Flood risk

The vulnerability of floodplains and the environmental impacts of flood protection measures

DRAFT

for consultation only – do not cite or quote

Prepared by / compiled by: Henk Wolters, Mathias Scholz, Lidija Globevnik, Luka Snoj and Wouter Vanneuville
Organisation: ETC/ICM – Delatares, UFZ, TC Vode

EEA project manager: Wouter Vanneuville

Version history

Version	Date	Author	Status and description	Distribution
1.7	01/09/2015	EEA, ETC/ICM	Draft for consultation	NRC Water quantity, NFP, CIS WG Floods and selected experts

Contents

1 Executive summary 3

2 Introduction 4

2.1 Flooding in Europe 5

2.2 Environmental aspects of floods and floodplains 6

2.3 The delineation of floodplains.......... **Error! Bookmark not defined.**

2.4 Strategic flood risk management 10

2.5 Outline and reading guidance 11

3 Chapter 3 63

3.1.1 Subsections use the ‘Heading 3’ style..... **Error! Bookmark not defined.**

4 Heading 1 .... Error! Bookmark not defined.

4.1 Heading 2 .... **Error! Bookmark not defined.**

4.1.1 Heading 3 .... **Error! Bookmark not defined.**

References (use the ‘Heading 4’ style) 64

Annex 1 Annexes use the ‘Heading 5’ style.......... Error! Bookmark not defined.

1 Executive summary

Will be developed later

2 Introduction

In 2012, the European Commission came up with "A Blueprint to Safeguard Europe's Water Resources" (EC 2012c) to tackle the obstacles which hamper action to further improve the status of EU waters. EEA's state of water reports ([1]) served as an important contribution to underpin the statements that water quality and water quantity need concerted action. There are numerous challenges to attaining the objectives of the Water Framework Directive (WFD) (EU 2000 (Art. 4)) and floods, inundations, modifications of the water flow and morphological changes are amongst the multitude of pressures affecting Europe's water bodies.

Where the report "Water resources in Europe in the context of vulnerability" (EEA 2012c) focussed on droughts, water scarcity and floods, this report focusses on flooding, the role of floodplains and the impact of hydromorphological alterations on the ecosystem services floodplains provide. While the aim is to support the implementation of the European Floods Directive (EU 2007) it at the same time looks at EU water and nature policies as well as thematic policies affecting floodplains to identify synergies and approaches to capitalize on them.

In 2016-2018, the EEA will prepare an update on the state of EU waters in assessments based on the information that becomes available from the second generation of River Basin Management Plans (RBMPs). Included in the update will be flood impacts and flood risk management. The most prominent information on flood impacts and flood risk management at EU level is based on the reporting under the Floods Directive: information on past and future floods, the Flood Hazard and Risk Maps (FHRMs) and the draft Flood Risk Management Plans (FRMPs). This report is a conceptual assessment on how this information can be used to get a more comprehensive assessment on the quantitative and qualitative status of Europe's water resources and the ecosystem services they provide. Without suggesting to be complete and aware of changes still being implemented in the FRMPs, the information allows us to make suggestions for an improved second cycle of implementation of the Floods Directive. It also enables us to develop a better understanding of freshwater ecosystem services, and of the environmental impact of flooding and flood protection measures.

Secondly, we want to explore the synergies between the Floods Directive and other water and nature legislation. In particular the WFD (EU 2000) and the Birds and Habitats Directives (EU 1992, 2010) are of interest, in the framework of streamlining environmental requirements as expressed in the Biodiversity 2020 Strategy (EC 2011a) and the potential revision of the WFD after 2018.

The third objective of this report is to identify and share good examples to improve the Preliminary Flood Risk Assessment (PFRA) in the next cycle of implementation of the Floods Directive in 2018. The second cycle will be started soon after the reporting of the Flood Risk Management Plans (FRMPs), which will complete the first cycle of implementation in March 2016. While many details about floods and their impacts are known on local level, it remains difficult to get a detailed European overview. The Floods Directive collects information on significant past floods as part of the PFRA (EU 2007, Art. 4). To be of most value for European wide assessments, the structured information provided needs to be detailed enough to create added value beyond some descriptive terms like 'extreme event' or 'large impact' but at the same time be general enough to be comparable. Where this is done to a certain extent in the PFRA in 2011, analysis of the information (e.g. (Kjeldsen, et al., 2013)) shows that more can be done in this regard.

[1] http://www.eea.europa.eu/themes/water/water-assessments-2012

For whom this report is made

The main audience in mind when writing this report are flood risk managers involved in the FRMPs and the programmes of measures. Under budget restrictions, and with water and land being scarce goods, searching for synergies with the other water and nature protection communities and creating integrated visions and measures is an (even the) effective and efficient way forward. In isolation it may seem as if your actions go faster (at least in the beginning), by working together you get much further.

It is also meant as an introduction to water managers involved in the RBMPs and people involved in nature conservation and restoration to better understand how their actions can contribute to a sustainable flood risk management. Given the importance of land use changes and developments like urbanisation as important pressures, spatial planners and developers will find information on synergies and sustainable development of floodplains. In general, this report gives examples for all those interested in how water management (and more specific flood risk management) based on an ecosystem services approach is shaped and how flood risk management is linked to a wide variety of thematic polices influencing and influenced by flood risk management.

2.1 Floods in Europe

Across Europe and throughout the ages floods have affected human health ([2]), the environment, cultural heritage and economic activities. The United Kingdom and Ireland floods from April 2012 onwards were caused by a series of weather events that lasted on through the winter of 2013. Central Europe was hit by extreme floods in May and June 2013 affecting both Elbe and Danube catchments. On many locations, these floods caused the highest water levels and/or discharges ever recorded (BfG 2013; Gierk, 2013; ICPDR 2014). Although the damage was still significant, the measures taken e.g. in Austria after the 2002 floods proved to be highly effective (Neuhold, 2013).

In May 2014, a low-pressure cyclone affected a large area of southeast and central Europe, causing floods and landslides, e.g. along the Sava river. Serbia and Bosnia and Herzegovina suffered the greatest damage. In Serbia only already over 50 fatalities were counted, roughly 32 000 people were evacuated, and over 1.5 million people were affected (Pavlović, 2014).

After a flood event, different numbers are circulating about the damages and people affected. However, a consistent database of the impacts of past floods is not available for Europe (EEA, 2011). Overviews of flooding on a European scale and its impacts were extracted from global disaster databases. Nevertheless, information on past flood events is the basis for a sound understanding of flood generating processes across Europe and for reliable predictions of future flood changes. Therefore the development of a comprehensive publicly available database of flood events and their impacts in Europe is desirable (EEA, 2011).

Based on the information on past floods reported by EU Member States in the Preliminary Flood Risk Assessment (PFRA) under the Floods Directive (EU 2007, Art. 4) and complemented by data from global databases like EM-DAT (EM-DAT 2015) or Dartmouth Flood Observatory (DFO) (Brakenridge, 2015), such an EU overview of significant flood and their impact is now available for the 39 EEA member countries and cooperating countries ([3]). More details can be found in Box 2.1

[2] Including social impacts to individuals ro the community
[3] http://www.eea.europa.eu/about-us/countries-and-eionet

Box 2.1 European Flood Impact Database

A European Flood Impact Database (EFID) was not available so far. In most European countries, national databases for natural hazards were available but they were very different in terms of type of hazards included, information on impacts, thresholds to include events, availability of the detailed data etc. (Mysiak et al., 2013). The amount of information available increased significantly after the reporting of the PFRA (mainly on the impacts, although often not quantified or expressed in monetary terms) and the information was better structured due to the template imposed by the Floods Directive reporting schemas. Nevertheless the PFRA reporting in itself is insufficient to act as the single database on European floods and flood impacts (Kjeldsen et al., 2013). In addition, floods are not bound to administrative boundaries and e.g. no information was available about non-EU European countries.

Therefore, a list of significant floods since 1980 as defined by the countries and selected attributes on hazard and impact were prefilled based on the PFRA reporting and global natural disaster database. A country consultation for corrections and additions ran from February until May 2015. The resulting database, where also environmental impacts and impacts on cultural heritage are included where available besides fatalities and economic damage, is available at: http://forum.eionet.europa.eu/nrc-eionet-freshwater/library/country-review-european-floods-impact-database-2015 (*). Results are discussed in Section 4.1 of this report.

(*) link to be replaced by reference to water data centre once data are available

Given the importance of natural water retention measures (NWRMs) and flood protection measures that work with natural processes, the Birds and Habitats Directives (EU 1992, 2010) are looked at in more detail as well. Notwithstanding the links in content and process between the FD, WFD and BHDs, there are also big differences between them. Where the Water Framework Directive and Birds and Habitat Directives are mainly environment related legislation (although with some overlaps to the economic and social issues), an essential element of the Floods Directive is its combination of environmental, economic and social issues (Evers, and Nyberg, 2013): human health, the environment, cultural heritage and economic activities are the four impact categories the EU Member States have to report on.

At the same time this indicates this report limits itself mainly to the environmental aspects related to floods and flood protection measures. Economic, health and cultural impacts will not be dealt with in detail, although they are necessary to come to an integrated (flood) risk management.

2.2 Environmental aspects of floods and floodplains

Water quantity management, including extremes like floods or hydrological droughts, should always be considered together with its impacts on the environmental quality and with water quality management. As mentioned in the Blueprint to Safeguard Europe's water resources (EC 2012c) water over-abstraction is the second most common reported pressure in the first generation of RBMPs. At the same time, the hydrological regime defines the physical habitat in and along water bodies. Flow requirements to reach a good ecological status thus go beyond minimum discharges during dry periods but have to take into account the full range of discharges: from base flows (including low flows) to flood regimes with different magnitudes, frequency, duration etc. This link between quantity and quality is clearly made in the guidance document on ecological flows in the implementation of the WFD (EC 2015c). The objectives on protection and conservation of freshwater-dependent ecosystems can only be reached when discharges and water levels can vary over weeks, months and years including flood events. Thereby it is possible that flow requirements for certain species or habitats following from the Birds and Habitats directives (BHDs) go beyond the ones to reach the good ecological status (GES) as defined by the WFD and should then be considered in the implementation of the WFD (EC 2015c).

