 November 2012.

JRC, 2012, *European Drought Observatory (EDO): Drought News March 2012* (Based on data until the end of February), Joint Research Centre (JRC), Institute for Environment and Sustainability (IES) (http://desert.jrc.ec.europa.eu/action/php/index.php?action=view&id=123) accessed 18 July 2012.

Kandilioti, G. and Makropoulos, C., 2011, 'Preliminary Flood Risk Assessment: The Case of Athens', *Natural Hazards,* 61 (2) 441–468.

Keirle, R. and Hayes, C., 2007, 'A Review of Catchment Management in the New Context of

Drinking Water Safety Plans', *Water and Environment Journal,* 21 (3) 208–216.

Kossida, M., Koutiva, I., Künitzer, A., Mimikou, M., Prchalova, H., Ronen,P., Scheidleder, A. and Tekidou, A., 2012, 'Thematic Assessment of Groundwater Quantitative Status', Draft report, NTUA, CENIA, UBA for European Commission — DG Environment.

Kottelat, M. and Freyhof, J., 2007, *Handbook of European freshwater fishes*, IUCN — International Union for Conservation of Nature. Publications Kottelat, Gland, Switzerland.

Kundzewicz, Z.W., Radziejewski, M. and Pínskwar, I., 2006, 'Precipitation extremes in the changing climate of Europe', *Climate Research,* 31, 51–58.

Kuusisto, E., 2004, *Droughts in Finland — Past, Present and Future* (http://hydrologydays.colostate.edu/Papers_2004/Kuusisto_Paper.pdf) accessed 19 July 2012.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C. and Xu, J., 2001, 'The Causes of Land-use and Land-cover Change: Moving Beyond the Myths', *Global Environmental Change,* 11 (4) 261–269.

Le Quesne, T., Matthews, J.H., Von der Heyden, C., Wickel, A.J., Wilby, R., Hartmann, J., Pegram, G., Kistin, E., Blate, G., Kimura de Freitas, G., Levine, E., Guthrie, C., McSweeney, C. and Sindorf, N., 2010, *Flowing Forward: Freshwater ecosystem adaptation to climate change in water resources management and biodiversity conservation,* Water Working Notes, WWF and Water Partnership Program for World Bank Group (http://www.worldwildlife.org/climate/Publications/WWFBinaryitem17968.pdf) accessed 14 July 2012.

Lupu, A. B., Ionescu, F.C. and Borza, I., 2010, 'The phenomenon of drought and it's [sic] effects within Romania', *Research Journal of Agricultural Science,* 42 (4) 102–109.

Maberly, S. C. and Elliott, J.A., 2012, 'Insights from Long-term Studies in the Windermere Catchment: External Stressors, Internal Interactions and the Structure and Function of Lake Ecosystems', *Freshwater Biology,* 57 (2) 233–243.

Macdonald, N. and Black, A.R., 2010, 'Reassessment of Flood Frequency Using Historical Information for the River Ouse at York, UK (1200–2000)', *Hydrological Sciences Journal,* 55 (7) 1 152–1 162.

Magdaleno Mas, F., 2010, *New E-Flows assessment and implementation programme in Spain* (http://www.eflownet.org/download_documents/Summary_EFRSpain_FMagdaleno_sep2010.pdf) accessed 21 November 2012.

MAOTDR, 2007, *Water Scarcity and Drought — A Priority of the Portuguese Presidency*, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Portugal, (http://ftp.infoeuropa.eurocid.pt/database/000042001-000043000/000042875.pdf) accessed 6 November 2012.

Marsh, T. and Hannaford, J., 2007, *The summer 2007 floods in England & Wales: a hydrological approach,* Centre for Ecology & Hydrology, Wallingford 'http://www.ceh.ac.uk/documents/CEH_FloodingAppraisal.pdf) accessed 17 July 2012.

Martínez-Santos, P., Llamas, M.R. and Martínez-Alfaro, P., 2008, 'Vulnerability Assessment of Groundwater Resources: A Modelling-based Approach to the Mancha Occidental Aquifer, Spain', *Environmental Modelling & Software,* 23 (9) 1 145–1 162.

Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.-K., Yohe, G.W. and Zwiers, F.W., 2010, *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties,*Intergovernmental Panel on Climate Change, Geneva, Switzerland (http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf) accessed 14 July 2012.