Where a flood, according to the definition in the Floods Directive (EU 2007, Art. 2 (1)), is “the temporary covering by water of land not normally covered by water”, the main area of interest is the floodplain where this flood happens. The natural floodplain can be defined in different ways (see section 2.3) and four key questions define the role this area can play in mitigating or reducing flood risk:

- What is the use of the area?
- What is the hydrological regime?
- What is the connectivity of the water body (river) and the floodplain? and
- What is the water quality?

Many former natural floodplains are nowadays under pressure from urbanisation, infrastructural developments and agriculture. In order to reduce negative economic and human impacts along many rivers, protection or regulation measures have been implemented. These have the negative side effect that the amount of water that can be stored is limited. Due to soil sealing or soil compaction, the water retention capacity to reduce the amount of overland flow is reduced as well.

However, the impact of soil sealing is certainly not limited to the floodplain itself as it even becomes more relevant at the scale of the catchment where it affects the river hydrology. Both peak flows causing floods and the low flows in dry periods are becoming more extreme with a higher variation of water levels over time. Contrary to this process, we have to question to which degree the water level is managed within narrow boundaries to support navigation, hydropower or other economic activities. This has to be compared with the hydrological regime close to the environmental flow with variations over time and periods of low flows and floods.

Connectivity is often related to flood protection. Dikes, dams and other infrastructural measures prevent the water from entering the area, unless a major flood event happens and the infrastructure is overtopped or fails. As flood protection provides increased security, the areas behind flood protection infrastructure are often highly developed, which causes large economic and social consequences once the flood event is of a higher magnitude than the protection level. In addition, these protection measures have a strong negative impact on the environmental quality of the water body and the floodplain, limiting the ecosystem services the area can provide.

A last issue is water quality and pollution. This deals both with the quality of the water entering the floodplain and the pollution that happens when contaminated inert soils are brought in suspense or when polluting installations (industries, but also oil and sceptic tanks) are flooded. In chapter 3 we look in more detail to these different aspects and how natural floodplains can provide several ecosystem services.

2.3 Floodplain areas

Where the European Floods Directive (EU 2007, Art. 2) defines a ‘flood’ as the temporary covering of water of land not normally covered by water, a ‘floodplain’ is not defined in this directive. Water management and flood risk management do not only comprise the riverbed or the lake area covered with water all year round. It includes the whole catchment, as the area from which raindrops flow into a river, lake or reservoir. Land cover patterns in the catchment, soil, topography … are some of the parameters defining how much and how fast rain ends in the river or lakes within the catchment.

A part of the catchment, outside the riverbed is the floodplain; an area that is irregularly but more or less frequently covered with water in times of high water conditions in its adjacent rivers. Despite several individual case studies there is no comprehensive classification of floodplains (Nanson, and Croke, 1992). The genetic floodplain, being the alluvial landform adjacent to a river and built of its sediments, differs from the hydraulic floodplain, being the area inundated with a certain frequency regardless land use, soil, etc. In this report, we will use the term ‘floodplain’ to describe intermittently inundated lands next to river channels (e.g. (Matella, and Jagt, 2014)). First of all we give an overview of terms closely related to ‘floodplains’, before discussing its status, functions and trends in chapter 3.

Alluvial areas

Floodplains in alluvial areas are the low-lying areas along a river characterized by the alternation of floods and low water, built of sediments deposited during overflow and lateral migration of the streams. As part of the river landscape, they are in a permanent state of exchange with the river and its catchment area. (Gautier, et al., 2009). Water sources are primarily from the lateral overspill of river water; although high groundwater levels can also contribute to floodplain inundation (Tockner, and Stanford, 2002). The water flow in floodplains is multidimensional. Upstream-downstream interactions constitute the longitudinal dimension. The lateral dimension includes interactions between the channel and riparian floodplain areas, whereas the vertical dimension encompasses exchanges with the groundwater aquifer. The fourth dimension i.e. time, provides the temporal scale (Ward, 1989). The soil of alluvial areas consists of sands, silts, clays or gravels and is called fluviosoils. Genetically floodplains with organic soils are not understood as being alluvial areas.

Flow variations together with different sediment deposition patterns create patches with different levels of connectivity to the stream and soil features. The heterogeneous and quickly changing habitats, together with natural fertilisation caused by suspended matter and nutrients introduced by flooding, lead to the high biodiversity and productivity in floodplains (Craft, and Casey, 2000; Naiman and, and Décamps, 1997; Robinson, et al., 2002)

Riparian zones

Riparian zones are transitional areas at the interplay of land and freshwater ecosystems, with a distinctive soil, hydrology and biotic conditions strongly influenced by the streamflow as typical characteristics (Naiman, et al., 2005). In this way, riparian zones not only refer to floodplains and wetlands, but also include uplands where a direct water-land interaction is important. For more details about concept and definitions, see (Clerici, et al., 2011). Mountainous areas show a high portion of riparian zones, where there presence is lower in the main European plains where the landscape is characterized by agricultural use (Clerici, et al., 2011). The Joint Research Centre (JRC) of the European Commission developed a zonation tool for riparian zones, that isn’t designed as a high-precision mapping tool, but provides a European overview, being a key component of the European Green Infrastructure ([4]) (Clerici, et al., 2011; EC 2013c)

Wetlands

Wetlands are a very general term (with many different definitions) to refer to areas like marshes, swamps, bogs, fens, mangroves etc. that all have in common that periodic inundation or prolonged waterlogging creates the suitable conditions for aquatic life (Tines, 2013). The Ramsar Convention (UNESCO 1994) uses a very broad definition where wetlands include “*all lakes and rivers, underground aquifers, swamps and marshes, wet grasslands, peatlands, oases, estuaries, deltas and tidal flats, mangroves and other coastal areas, coral reefs, and all human-made sites such as fish*

[4] EEA will make a publication on “Green Infrastructure and Flood Management” in 2016

ponds, rice paddies, reservoirs and salt pans” (Ramsar Convention Secretariat 2014). In total, 42 different wetland types are distinguished in the Ramsar multinational classification system: 12 types of marine and coastal wetlands, 20 inland wetland types and 10 man-made types of wetland (Ramsar Convention Secretariat 2013). Floodplains are not listed as a specific type of wetlands, but overlap partly or in full with several wetland types.

According to (Stevenson, and Frazier, 1999a, 1999b) there are over 37 million hectares (ha) of wetland in EEA member and cooperating countries. Over one third (12.8 million ha) of it can be found in Sweden alone, and Estonia, Finland and Norway mapped over 3 million ha each. Other countries with extensive wetland areas (all over 1 million ha) mapped are Denmark, Poland, the United Kingdom, Germany, Turkey and France. It may be clear that the area of wetlands is not very precise: not only are data missing for many countries, but also the methodologies to delineate wetlands are subject to improvement to better include seasonal and inter-annual climate variations and anthropogenic influences as well as to eliminate variations introduced by the experience of the delineator (Kriegner, et al., 2015).

As part of the Copernicus Land Services, a high-resolution layer for wetlands is currently under development. Based on remote sensing, it must provide a more homogeneous overview of Europe’s wetlands but the results aren’t validated so far (Copernicus Land Monitoring Services 2015; Langanke, 2013).

Hydraulic floodplain

The hydraulic floodplain delineates an area flooded with a certain statistical probability. Mapping of these floodplains is based on evidence from historic events and/or hydraulic modelling. Different methodological choices, including but not limited to extreme value statistics, equations for flow computations in the river channel and adjacent floodplain, the accuracy and precision of a digital elevation model, the inclusion of flood defences or not … make the detailed results existing in most (if not all) EU member States difficult to compare or join into a European map.

A global overview of river flood extents is publicly available on the PREVIEW Global Data Platform ([5]) (Herold and Mouton, 2011). The JRC makes European flood maps based on simulation with the LISFLOOD model (Rojas, et al., 2012, 2013) for eight different return periods between 2 and 500 years. While these results have their value for European wide studies on climate change impacts, the river routing network does not include the plentiful small tributaries.

Remaining floodplains at European scale correspond roughly to the FD reporting categories of flood hazard and risk areas with floods with a high or medium probability (likely return period of 100 years or more exceptional). Former floodplains are usually disconnected from the flood dynamic by dyke constructions, but as the groundwater table in these areas generally is still connected to the river dynamics and during floods seepage water can occur. In case of flood hazards and dike failures these areas are prone to flooding and are often reported under the FD as flood risk area with low probability. Active and inactive floodplains together are defined the morphological floodplain.

In the EU Floods Directive (EU 2007, Art. 6) flood hazard maps for different scenarios have to be produced where the medium probability scenario for all mapped floods in the FHRMs is the 100 year return period flood event. As explained in the first paragraph, this does not mean they can easily be merged to get one fully homogeneous flood hazard map for Europe but at least for these countries where data were available they give the most detailed overview available so far. All the above

[5] See http://preview.grid.unep.ch online

confirms that there is no single data set suitable to answer all questions and that many data sets are still under development and needs improvement.

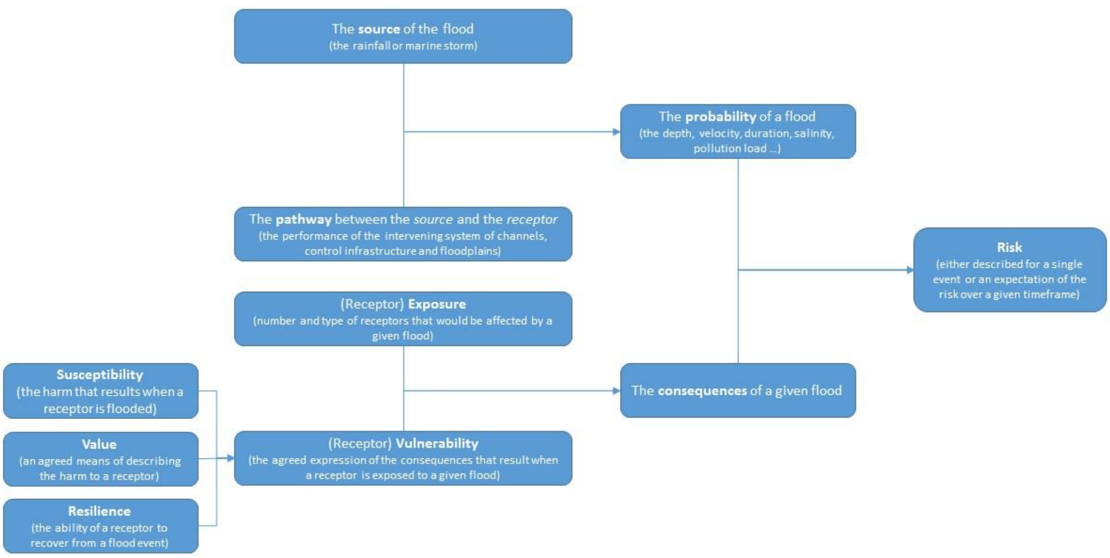
2.4 Strategic flood risk management

Strategic flood risk management can be described as a section of the wider integrated water management and planning approach for river basins and coastal areas. It focusses on reducing flood risks AND promoting environmental, societal and economic opportunities nowadays AND in the long term (Sayers, et al., 2015). The concept of risk management is under constant evolution, in particular in adopting an adaptive approach, which works with natural processes, contributes to ecosystem services in a positive way and is part of an integrated water management approach (Sayers, et al., 2013; WMO 2009). Although always appreciated in academia and at local scale, the attention for beneficial relationship between floods and ecosystem services at planning level is a rather recent development (Sayers, et al., 2015).