McGowan, S., Barker, Ph., Haworth, E.Y., Leavitt, P.R., Maberly, S.C. and Pates, J., 2012, 'Humans and Climate as Drivers of Algal Community Change in Windermere Since 1850', *Freshwater Biology,* 57 (2) 260–277.

McKee, T.B., Nolan, J. and Kleist, J., 1993, *The relationship of drought frequency and duration to time scales*, Preprints, Eighth Conf. on Applied Climatology, Anaheim, CA, Amer. Meteor. Soc., 179-184.

McKee, T.B., Nolan, J. and Kleist J., 1995, *Drought monitoring with multiple time scales*, Preprints, Ninth

Conf. on Applied Climatology, Dallas, TX, Amer. Meteor. Soc., 233-236.

MED WS&D WG, 2007, *Mediterranean Water Scarcity and Drought Report: Technical report on water scarcity and drought management in the Mediterranean and the Water Framework Directive*, Technical report. Mediterranean Water Scarcity & Drought Working Group. European Commission Environment Directorate-General and Joint Mediterranean EU Water Initiative (http://www.emwis.net/topics/WaterScarcity/PDF/MedWSD_FINAL_Edition/) accessed 16 July 2012.

MEPA and MRA, 2010, *Draft Water Catchment Management Plan for the Maltese Islands (Final Draft)*, Malta Environment and Planning Authority and Malta Resources Authority (http://www.mra.org.mt/Downloads/Consultations/Water%20Resources/MT_Water_Catchment_Management_Plan.pdf) accessed 16 July 2012.

Merz, B., Hall, J., Disse, M. and Schumann, A., 2010, Fluvial Flood Risk Management in a Changing World', *Natural Hazards and Earth System Science,* 10 (3) 509–527.

Metzger, M.J., Rounsevell, M.D.A, Acosta-Michlik, L., Leemans, R. and Schröter, D., 2006, 'The Vulnerability of Ecosystem Services to Land Use Change', *Agriculture, Ecosystems & Environment,* 114 (1) 69–85.

Miao, J.-F., Kroon, L.J.M., Vilà-Guerau de Arellano, J. and Holtslag, A.A.M., 2003, 'Impacts of Topography and Land Degradation on the Sea Breeze over Eastern Spain', *Meteorology and Atmospheric Physics,* 84 (3-4) 157–170.

Millán, M.M., Estrela, M.J., Sanz, M.J., Mantilla, E., Martín, M., Pastor, F., Salvador, R., Vallejo, R., Alonso, L., Gangoiti, G., Ilardia, J.L., Navazo, M., Albizuri, A., Artíñano, B., Ciccioli, P., Kallos, G., Carvalho, R.A., Andrés, D., Hoff, A., Werhahn, J., Seufert, G. and Versino, B., 2005, 'Climatic Feedbacks and Desertification: The Mediterranean Model', *Journal of Climate,* 18 (5) 684–701.

Millán, M.M., 2012, *Water begets water, and vegetation is the midwife*, presented at the Green Week 2012, 23 May, Brussels (http://ec.europa.eu/environment/greenweek/sites/default/files/2-3_millan.pdf) accessed 24 August 2012.

Millennium Ecosystem Assessment, 2005, *Ecosystems and human well-being. Volume 1, Current state and trends* (Hassan, R.M., Scholes, R. and Ash, N. (eds.)), Island Press, Washington (DC), Covelo (Calif.) and London.

Moriondo, M., Giannakopoulos, C. and Bindi, M., 2010, 'Climate Change Impact Assessment: The Role of Climate Extremes in Crop Yield Simulation', *Climatic Change,* 104 (3-4) 679–701.

Müller, U., Greis, S. and Rothstein, B., 2007, *Impacts on Water Temperatures of Selected German Rivers and on Electricity Production of Thermal Power Plants due to Climate Change,* DKKV/CEDIM, Karlsruhe University (http://www.cedim.de/download/33_Mueller_etal.pdf) accessed 16 July 2012.

Natale, L., and Savi, F., 2007, 'Monte Carlo Analysis of Probability of Inundation of Rome', *Environmental Modelling & Software,* 22 (10) 1 409–1 416.