Large flood events have an impact on thinking, policy and practices in flood risk management. The river floods in 1947 and devastating coastal floods of 1953 raised issues on food security and the need for clear roles and responsibilities in flood risk management together with a boost in increased performance of warning systems. The large river floods in several years during the 1990s paved the way for a basin-wide flood risk management and a larger role for non-structural measures in addition to the structural ones and an increased awareness for the role of spatial planning (e.g. in Room for the River and related policies and practices) . The 2007 floods in the UK, and the whole review process (Pitt, 2008) clearly indicates the need to consider all sources of flooding and their combined occurrence as well as the need for detailed spatial information. It is probably too early to define how the recent floods (see section 2.1) in Central Europe and the Balkan shaped and changed our thinking on flood risk management.

To understand flood risk, one has to understand its different components and their interrelations to make informed decisions. Figure 2.1 gives a clear overview of them.

Figure 2.1 The components of risk



Source: (Sayers, et al., 2015)

Flood risk management, as the management of natural hazards in general, is one of the elements supporting the broad aims of sustainable development (UNISDR 2015) as clearly stated in the Sendai Framework for Disaster Risk Reduction 2015–2030 (UN 2015). A strategic flood risk management approach supporting sustainability is therefore, in contrast to the still widespread misconception, much more than maintaining the integrity of flood control structures now and over long time horizons (Sayers, et al., 2015). It includes maintaining, restoring and strengthening the long-term health of all associated ecosystems, societies and economies by promoting the following key principles (Sayers, et al., 2015):

- efficiency and fairness: maximizing the utility of an investment while ensuring a process that also protects the most vulnerable members of society;
- resilience and adaptive capacity: purposeful approaches to strategy development and design that are inherently risk based and actively manage uncertainty; and
- safeguarding ecosystem services: soft path measures (like land use changes or wetland restoration) and selective hard path measures (e.g. bypass channels or controlled storage) both offer opportunities to simultaneously manage flood risk and promote ecosystem services.

The synergies between different types of measures, even between different types of infrastructural measures are often overlooked and concepts like working with natural processes or natural water retention measures need to be in the core toolkit of every flood risk manager.

The flood risk manager (and water manager) cannot do this alone, as a wide variety of EU policies are influencing the intersections between flood risk management, flood vulnerability and environmental impacts in a significant way (see chapter 4). These are not only environmental policies, like the WFD and BHDs, but also policies on agriculture or pollution. While there are many examples of improved environmental quality in Europe's environment (EEA 2015e) including Europe's waters (EEA 2015a), there is still room for improvement by better implementation of policies and public participation with active involvement rather than only information supply or consultation. For the later one, many good examples can be found to learn from (EEA 2014e) although in general, there is a lack of data really tailored to purpose (see also subsection 4.2.4 on Governance).

Where many environmental problems which require concerted action (because of their global or cross-border nature, or because they can be handled more efficiently and transparently on EU level) benefit from EU policies, there's a gap to bridge in cross-boundary goal settings for specific issues (IEEP 2013), including flood risk management and in the implementation of the existing policies (EC 2012c). As chapter 4 further clarifies synergies between water (WFD, floods directive) and nature legislation (BHDs) is underexploited, a conclusion that can be repeated for synergies between water legislation and thematic policies like the rural development regulation (EU 2013b) of the Common Agricultural Policy (CAP).

Policies and their implementation are complemented by practices. For several EU countries, the floods directive as such did not radically change all existing practices of which some already exist for decades or even ages. Other practices get renewed or new attention. A flood risk management approach focussing on reducing fatalities and affected people is an example of the previous one, where mapping the environmental vulnerability is (at country level) new for most countries. The same is true for natural water retention measures or measures working with natural processes (EC 2014a): some measures will sound very familiar to flood managers while others will be new in some regions of Europe or are used but without fully exploiting the synergies with water and nature goals.

2.5 Outline and reading guidance

[will be added to the final version]

3 Status of Europe's floodplains

Europe's floodplains once covered wide stretches along the European rivers. Cleared for agriculture and completely changed through urban expansion and flood control structures, only fractions of floodplains remain. Some of the largest and best-preserved floodplains in Europe are found along the Danube, the Sava, Drava and March River in Austria, Slovakia, Hungary and Croatia (Klimo, and Hager, 2001; Lazowski, and Schwarz, 2014; Mölder, and Schneider, 2010; Španjol, et al., 1999), and along the Oder (WWF Germany 2000) and the Elbe (Scholz, et al., 2005) in Germany. One of the last morphologically-intact river corridors in the Alps is the Tagliamento River in Italy (Bertoldi, et al., 2009; Tockner, et al., 2003). The Allier and Durance River in France are examples of morphologically intact river sections with a high connectivity to the surrounding floodplains, as are the Biebrza and Narew valleys in northeast Poland.

3.1 Environmental importance of floodplains

Floodplains play an important role in flood risk management (see also section 3.4), by modifying the river discharge and protecting societies and economic activities from damages. Floodplains are also very heterogeneous habitats creating favourable conditions for many species and so have a high environmental value.

Floodplain water bodies

Under natural conditions, floodplains can contain a wide range of freshwater ecosystems including permanently flowing and temporal channels, oxbow lakes, spring brooks, tributaries and temporary wetlands. They are found along a gradient of decreasing hydrological connectivity from permanent to temporary links with the main channel of the river (Paillex, et al., 2007). The degree of hydrological connectivity influences major habitat components such as water physicochemical properties, its nutrient content, substrata and the morphology, which are the main drivers of biodiversity in floodplain freshwater ecosystems (Amoros, and Bornette, 2002). For example, studies on fish communities underlined the importance of diverse waterbodies in riverine landscapes for spawning and as nurseries, feeding and refuge areas (Aarts, et al., 2004), which can also support the re-settlement of the river after extreme disturbances.

Floodplain forests

The natural vegetation of floodplains in most European areas is dense riverside forest (Glaeser, and Wulf, 2009; Klimo, et al., 2001). Only a few areas such as open water, flood channels, silted up areas, and gravel banks are naturally non-wooded. The floodplain forests occur on nutrient rich soils, which have over time been deposited by rivers during flooding. They are among the richest and most complex forest ecosystems of Europe.

Rapidly growing softwoods such as willows and poplars are characteristic for floodplains near rivers with soil largely comprising sediment. Floodplain areas further away from rivers tend to have a lower water table and older soil, and therefore are often made up of hardwood tree species such as the English oak, ash or elm, but they also contain a high diversity of other tree species. While softwood forests annually experience between 60 and 180 inundation days, hardwood floodplain forests can be flooded between 1 and 60 days per year in the growing season. Because of their nutrient rich soils, a good water supply and diversely structured forest strata, old hardwood forests host one of the most species-rich and unique plant, bird or invertebrate communities of European forests (Scholz, et al., 2005).

Floodplain grasslands

Since centuries, floodplains have been used extensively for livestock feeding. Population growth and increased knowledge on flood-protection led to more intensive grazing and farming activities in floodplains during the Middle Age. Forests became more and more degraded and replaced by productive farmland and open extensive grassland. These man-made grasslands are characteristic of seasonally flooded areas and are characterized by a high diversity of grass and herbaceous species and regular management (EC 2008; Leyer, 2004). Such grasslands have small-scale relief features, including hollows and lower and higher areas with different flood return frequencies and different groundwater levels. Although floodplain grasslands cover most of the active floodplains in Western, Central and Eastern Europe, most of them are threatened by hydrological alterations, intensified and changing agricultural needs and changing policies (EC 2008; EEA 2015d).

3.2 *Status of Europe's floodplains: remaining areas and environmental quality*

When assessing the status of Europe's floodplains it is important to look at the location and remaining areas of floodplains, but at their functionality and at the quality of the ecosystem services they provide too.

3.2.1 Today's floodplains in Europe

In Europe already up to 90 % of the former riparian floodplains have been lost during the last centuries or they are functionally no longer intact (Tockner, et al., 2009, 2002). The main reason for the loss of active floodplains is the continued decline in floodplain area due to flood protections to prevent land uses not or less compatible with inundations (such as agriculture, or urban expansion), or infrastructure for hydropower development or maintenance of shipping channels (see section 3.3).

For example in Germany, where a national inventory accounted 70 to 90 % of floodplain area loss along 10 000 kilometres of 79 larger rivers and streams of 8 river basins (BMU and BfN 2009; Brunotte, et al., 2009). For the larger rivers, the loss is around 90 % of the 15 000 km² there once was, and in general only 1 % to 2 % of the former morphological floodplain is currently covered with near-nature floodplain forest (Brunotte, et al., 2009). For the different river sections of the Danube River the floodplain area loss varies between 73 and 95 %, where the Danube delta only lost around 30 % (Schneider, 2010; Schneider, et al., 2009). When including the tributaries, the floodplain loss can be estimated at 80 % (see table 3.1).