NatCatService, 2012, *NatCatService — Downloadcenter for statistics on natural catastrophes,* Munich Re (http://www.munichre.com/geo) accessed 17 July 2012.

Nehls, T., Jozefaciuk, G., Sokołowska, Z., Hajnos, M. and Wessolek, G., 2006, 'Pore-system Characteristics of Pavement Seam Materials of Urban Sites', *Journal of Plant Nutrition and Soil Science,* 169 (1) 16–24.

Pall, P., Aina, T., Stone, D.A., Stott, P.A., Nozawa, T., Hilberts, A.G.J., Lohmann, D. and Allen, M.R., 2011, 'Anthropogenic Greenhouse Gas Contribution to Flood Risk in England and Wales in Autumn 2000', *Nature,* 470 (7334) 382–385.

Papathanasiou, C., Safiolea, C., Makropoulos, C. and Mimikou, M., 2009, *The FLADAR Project and Its Contribution to the Implementation of the EU Flood Directive 2007/60*, In Proc. 11th International Conference on Environmental Science and Technology (CEST09), Chania, Crete, Greece (http://www.srcosmos.gr/srcosmos/showpub.aspx?aa=12516) accessed 15 September 2012.

Petrow, T., and Merz, B., 2009, 'Trends in flood magnitude, frequency and seasonality in Germany in the period 1951–2002', *Journal of Hydrology,* 371 (1–4) 129–141.

Pike, R., 2003, 'Forest Hydrologic Cycle Basics', *Streamline Watershed Management Bulletin,* 7 (1) 1–5.

Pitt, M., 2008, *The Pitt Review — Learning the Lessons from the 2007 Floods,* Cabinet Office, London (http://webarchive.nationalarchives.gov.uk/20100807034701/http://archive.cabinetoffice.gov.uk/pittreview/_/media/assets/www.cabinetoffice.

gov.uk/flooding_review/pitt_review_full%20pdf.pdf) accessed 17 July 2012.

Poff, N.L., 2009, 'Managing for Variability to Sustain Freshwater Ecosystems', *Journal of Water Resources Planning and Management,* 135 (1) 1–4.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C., 1997, 'The Natural Flow Regime', *BioScience*, 47 (11) 769.

Poff, N.L., Olden, J.D., Merritt, D.M. and Pepin, D.M., 2007, 'Homogenization of Regional River Dynamics by Dams and Global Biodiversity Implications', *Proceedings of the National Academy of Sciences*, 104 (14) 5 732–5 737.

Poff, N. L. and Zimmerman, J.K.H., 2010, 'Ecological Responses to Altered Flow Regimes: a Literature Review to Inform the Science and Management of Environmental Flows', *Freshwater Biology,* 55 (1) 194–205.

Postel, S. and Richter, B.D., 2003, *Rivers for life managing water for people and nature*, Island Press, Washington.

Rapport, D.J. and Singh, A., 2006, 'An EcoHealth-based Framework for State of Environment Reporting', *Ecological Indicators,* 6 (2) 409–428.

Reidsma, P., Ewert, F., Oude Lansink, A. and Leemans, R., 2010, 'Adaptation to Climate Change and Climate Variability in European Agriculture: The Importance of Farm Level Responses', *European Journal of Agronomy*, 32 (1) 91–102.

Renard, B., Lang, M., Bois, P., Dupeyrat, A., Mestre, O., Niel, H., Sauquet, E., Prudhomme, C., Parey, S., Paquet, E., Neppel, L. and Gailhard, J., 2008, 'Regional methods for trend detection: Assessing field significance and regional consistency', *Water Resources Research*, 44 W08419.

Rienks, W.A., Hoek, S.B., Verweij, P.J.F.M. , Lokers, R.M. and Vanmeulebrouk, B., 2008, *Eururalis, a discussion support tool for rural Europe*, International Environmental Modelling and Software Society (iEMSs), Barcelona, 2, 988–998 (http://www.iemss.org/iemss2008/uploads/Main/S11-09-Verweij%20et%20al.pdf) accessed 5 September 2012.

Rockström, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J. and Qiang, Z., 2010, 'Managing Water in Rainfed agriculture — The Need for a Paradigm Shift', *Agricultural Water Management,* 97 (4) 543–550.

Rübbelke, D.T.G. and Vögele, S., 2011, *Distributional consequences of climate change impacts on the power sector who gains and who loses?,* Centre for European Policy Studies, Brussels (http://www.ceps.eu/book/distributional-consequences-climate-change-impacts-power-sector-who-gains-and-who-loses) accessed 19 July 2012.

Sakalauskiene, G. and Ignatavicius, G., 2003, 'Effect of Drought and Fires on the Quality of Water in Lithuanian Rivers', *Hydrology and Earth System Sciences,* 7 (3) 423–427.

Sánchez Navarro, R. and Schmidt, G., 2012, 'Environmental flows in the EU — discussion paper — draft 1.0 for discussion at the EG WS&D'. European Commission, Intecsa-Inarsa s.a. and Typsa.

Scalenghe, R. and Ajmone Marsan, F., 2009, 'The Anthropogenic Sealing of Soils in Urban Areas', *Landscape and Urban Planning,* 90 (1–2) 1–10.

Schanze, J., Hutter, G., Olfert, A., Penning-Rowsell, E.C., Parker, D., Harries, T., Nachtnebel, H.-P., Holzmann, H., Neuhold, C., Meyer, V., Kuhlicke, C., Schildt, A., Jessel, B., Königer, Ph. And Werritty, A., 2008, *FLOOD-ERA: Systematisation, evaluation and context conditions of structural and non-structural measures for flood risk reduction*, 1st CRUE ERA-Net Common Call Effectiveness and Efficiency of Non-structural Flood Risk Management Measures. CRUE Flooding ERA-NET (http://www.crue-eranet.net/partner_area/documents/FLOOD-ERA_Joint_Report_FINAL_web.pdf) accessed 17 July 2012.

Scheffer, M, Carpenter, S., Foley, J.A., Folke, C. and Walker, B., 2001, 'Catastrophic Shifts in Ecosystems', *Nature,* 413 (6856) 591–596.

Schmidt, G. and Benítez, C., 2012, *Topic Report on Water Scarcity and Droughts Aspects in a selection of European Union River Basin Management Plans*, Topic Report, Version 3.0. Service contract for the support to the follow-up of the Communication on Water Scarcity and Droughts. European Commission, Intecsa-Inarsa S.A. and Typsa.

Schmidt, G., Benítez, J.J., and Benítez, C., 2012, 'Working definitions of Water scarcity and Drought', European Commission, Intecsa-Inarsa s.a. and Typsa.

Schröter, D., Cramer, W., Leemans, R., Prentice, I.C., Araujo, M.B, Arnell, N.W., Bondeau, A., Bugmann, H., Carter, T.R., Gracia, C.A., de la Vega-Leinert, A., Erhard, M., Ewert, F., Glendining, M., House, J.I., Kankaanpää, S., Klein, R.J.T., Lavorel, S., Lindner, M., Metzger, M.J., Meyer, J., Mitchell, T.D., Reginster, I., Rounsevell M., Sabaté, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M.T., Thonicke, K., Thuiller, W., Tuck, G., Zaehle, S. and Zierl, B., 2005, 'Ecosystem Service Supply and Vulnerability to Global Change in Europe', *Science*, 310 (5752) 1 333–1 337.

Sepulcre-Canto, G., Horion, S., Singleton, A., Carrao, H. and Vogt, J., 2012, 'Development of a Combined Drought Indicator to detect agricultural drought in Europe', *Natural Hazards and Earth System Science*, forthcoming.

Singer, M. J. and Shainberg, I., 2004, 'Mineral Soil Surface Crusts and Wind and Water Erosion', *Earth Surface Processes and Landforms*, 29 (9) 1 065–1 075.

Sinreich, M., Kozel, R., Lützenkirchen, V., Matousek, F., Jeannin, P.-Y., Löw, S. and Stauffer, F., 2012, 'Grundwasserressourcen der schweiz — Abschätzung von Kennwerten', *Aqua & Gas* (9) 16–28.

Smolar-Žvanut, N., Maddock, I. and Vrhovšek, D., 2008, 'Evaluation and Application of Environmental Flows for Running Waters in Slovenia', *International Journal of Water Resources Development*, 24 (4) 609–619.