Table 3.1 Examples for Floodplain area loss along large rivers in Europe

River section	Morphological floodplain area (km^2)	Remaining floodplain area (km^2)	Loss of floodplain area (%)
Upper Danube (a,b)	1 762	95	95
Central Danube (a)	8 161	2 002	75
Lower Danube (a)	8 173	2 193	73
Danube Delta (a)	5 402	3 799	30
Tisza (HU, RO, UA) (c)	36 000	1 800	95
Upper Rhine (FR, DE) (d)			93
River Rhine (A, CH, F, DE, NL) (d)	8 000	1 200	85
River Rhine (DE) (b)	2 064	454	80
Rhine and Meuse (NL) (e)			90 – 100

River section	Morphological floodplain area (km²)	Remaining floodplain area (km²)	Loss of floodplain area (%)
Seine (f)			99
Oder (PL, DE) (g)	3 593	970	73
Oder (only DE) (b)	941	94	90
Middle Ebro River (ES) (h)			58

Sources: (a) (Schneider, et al., 2009) (b) (Brunotte, et al., 2009) (c) (Haraszthy, 2001), (d) (Schmid-Breton, 2015) (e) personal communication Tom Buijse, Deltares (NL) (*) (f) (Tockner, et al., 2009), (g) (WWF Germany 2000) (h) (Ollero, 2010)
(*) reference to be updated

The remaining floodplains in Europe are very often far away from being functionally intact, and are faced by a multitude of hydraulic measures or separated from the riverbed by summer levees. Despite these alterations, the fragments of remaining floodplains are important areas for nature conservation: more than 30 % of all classified riparian zones are protected under EU law (Clerici, et al., 2013), i.e. are part of the Natura2000 network.

At the European scale no floodplain inventory or systematic assessment on floodplain status has so far been made. Floodplain loss and assessment of its quality is not registered or reported in a consistent way in the EU. With new spatial data reported under the European Floods Directive (EU 2007), combined with Corine Land Cover (CLC) data as well as information reported under the Habitats Directive (EU 1992), potentially new overviews will be possible but still these will have limitations (see subsection 3.2.2)

Where the German floodplain inventory (see Box 3.1) contains information of remaining and former floodplains of larger rivers, the Austrian (Lazowski, et al., 2014) and the Swiss (Hausammann, et al., 2005) inventories focus on the remaining high value areas. The latter contains a multitude of spatial, hydromorphologic, habitat and management information, including threats and pressures on the selected floodplain areas.

Box 3.1 German floodplain inventory and assessment

A first nationwide consistent and updatable inventory of the loss and quality status of German floodplains provides an efficient overview of the position, dimension and status of floodplains at larger rivers in Germany (Brunotte, et al., 2009). The survey of the floodplain areas was conducted for sections of the rivers with a catchment area of at least 1 000 km² and tidal waters were not included. The geomorphologic floodplain, consisting of the remaining active and former floodplains, which is defined in this case as the area which could be inundated, if there were no man-made dikes was assessed. For each 1-km section of the rivers, separately for the left and the right side, the active and former floodplain areas were mapped and land use cover in seven classes, nature conservation value, and protection status were documented

Based on a standardized approach (Koenzen, 2005) to define reference conditions for riverine landscapes (their potential natural status), the status of all mapped floodplains was assessed. Main input data for this assesment comprises the main factors of habitat quality for all species, including the geomorphologic and hydrologic habitat conditions, and land use.

As for the Water Framework Directive (EU 2000) the floodplain assessment methodology refers to a reference status (which is close to being unaffected by human intervention) and the results are presented in five classes giving the degree of modification compared to the potentially natural status (table 3.2).

Floodplains of larger rivers in the past covered about 15 000 km², which corresponds to 4.4% of the German territory. Two-thirds of the morphological floodplain was lost by embanking. At large parts of rivers like Rhine, Elbe, Danube and Oder only 10-20 % of the former floodplains can still be inundated nowadays. More than one-third of the remaining active floodplains are intensively used as arable land use (28 %) or urban (6 %) areas and less than 10 % of the active floodplains fully provide their ecological functions. The remaining near-natural hardwood forests of floodplains cover only about 1 % of the active floodplain area. Compared to the potential natural status, less than 1% of the assessed active floodplain sections are classified as “nearly natural” (see figure 3.1), while 54 % of the floodplain sections are assessed as “severely modified” or “totally modified”. On the one hand, this situation resulted from the intense agricultural use on fertile soils of floodplains and on the other hand from the former importance of rivers as waterways for transport and trade as well as the arising urbanisation.

As expected, the classes severely modified and totally modified are more abundant (79 %) in the former floodplains compared to active floodplains (54%). However, there is a small percentage (4 %) of “slightly modified” former floodplain sections, which apparently still maintained a “floodplain-like” environment without being inundated for a longer period. Hence, these areas should be targeted for a potential restoration (activation) of former floodplains.

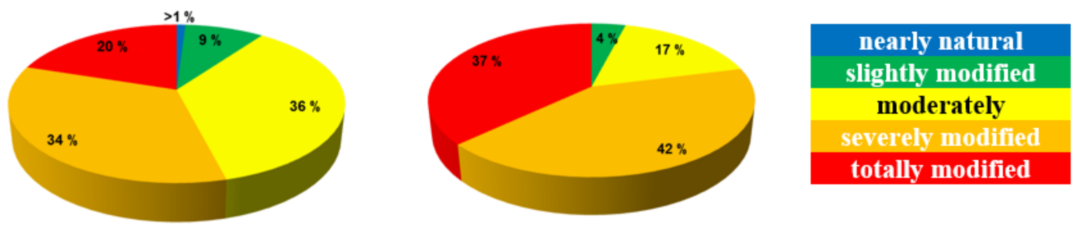
Source: (BMU et al., 2009), see http://www.geodienste.bfn.de/flussauen online

Table 3.2 The five classes of floodplain status with a condensed specification

Class		Specification
1	nearly natural	➢ Floodplains not or to a very small degree disconnected from floods by river regulation and/or flood protection measures ➢ Rivers only slightly regulated, with high flooding possibility ➢ Mainly no or very low intensity land use, mostly forest, wetlands, and rarely grassland
2	slightly modified	➢ Floodplains to a small degree disconnected from floods by river development and/or flood protection measures ➢ Rivers variably regulated, but usually with high flooding possibility ➢ Mainly low intensity land use, mostly forest, wetlands and grassland
3	moderately modified	➢ Floodplains partly disconnected from floods by river development and/or flood protection measures ➢ Rivers generally regulated, but usually with flooding possibility ➢ Variable intensity of land use
4	severely modified	➢ Floodplains widely disconnected from floods by river development and/or flood protection measures ➢ Rivers generally regulated, partly dammed ➢ High intensity land use, mainly intensive agriculture and urban areas
5	totally modified	➢ Floodplains completely disconnected from floods by river development and/or flood protection measures ➢ Rivers generally regulated heavily, frequently dammed ➢ High intensity land use, mostly with high percentage of urban areas

Source: (Brunotte, et al., 2009)

Figure 3.1: Comparison of the distribution of the floodplain status classes



Note: for all assessed sections of active floodplains (left) with former floodplain areas (right)

3.2.2 Distribution of floodplain areas

To get an overview where active floodplains still occur, reported flood hazard and risk maps (FHRMs) (EU 2007, Art. 6)are used as proxies. The medium probability flood hazard maps, all with a likely return period of 100 years ([6]), for nine countries (see table 3.3) overall covers around 5% of the total area of these countries, with significant differences from country to country. Under 2% of the country territory for the Czech Republic, Austria and Slovenia up to over 10% for Romania, Italy and Hungary is mapped as being part of the medium probability flooded area. In Germany, more than 6 % is mapped as belonging to the flooded area of this scenario. This is slightly more than the national floodplain inventory but incudes more rivers. It should be noted that important floodplain areas along the Danube were not included in the FHRMs and that it was not always possible to clearly distinguish between river floodplains and coastal flood-prone areas.

Table 3.3 Medium scenario flood hazard maps for selected countries as a proxy for floodplain occurrence

country	FHRM Area [km2]	Flood hazard Area [%]
AT [(a)]	903	1.08
CZ	200	0.25
DE [(b)]	20 189	5.64
HR	3 929	6.94
HU	14 510	15.60
IT	36 540	12.15
PL [(a)] [(b)]	12 390	3.97
RO	25 424	10.67
SI [(c)]	352	1.74

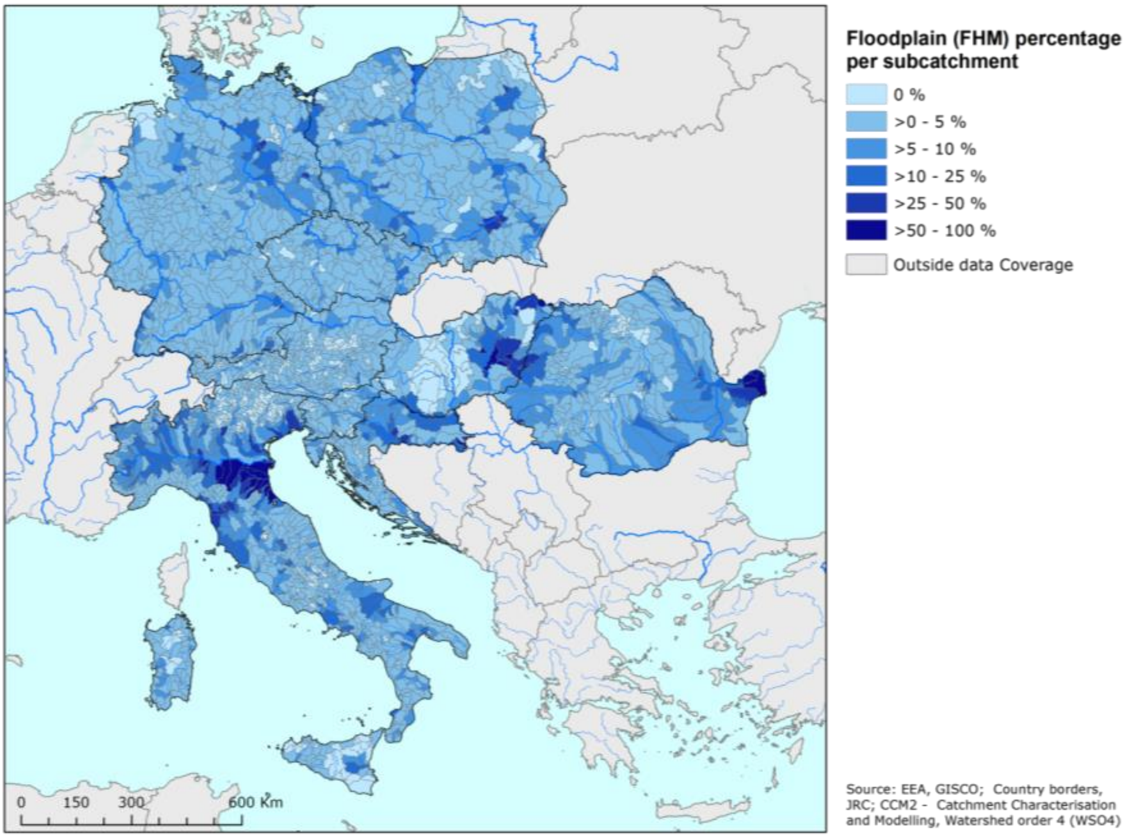
[(a)] Danube floodplain is missing
[(b)] Some flood hazard areas especially closely to the coastline close to the North Sea (DE) or Baltic Sea (DE, PL) are clearly prone to sea flooding
[(c)] Data obtained from national portal