Stahl, K., Hisdal, H., Hannaford, J., Tallaksen, L.M., van Lanen, H.A.J., Sauquet, E., Demuth, S., Fendekova, M. and Jódar, J., 2010, 'Streamflow trends in Europe: evidence from a dataset of near-natural catchments', *Hydrology and Earth System Sciences*, 14 (12) 2 367–2 382.

Stahl, K., Tallaksen, L.M., Hannaford, J. and van Lanen, H.A.J., 2012, 'Filling the White Space on Maps of European Runoff Trends: Estimates from a Multi-model Ensemble', *Hydrol. Earth Syst. Sci.*, 16 (7) 2 035–2 047.

Stella Consulting, 2012, 'Costs, benefits and climate proofing of natural water retention measures (NWRM)', Final report. Stella Consulting for European Commission — Environment Directorate-General.

Thackeray, S.J., Henrys, P.A., Jones, I.D. and Feuchtmayr, H., 2012, 'Eight Decades of Phenological Change for a Freshwater Cladoceran: What Are the Consequences of Our Definition of Seasonal Timing?', *Freshwater Biology*, 57 (2) 345–359.

Tockner, K., Uehlinger, U. and Robinson, C.T., 2009, *Rivers of Europe*. Academic Press, Amstardam and London.

Turner, B. L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A. and Schiller, A., 2003, 'A Framework for Vulnerability Analysis in Sustainability Science', *Proceedings of the National Academy of Sciences of the United States of America*, 100 (14) 8 074–8 079.

UN, 1992, *United Nations Framework Convention on Climate change*, United Nations (http://unfccc.int/resource/docs/convkp/conveng.pdf) accessed 14 July 2012.

UNEP, 2009, *Water security and ecosystem services: the critical connection*, United Nations Environment Programme, Nairobi, Kenya (http://www.unep.org/themes/freshwater/pdf/the_critical_connection.pdf) accessed 15 September 2012.

UNEP, 2012, *Measuring water use in a green economy*, A Report of the Working Group on Water Efficiency to the International Resource Panel. McGlade, J., Werner, B., Young, M., Matlock, M., Jefferies, D., Sonnemann, G., Aldaya, M., Pfister, S., Berger, M., Farell, C., Hyde, K., Wackernagel, M., Hoekstra, A., Mathews, R., Liu, J., Ercin, E., Weber, J.L., Alfieri, A., Martinez-Lagunes, R., Edens, B., Schulte, P., von Wirén-Lehr, S., Gee, D., United Nations Environment Programme, Nairobi, Kenya.

UNISDR, 2009, *UNISDR Terminology on Disaster Risk Reduction,* United Nations International Strategy for Disaster Risk Reduction, Geneva (http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf) accessed 14 July 2012.

Uradni list RS, 2009, Decree on the Criteria for Determination and on the Mode of Monitoring and Reporting on Ecologically Acceptable Flow OG RS No. 97/2009, Government of the Republic of Slovenia (http://www.appa.provincia.tn.it/binary/pat_appa/agenda_eventi_ambientali/Blumauer.1317219988.pdf) accessed 28 September 2012.

Uyttendaele, G., van der Craats, I., Schelfaut, K., Krywkow, J. and Mysiak, J., 2011, *FREEMAN — flood Resilience Enhancement and Management: a pilot study in Flanders, Germany and Italy*, 2nd ERA-NET CRUE Research Funding Initiative: Flood Resilient Communities — Managing the Consequences of Flooding, CRUE Flooding ERA-NET (http://www.crue-eranet.net/partner_area/documents/FREEMAN_frp(1).pdf) accessed 14 July 2012.

Valenzuela Montes, L.M. and Matarán Ruiz, A., 2008, 'Environmental Indicators to Evaluate Spatial and Water Planning in the Coast of Granada (Spain)', *Land Use Policy,* 25 (1) 95–105.

van Delden, H., Stuczynski, T., Ciaian, P., Paracchini, M.L., Hurkens, J., Lopatka, A., Shi, Y., Gomez Prieton, O., Calvo, S., van Vliet, J. and Vanhout, R., 2010, 'Integrated Assessment of Agricultural Policies with Dynamic Land Use Change Modelling', *Ecological Modelling,* 221 (18) 2 153–2 166.