Source: reporting obligation of flood hazard and risk maps for the Floods Directive (EU 2007), http://rod.eionet.europa.eu/obligations/602

The nine countries (see table 3.3) with spatial information on flooded areas available, consist of 4029 subcatchments (catchments with fourth Straler order CCM2/WS04 (JRC 2008)) with an average area of 383 km². Higher floodplain coverage (see Map 3.1) is significant for subcatchment for the Italian rivers Reno, Arno, Po, the Croatian parts of Sava and Drava rivers, the Tisza river in Hungary, the Elbe river in northern Germany and the Danube river in the eastern Romania.

Map 3.1 Floodplain distribution

[6] To be understood as an annual probability of occurrence of 1%



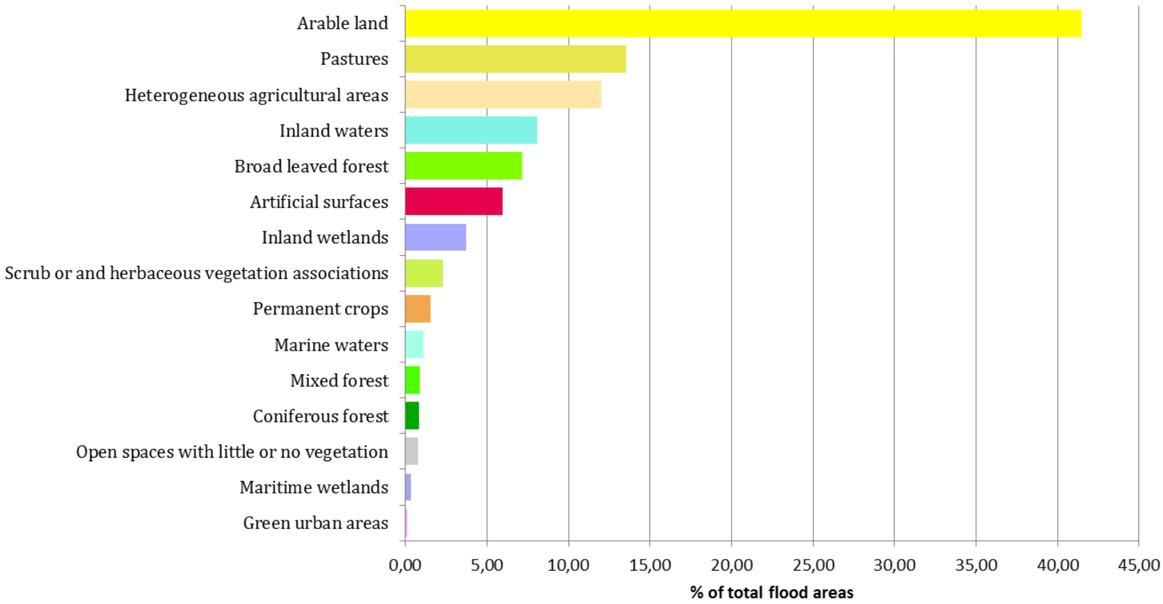
Note: Percentage of flood hazard area (medium probability) per subcatchment used as a proxy for floodplain coverage

Land uses in floodplains

An intersection of the medium scenario flood hazard maps with the land uses types is shown in Figure 3.2. The 15 land use types are aggregated from the Corine Land Cover types on level 2 and3 (EC and EEA 1995), providing most detail on forest, semi-natural areas and wetland and being more aggregated for artificial surfaces ([7]). More than 40% of the floodplains are used for arable farming, being almost exclusively (over 99 %) non-irrigated. With 57 % (or 16 000 km²) the highest absolute coverage of arable land in floodplains of the nine selected countries can be found in Italy. The vast majority of these areas are located in northern Italy within the Po and Reno catchments (Map 3.1).

Figure 3.2 Share of land use types in floodplains

[7] Corine Land Cover 2006 seamless vector data, see http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-3 online



Note: for nine countries: AT, CZ, DE, HR, HU, IT, PL RO and SI, see Table 3.3 with flooded areas under the medium scenario in the FHRMs as a proxy for floodplains.

Pastures are covering almost 13.5 % of total floodplain area for all nine countries together. In Poland, pastures cover around one third of floodplains, making it the most present land use category in the floodplains for this country and with pastures equally distributed over Oder and Vistula catchments.

Forests cover around 9 %, where Croatia has the highest floodplain coverage with forests (nearly 30 %). Italy and Hungary only reach around 4 % of forest and all other countries in this exercise are close to the average of 10 % forest coverage.

Inland wetlands in floodplains reach in total about 4 % of the floodplain area, where Romania (with around 15%) reaches the highest cover for this land use category. Artificial areas, being mostly urban areas, cover around 6% of the assessed floodplains 6 % with large differences in between countries: from 25% in Austria and 14% in the Czech Republic to roughly 4% in Hungary and only 2% in Croatia.

Box 3.2 River Mur recognised for effective river basin management

The River Mur flows from Austria, Slovenia, Hungary and Croatia before reaching the River Drava, a tributary of the Danube. The organisation managing the Mur Basin was awarded the second European River Prize during the 6th European River restoration conference (ERRC) in October 2014 (EEA 2014f).

Systematic river regulation since the late 19th Century has separated the river loops, branches and floodplain forests, which are important for the health of natural systems. Modifications including hydropower stations (in the upper part) and embankments have also degraded habitats. Nonetheless the Upper Mur is considered an ecologically valuable rivers in Europe, not least because it is the natural breeding site of the Danube salmon. It also has the second largest alluvial forest in Austria, one of Europe´s most species-rich habitats. The River Mur corridor in Slovenia is up to 1 km wide, and has a high variety of typical plant and animal communities ranging from pioneer to mature stages, including Pannonian–Dinaric and Pontic–Caspian elements, with large floodplain forests and side arm systems (Globevnik, and Mikoš, 2009).

Due to its high biotic diversity, a large part of the Mur corridor in Slovenia has been designated as a Natura 2000 site. The Natura-protected habitats are alluvial forests and hydrophilous tall herb fringe communities of floodplains. Nevertheless, ecological conditions for flood forest tree species in floodplains are deteriorating due to water shortage in oxbows, side arm channels and soils. The mouth of the River Mur is one of the last remaining preserved system lowland rivers in Europe. Here both rivers, Drava and Mura are unregulated and continually create new habitats and restore existing which maintains high biological diversity.

River management on the Mur has largely focused on restoring old structures and recovering natural river habitats by reconnecting them with the dynamic river-system. Besides environmental benefits, these measures have other advantages including better passive flood protection and new natural recreation areas for the residents. Looking ahead, a section of the river will be designated where hydropower plants will be prohibited. Such measures show that management of the Mur is a good example of policy integration and stakeholder dialogue, two elements that are vitally important in successful river basin management.

3.3 Anthropogenic Drivers and Pressures

The driving forces and pressures are part of a framework to assess and manage environmental problems. The DPSIR (driving forces, pressures, state, impact and response) framework describes interactions in between the environment and society. Driving forces are the socio-economic (and cultural) forces driving human activities, which increase (or mitigate) pressures on the environment. Pressures are the direct stresses of human activities on the environment (Stanners, et al., 2007). A clear distinction in between driving forces and pressures is not always possible, and is depending on the environmental issue looked at, but together they define the condition or state of an environment.

3.3.1 Socio-economic development and land use change

Demographic changes and economic developments have a direct impact on the intensity in which rivers are used for functions such as transport, hydropower production and cooling of power plants and industries.

Moreover, part of the socio-economic developments are physically taking place in the floodplains. As a result the land use is changed, e.g. from a natural vegetation to an agricultural area, from an agricultural area to housing or industrial areas, or from natural vegetation to open water in the case of minerals mining. Part of the floodplains may be used for infrastructure such as roads and power lines as well. Where land use is accompanied by significant investments, the changes may lead to the implementation of additional flood protection measures.

Finally, also land use changes outside the floodplains but within the catchment, such as shifts from forestry to agriculture, from pasture to arable land, from rain-fed to irrigated agriculture, or from agricultural use to urbanised areas, can act as drivers for changes in floodplains.

Intensification of economic uses in the floodplain and in the wider catchment brings about hydromorphological pressures, as discussed in subsection 3.3.3.