Van der Salm, C., Denier van der Gon, H., Wieggers, R., Bleeker, A. and van den Toorn, A., 2006, 'The Effect of Afforestation on Water Recharge and Nitrogen Leaching in The Netherlands', *Forest Ecology and Management,* 221 (1–3) 170–182.

van Loon, A., 2011, *DROUGHT in The Netherlands — 2011 May 23* (https://www.researchgate.net/publication/233726696_DROUGHT_in_The_Netherlands_-_Spring_2011) accessed 21 November 2012..

van Vliet, M.T.H., Yearsley, J.R., Ludwig, F., Vögele, S., Lettenmaier, D.P. and Kabat, P., 2012, 'Vulnerability of US and European electricity supply to climate change', *Nature Climate Change* (3 June).

Vidal, J., 2011, 'Europe's dry spring could lead to power blackouts, governments warnRiver levels may cause nuclear reactors to go offline, while dry weather in northern and eastern Europe will raise food prices', *The guardian*, 31 May 2011.

Viglizzo, E.F., Paruelo, J.M., Laterra, P. and Jobbágy, E.G., 2012, 'Ecosystem Service Evaluation to Support Land-use Policy', *Agriculture, Ecosystems & Environment,* 154 (July) 78–84.

Villarini, G., Smith, J.A., Serinaldi, F., Ntelekos, A.A. and Schwarz, U., 2012, 'Analyses of Extreme Flooding in Austria over the Period 1951–2006', *International Journal of Climatology,* 32 (8) 1 178–1 192.

VMM, 2011, *How to deal with flooding — Preparations for drafting the flood risk management plans for the river basins of the River Dijle upstream of Leuven and the River Woluwe in Flanders*, Vlaamse Milieumaatschappij. D/2011/6871/037.

Vogt, J., 2012, *The European Drought Observatory (EDO)*, presented at the GDIS Workshop, 4 November 2012, Frascati.

Walker, B., Holling, C.S., Carpenter, S.R. and Kinzig, A., 2004, 'Resilience, Adaptability and Transformability in Social-ecological Systems', *Ecology and Society* 9 (2).

Water Scarcity and Droughts Expert Network, 2007, *Drought Management Plan Report — Including Agricultural, Drought Indicators and Climate Change Aspects*, Technical report. European Communities, Brussels (http://ec.europa.eu/environment/water/quantity/pdf/dmp_report.pdf) accessed 29 August 2012.

Watkiss, P. (ed.), , 2011, *The ClimateCost Project*. Final Report. Volume 1: Europe. Published by Stockholm Environment Institute, Sweden (http://www.climatecost.cc/images/Policy_Brief_ClimateCost_Draft_Final_Summary_vs_4.pdf) accessed 6 November 2012.

Weiß, M. and Alcamo, J., 2011, 'A Systematic Approach to Assessing the Sensitivity and Vulnerability of Water Availability to Climate Change in Europe', *Water Resources Research,* 47 (2).

WG F Drafting Group, 2011a, 'List of types of measures', Working Group on Floods of the Common Implementation Strategy for the Water Framework Directive.

WG F Drafting Group, 2011b, 'Draft list of flood types and list of consequences', Working Group on Floods of the Common Implementation Strategy for the Water Framework Directive.

Wilhite, D.A., Svoboda, M.D. and Hayes, M.J., 2007, 'Understanding the Complex Impacts of Drought: A Key to Enhancing Drought Mitigation and Preparedness', *Water Resources Management,* 21 (5) 763–774.

Wilson, D., Hisdal, H. and Lawrence, D., 2010, 'Has Streamflow Changed in the Nordic Countries? — Recent Trends and Comparisons to Hydrological Projections', *Journal of Hydrology,* 394 (3–4) 334–346.

WMO, IOC, UNEP and ICSU, 2010, *Implementation plan for the Global Observing System for Climate in support of the UNFCCC (2010 update),* World Meteorological Organisation, Geneva (http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf) accessed 21 August 2012.

Wolf, L., Klinger, J., Hoetzl, H. and Mohrlok, U., 2007, 'Quantifying Mass Fluxes from Urban Drainage Systems to the Urban Soil-Aquifer System', *Journal of Soils and Sediments,* 7 (2) 85–95.

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