Data to illustrate the above developments are only available as approximations, first because the delineations of the administrative boundaries within Europe (NUTS-levels ([8])) do not coincide with

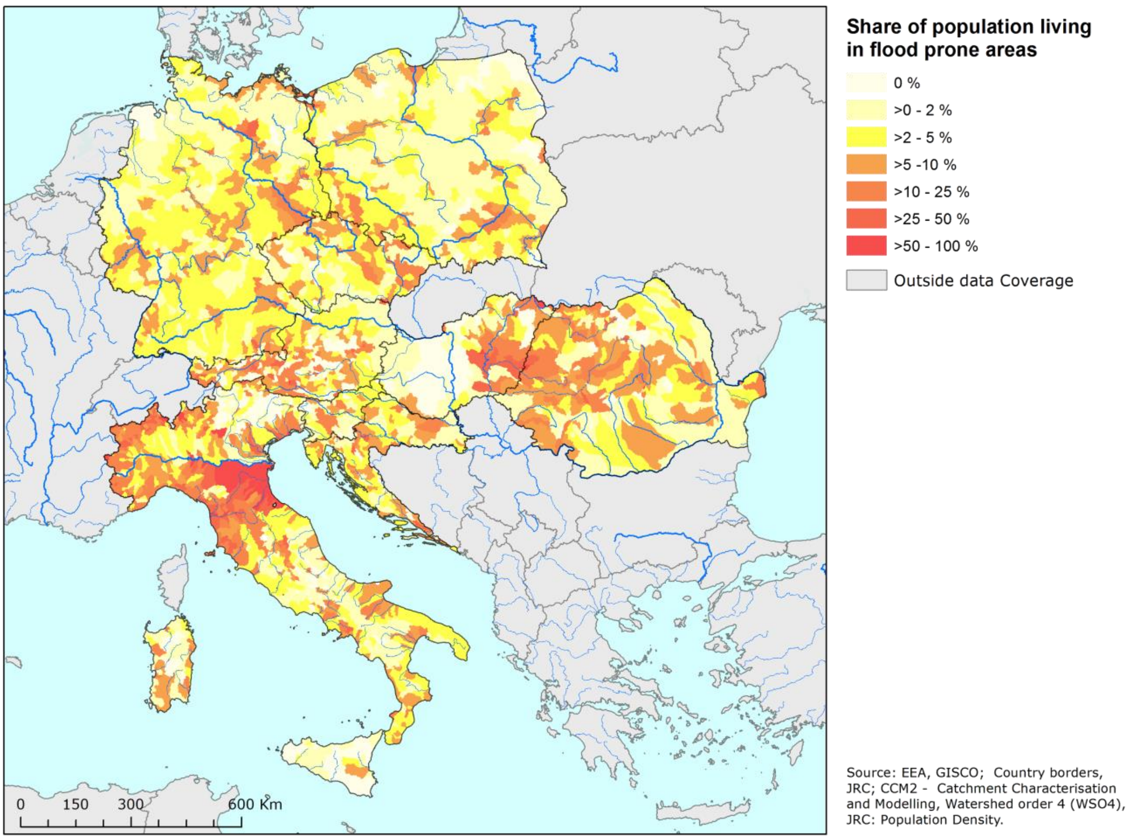
[8] NUTS: Nomenclature of territorial units for statistics, see http://ec.europa.eu/eurostat/web/nuts/overview online

floodplains or even river catchments and second because at EU level no maps with reliable delineations of floodplains (see section 3.2) are available.

Population in flood prone areas

Based on the intersection of flood hazard and risk maps (FHRMs) reported for nine countries (see subsection 3.2.2) and population density, more than 14 million people are living in areas flooded in a medium scenario with a 100-year return period. This represents 6 % of all population living in these countries (Map 3.2). The largest population living in the flood prone areas, being 6.7 million people (11% of total population), can be found in Italy and the majority of them in north Italy. On the other hand, the highest relative amount of population living in flood hazard areas can be found in Hungary (18 % of Hungarian population, being 1, 8 million people). The most populated flood prone settlements are located in the eastern part of the Great Hungarian floodplain of the Tisza and Körös catchments (e.g. Szeged, Szolnok). In Austria, Czech Republic, Romania and Croatia there is around 5 % of the population is living in flood hazard areas in the medium scenario, being slightly more than in Slovenia (4%) and Poland and Germany (3%). The most populated German flood prone settlements are situated in the upper Elbe valley (e.g. Dresden). Also the Middle Rhine and the Mosel have a higher population density in flood hazard areas, because of the narrow river valley.

Map 3.2 Share of population living the flood prone areas per subcatchment.



3.3.2 Climate change

Climate change is expected to affect all water-related functions and policies discussed in chapter 4 of this report (Ciscar, et al., 2014; EC 2013b; IPCC 2014). The shifts in the extremes, rather than the trend in the averages are likely to be the biggest challenge for adaptation (IPCC 2012) and also likely to be the cost drivers for adapting the infrastructure (OECD 2013).

Sea level rise and increases in extreme rainfall are projected to further increase coastal, fluvial and pluvial flood risk in Europe and, without adaptive measures, will substantially increase flood damages (in terms of number of people affected, economic losses and, although less often quantified, most probably also cultural heritage and ecosystem services). Direct economic river flood damages in Europe have increased over recent decades but this increase is mainly due to development in flood prone areas and probably also a reporting bias (EEA 2012a) (*). A clear climate change signal cannot be detected from the data. Some areas in Europe show changes in river flood occurrence related to observed changes in extreme river discharge.

(*) to be updated, paragraph to be complemented with CCIV2016 report information

Variability of climate change and climate change impacts across Europe

Observed climate trends and future climate projections show regionally varying changes in temperature and rainfall in Europe, with projected increases in temperature throughout Europe and increasing precipitation in Northern Europe and decreasing precipitation in Southern Europe. Climate projections show a marked increase in high temperature extremes, meteorological droughts and heavy precipitation events with variations across Europe, and small or no changes in wind speed extremes except increases in winter wind speed extremes over Central and Northern Europe (IPCC 2013).

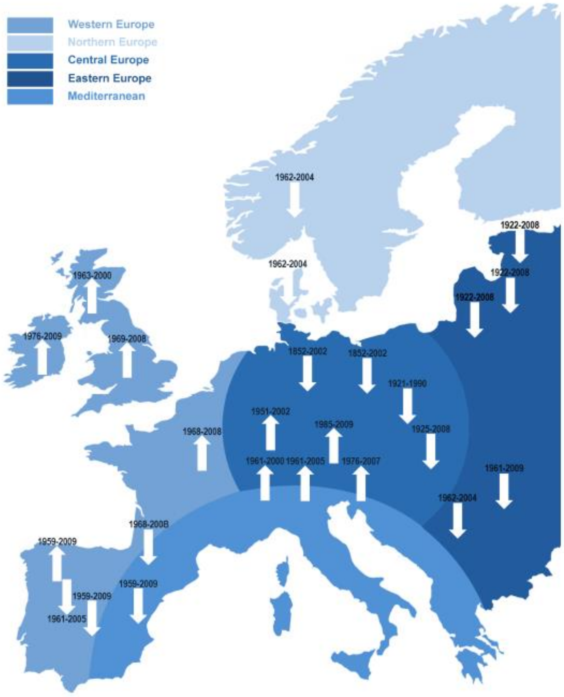
Fluvial flood regime changes

The available literature and dedicated studies performed to identify trends in mean annual discharges or annual maxima have recently been inventoried and summarized by (IPCC 2013; EEA, 2012a; Hall, et al., 2014) (*). These studies converge in their overall conclusions, to be summarized as (see figure 3.3):

(*) EEA report to be replaced by CCIV2016 in final version

- increase in Western Europe;
- mixed patterns in Central Europe;
- decrease in the Mediterranean and in Eastern Europe; and
- the above trends are in most cases not very firm, the uncertainties are high, and as (Hall, et al., 2014)emphasize: “*don't use the outcomes without consulting the original publications*”.

Figure 3.3 Schematic summarising the observed flood changes in Europe



Note: Schematic summarising the observed flood changes in Europe derived from cited studies using different not directly comparable change analysis methods and time periods.
Arrows in the schematic indicate the majority of trends including regions with weak and/or mixed change patterns. Areas with no/inconclusive studies due to insufficient data (e.g. Italy) and inconclusive change signal (e.g. Sweden) are not shown.

Source: (Hall, et al., 2014)

In those cases where a trend was identified, the next step is to identify potential causes of the trends. Climate change is one, changes in land use, implementation of flood protection measures, changes in assessment methods are others.

Climate change is projected to affect the hydrology of river basins (IPCC 2012, Chapter3)(IPCC, 2014, Chapter4). The occurrence of current 100-year return period discharges is projected to increase in Continental Europe, but decrease in some parts of Northern and Southern Europe by 2100 (Dankers, and Feyen, 2008; Rojas, et al., 2012). Although snowmelt floods may decrease, increased autumn and winter rainfall could lead to higher peak discharges in northern Europe (Lawrence, and Hisdal, 2011).

Pluvial floods

Few studies have estimated future damages from inundation in response to an increase in intense rainfall (e.g. Willems, et al., 2012). Processes that influence flash flood risk include increasing exposure from urban expansion, and forest fires that lead to erosion and increased surface runoff (Lasda, et al., 2010).

Pluvial floods are of particular interest in urban areas. The required investments to adapt storm water sewer systems to higher design precipitation events are huge. Mayors Adapt ([9]) is a covenant that was set up by the European Commission to engage cities in taking action to adapt to climate change (EC

[9] See http://mayors-adapt.eu/ online

2014b). Cities that adopt the initiative commit to develop a local adaptation strategy or to integrate adaptation to climate change into relevant existing plans. Mayors Adapt supports these activities, amongst others by providing technical support, by providing a platform for greater engagement and networking by cities, and by raising public awareness about adaptation and the measures needed.

[the impact of climate change on ecosystems will become an additional subheading]

3.3.3 Hydromorphological changes

Hydromorphological changes involve changes in:

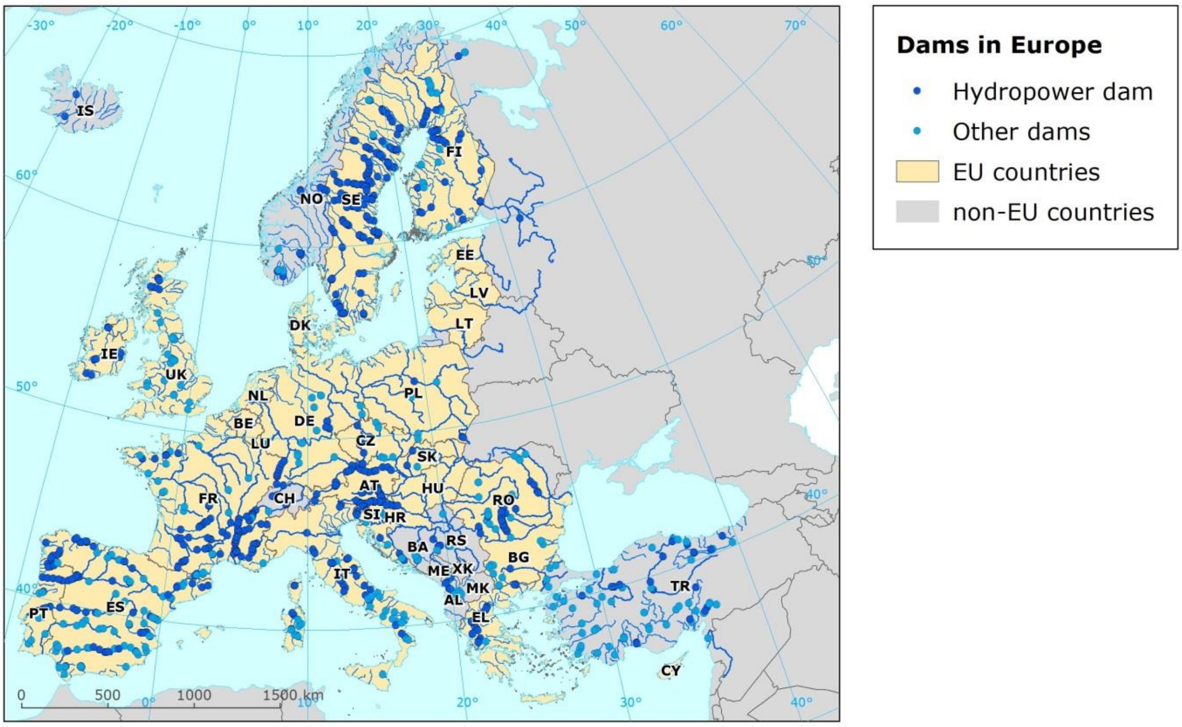
- the hydrological regime: quantity and dynamics of flow, connection to groundwater;
- changes in continuity and connectivity: the ability of sediment and migratory species to pass freely up and down rivers and laterally with the floodplain; and
- changes in morphology; i.e. physical habitat: compositions of substrate, width/depth variation, structure of bed, banks and riparian zone.

Hydrological regime

While flood control projects prevent and limit the impact of floods to mankind and assets, other benefits of water are also being employed, such as hydropower for electricity production, water supply and irrigation. For this purpose more than 850 dams with reservoirs were built throughout Europe on larger ([10]) rivers, whereas more than half of these serve for electricity production (Map 3.3). The Alpine region has the highest density of dams, but also on the Danube and its tributaries, more than 130 dams can be found, and as many in Spain on larger rivers only. On the Rhone, there are more than 30 dams, and on the Rhine, you can find seven of them. Hydropower dams pose barriers to the movement of aquatic species and bring the risk of fish entrainment in turbine intakes. They alter the flow regime in the river and the structure of the reservoir shore zone habitat. Sediment transport in the river is affected by retention in the reservoirs, which may lead to an altered structure and conditions of bed and banks of downstream river stretches. As an example, this sequence of the construction of dams to its impacts on hydrological regime, sediment transport, morphology and ecology has been illustrated for the middle Ebro by (Magdaleno Mas, 2011).

Map 3.3 Dams with reservoirs on rivers in Europe

[10] Rivers with catchment areas larger than 10 000km^2.



Note: for rivers with a catchment larger than 10 000 km2 only

Dams are designed in a way that extreme floods would not result in a breach due to overtopping and sudden loss of stored water. No damage to the structures is permitted during the occurrence of the flood that just utilizes the full amount of controlled reservoir storage space.

General recommendations for hydrologic design for dams that are built primarily for flood mitigation are based on two fundamental conditions: a) hydrological dam safety and b) the level of protection against flooding of the direct hinterland and downstream areas. Flood protection level against flooding differs between rural and urban areas. In extraordinary cases with major cities or highly populated areas and if the economic, social and environmental considerations are favourable, return periods of 500 or even 1 000 years may be justified.

Reservoirs of hydropower facilities on large rivers usually store water on a permanent basis and do not really act as important flood reduction measure. They may even pose higher flood risk if not properly managed. The level of flood protection provided is usually expressed as the return period of the largest flood for which inflows can be completely controlled to non-damaging levels downstream by regulation of reservoir releases. Everywhere in Europe, hydropower facilities on rivers with no large difficulties regulate frequent flood waves but less frequent flood waves (with return periods larger than 50 or 100 years) can only be regulated with active management of the facilities.

The water storage operation too often follows the aim of the highest possible to gain such as production of electricity, drinking water or recreation activities, so water releases from reservoirs along one river are not always coordinated . The most prominent issue is a sudden loss of stored water, creating an extraordinary flood wave traveling downstream in a river as unsteady flow with destructive power as it was the case in Drava river flood in 2012 (Slokar, and Papež, 2013). This can result in damage to facilities and spreading of floods to areas that were protected against flooding (Box 3.3).

The hydrological regime is also expected to change as a result of climate change, despite the many unknowns and uncertainties that still exist (see subsection 3.3.2) leading to more extreme events (both floods and droughts) in some areas, an overall decrease of discharge in others, or in changes in the occurrence of floods during the year. Land use change can affect the hydrological regime by reducing the retention capacity of a catchment, e.g. by soil sealing or compaction (leading to more extreme floods and low flows) or by affecting the annual evapotranspiration (e.g. in case of deforestation)

Box 3.3 Hydropower dams on the Drava River

A long and extremely wet period in autumn 2012, together with improper management of hydropower facilities in the upstream part of the Drava River in Austria caused large floods on the lower sections of the Drava River in Austria and Slovenia (Klaneček, 2013). The hydrological conditions with no river flow regulation would characterise the event having a 50-year return period. Although, since the stored waters in the hydropower reservoirs in Austria were released suddenly and too late for the additionally predicted runoff, a catastrophic flood wave occurred on 6th of November 2012 with a 100-year return period peak causing extreme flooding (Klaneček, 2013). All settlements along the downstream river were flooded and among others, the hydropower plant Formin in Slovenia (figure 3.4) has been inundated and its infrastructure and diversion channel damaged (figure 3.5) leading to a shut down of the power plant.

Figure 3.4 Situation of the hydropower plant FORMIN on the Drava river in Slovenia

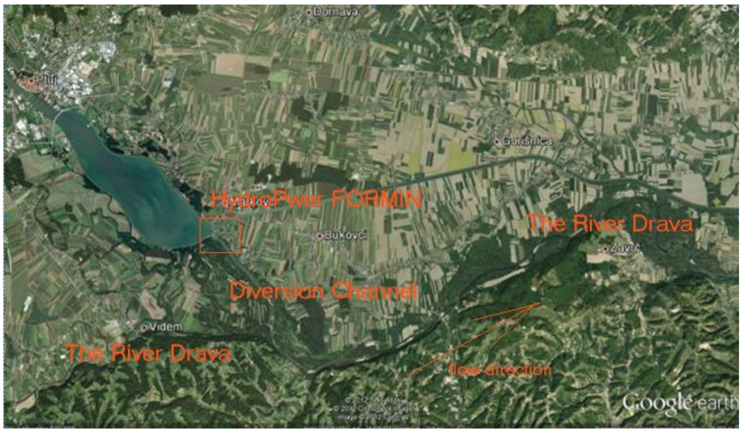


Figure 3.5 Situation of the dyke break at the diversion channel

Note: The floodwater came from behind from the river Drava

Connectivity

Connectivity has a longitudinal dimension (the ability of sediment and nutrients to flow freely from upstream to downstream, the ability of organisms to move either way) and a transversal dimension (exchange of water, nutrients, sediments and organisms between the riverbed and the floodplain).

Various types of man-made infrastructures have a negative effect on connectivity: dams retain sediments and prohibit migration of water-borne organisms, ship locks pose barriers to these organisms, lateral flood protection works (dikes) cut off floodplains from the river. In the remaining active floodplain area, inundations tend to become deeper than under natural conditions, because the area available for discharge and storage of water has become smaller. By contrast, in the cut-off floodplain inundation frequency is reduced strongly, to the recurrence interval for which the dikes were designed to fail or be overtopped. In many European countries rivers dike construction has started in the Middle Ages, but because of the technical progress the highest impact of closing and reinforcing of dikes on floodplains in Europe was in the 19th and 20th century. Today along many European rivers only one-third to 10 % of the former floodplain is still functioning as inundation retention area for high and medium flooding events (see subsection 3.2.1)

Morphology

In the 19th and 20th century, technical measures to improve navigability were implemented at a large scale in Europe. Measures involved are dredging, the construction of groynes to concentrate the flow and maintain a minimum water depth, bank protection to prevent erosion and subsequent silting, channelization and straightening of river beds, construction of weirs and connected ship-locks to control the water level, and the construction of channels with controlled water levels parallel to the river. These measures have had a large impact on the river morphology, reducing such elements as sandbars and islands, reducing land-water transitional areas, flow velocity diversity, erosion and sedimentation processes and transversal and longitudinal connection. This in turn has led to a dramatic loss of river and floodplain biodiversity over the past century.

A prominent example in Central Europe is the straightening of the Upper Rhine River, the border river between Germany and France by the Engineer Tulla during the 19th century (Blackbourn, 2007), followed in 20th century by the construction of dams for hydropower and navigation between Basel and Iffezheim. Today most parts of the alluvial zones have been disconnected from the discharge dynamics (Blackbourn, 2007; Schneider, 2010).

Dramatic floodplain modification has also been reported for the Tisza River or the Danube for land reclamation, hydropower and technical flood retention measures. The German and Austrian river stretch of the Danube is nowadays mostly impounded for hydropower and navigation. These hydraulic impacts have started especially in the 19th century, but continued until the end of the 20th century and resulted in disconnected riparian floodplains with a multitude of ecological consequence (Hohensinner, et al., 2004; Schneider, 2010). In the late 1980s, the project of Gabčíkovo-dam along the Danube in Slovakia, close to the Hungarian border, was one of the last big projects to impact the Danube floodplain (Balon, and Holčík, 1999). Especially in Croatia, Serbia or Bosnia-Herzegovina some of the most intact floodplains remain, but these are under pressure from navigation infrastructure or hydropower plans (Schwarz, 2010, 2013; Zarfl, et al., 2015).

For the Austrian Danube floodplain, channelization and construction of hydropower plants resulted in a truncated fluvial system. Consequently, gravel/sand bars and vegetated islands decreased by 94% and 97% respectively, whereas the area of the various backwaters doubled. In 1991, the former ‘flow pulse’ was halved due to artificial levees and embankments, greatly diminishing hydrological connectivity and decoupling large areas of the floodplain from the main channel. Active overflow, formerly playing an important role, is now replaced by backwater flooding and seepage inflow in isolated water bodies (Hohensinner, et al., 2004)

The Rhône River in France has been deeply modified by numerous uses and activities like navigation, irrigation, flood protection or hydroelectricity and over the last centuries lost its floodplain connectivity. Embankment, dams and groin constructions, water diversion, and secondary channel with artificial cut-off generated severe morphological changes such as channel degradation and narrowing and bank stabilization. These changes resulted in a fundamental modification of flowing conditions during floods and connections between channel and floodplain ecosystems (Bravard, 2002; Dufour, et al., 2008; Provansal, et al., 2014; Raccasi, 2008).

3.3.4 Pollution and historical contamination of floodplains

[The following text is a draft version not containing all aspects to be covered in this subsection and should be further developed. The actual text focusses on heavy metals while attention for nutrients and organic pollution should be mentioned. It also doesn't describe the issue of legacy pollution stored in floodplains and its role during and after flooding. As authors, we're searching for descriptions that cover Europe, or at least larger international river basins for one or more of these aspects to further develop the final text.]

Trace element concentrations in rivers increased considerably in Europe during the 19th and 20th centuries. However, even if harmful metal concentrations decreased in many European rivers over recent decades, levels are still high compared to natural values and future target quality levels. In the last decades in many European member states water quality (in terms of chemical status) has increased significantly due to the treatment of urban waste water (EU 1991) and the implementation of the Water Framework Directive (WFD) (EU 2000). Nevertheless, managing diffuse pollution remains a big challenge in many European river basins (EEA, 2012b). Especially in the case of flood events, and particularly in extreme events, not only the amount of urban wastewaters increase but also the re-mobilization of formerly deposited contaminants from floodplain soils can result in severe problems. As riverine floodplains can adopt water quality functions for rivers during periods of flooding those areas are usually heavily polluted (Schulz-Zunkel, and Krueger, 2009).

Due to the fact that floodplains are, naturally, a complex mosaic of habitat patches, each slightly differing in productivity, standing biomass, soil organic content and capacity to transform organic matter (Tockner, et al., 2010) and therefore displaying strong spatial as well as seasonal heterogeneity, they can be both sinks and sources for trace elements. Redox processes in combination with pH-value changes are the most important factors that determine retention and remobilization of pollutants triggered by hydrological conditions within floodplains and across river floodplain gradients (Frohne, et al., 2015; Schulz-Zunkel, et al., 2009).

By now, the process of pollutant retention is very well known whereas only few studies exist that investigate the release of trace metals in floodplains under field conditions. This is maybe due to fact that the bioavailability of pollutants is not a constant factor. The quantification of pollutant mobilization, particularly on the basis of changing biogeochemical conditions, e.g. during fluctuation between floods and droughts, is still lacking. Moreover, mobile amounts of pollutants in the soil solution do not indicate to which extent remobilized substances will be transported to water bodies or plants and therefore potentially have toxicological effects. Consequently, floodplain areas still need to be taken into consideration when studying the role and behaviour of sediments and soils for transporting pollutants within river systems, particularly concerning the WFD.

3.4 Floodplain management and restoration

The complexity of floodplain management, with highly dynamic ecosystems and long-term socio-economic pressures, requires holistic approaches where scientific evidence and expert knowledge are operationalised for policy needs (Antrop, et al., 2013). Floodplains originally provided a high variety and quantity of ESs (and a biodiversity hotspot) but in many cases experienced strong human impacts that declined the delivery of ecosystem services. The impact of interventions upstream on the more downstream located regions and finally on the total ESs provided requires in-depth knowledge and understanding of the complex floodplain ecosystems (Scholz, et al., 2012) (See Box. 3.X). It is supposed that floodplains are particularly vulnerable to the impacts of climate change and therefore well-planned floodplain management is more and more required while demand for floodplain ESs are growing (Capon, et al., 2013).

When remaining active floodplains are compared with floodplains that have been cut off from the inundation regime, the remaining floodplains show a much greater ability to act as flood retention areas, as reservoirs for groundwater, as filters (or sinks) for sediments and dissolved pollutants, as carbon sinks, recreation areas and natural habitats for highly specialised flora and fauna (e.g.(Scholz, et al., 2012)). They are also natural flood protection areas that delay the discharge of flood waves and, thus, contribute to mitigate flood peaks, especially when the floodplains are covered with near-natural forests (see e.g. (Hughes, et al., 2003; Moss, and Monstadt, 2008)).

Box 3.4 Ecosystem services

Ecosystem services (ESs) can be described as the benefits that people obtain from ecosystems (Millennium Ecosystem Assessment 2005) and can be grouped into provisioning, regulating, cultural and supporting services (figure 3.6). Most ESs refer specifically to the 'final' outputs from landscapes, providing benefits for humans and society (Maes, et al., 2012).In a simplified conceptual ecosystems and socio-economic systems are linked by flows of ESs and drivers of change (figure 3.7). Ecosystems are shaped by the interactions of biotic and abiotic environment. Ecosystem functions are the capacity or potential to deliver ESs, where ESs the realised flow (EC 2013f).

As one of the most important ecosystem services of floodplains flood regulation supply addresses the capacity of the ecosystem to decrease flood hazards by reducing the runoff. As such, flood regulation is an ES contributing to human well-being (Millennium Ecosystem Assessment 2005). For the ES flood regulation, there is a spatial link in between downstream areas of a river catchment that are mainly benefitting from increased flood protection, and the headwaters and upstream areas being the flood regulation supplying areas (Syrbe, and Walz, 2012).

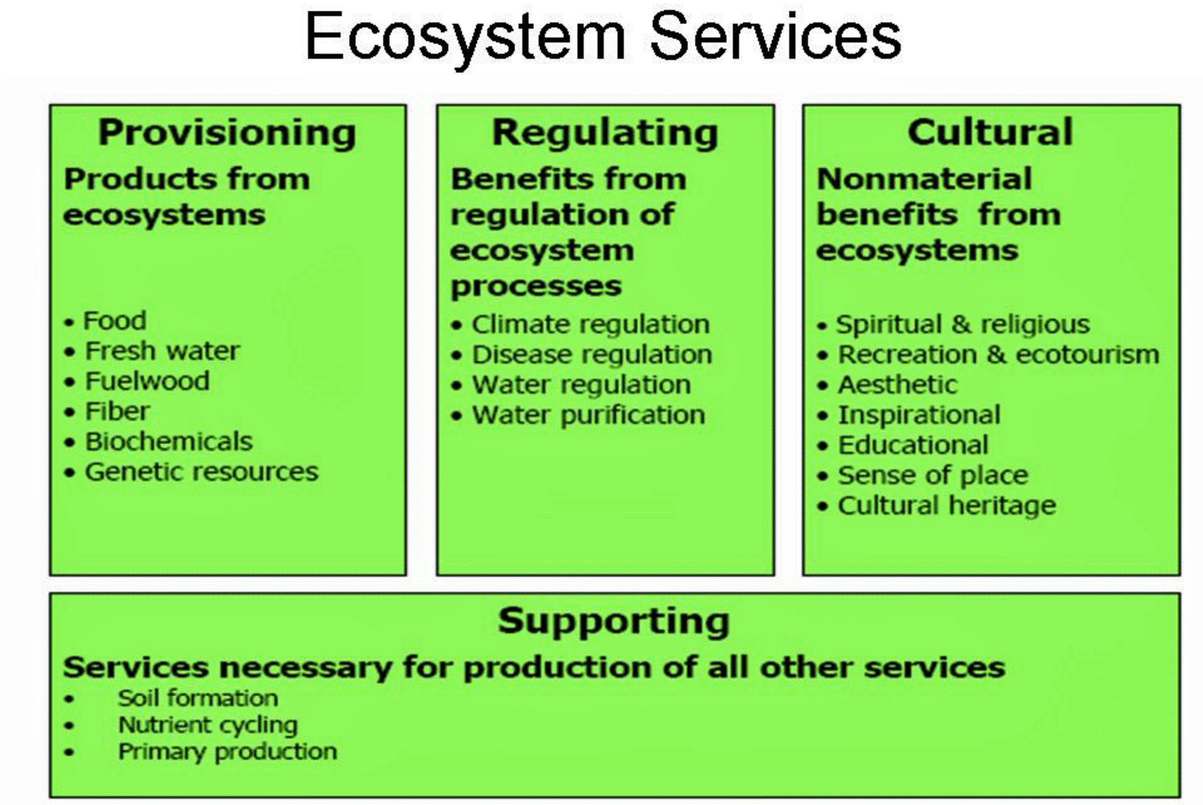
Optimizing a balanced supply of multiple ESs can be done by green infrastructure (GI), being an interconnected network of green areas for the conservation of ecosystem functions and providing benefits to society (Schindler, et al., 2014). The European Commission published a communication on GI (EC 2013c) and the concept is also linked to the Habitats Directive (EU 1992, Art. 10) with the aim to overcome landscape fragmentation and the Biodiversity strategy (EC 2011a) with the demand of maintaining and enhancing ecosystems and their services by 2020 by "establishing green infrastructure and restoring at least 15% of degraded ecosystems. The importance of investing in ecosystems, including floodplains as a particular area of interest, is also recognized as a source of economic development for the regional and cohesion policy of the EU (EC 2011b).

To estimate the effect of protecting and restoring floodplains, one needs an overview of the different ESs and their quantity provided by that area. On the European level, this exercise is ongoing for all terrestrial and marine ecosystems ([a]) in the Mapping and Assessment of Ecosystems and their Services (MAES) process (EC 2013f, 2014e) (see also Box 3.5).

In a study on the Somerset Levels and Moors (SLM) wetlands (Acreman, et al., 2011) the different ESs are looked at individually before combining them as the real added value in terms of management of the area is in the synergies or conflicts between the ESs. Besides mapping the ESs the different ESs also needs to be assessed to value their importance by means of indicators (EC 2014e). This assessment is site specific and, for example, in the SLM wetlands case most ecosystem services are based on the area being wet but with the exceptions of flood storage and methane emissions (Acreman, et al., 2011). The active involvement of an area for flood risk protection needs to consider this, and leads to trade-offs between different land management practices. In addition, climate change may make it difficult to maintain actual or preferred conditions (Acreman, et al., 2009) and the example demonstrates that not all services can be maximized simultaneously (Acreman, et al., 2011).

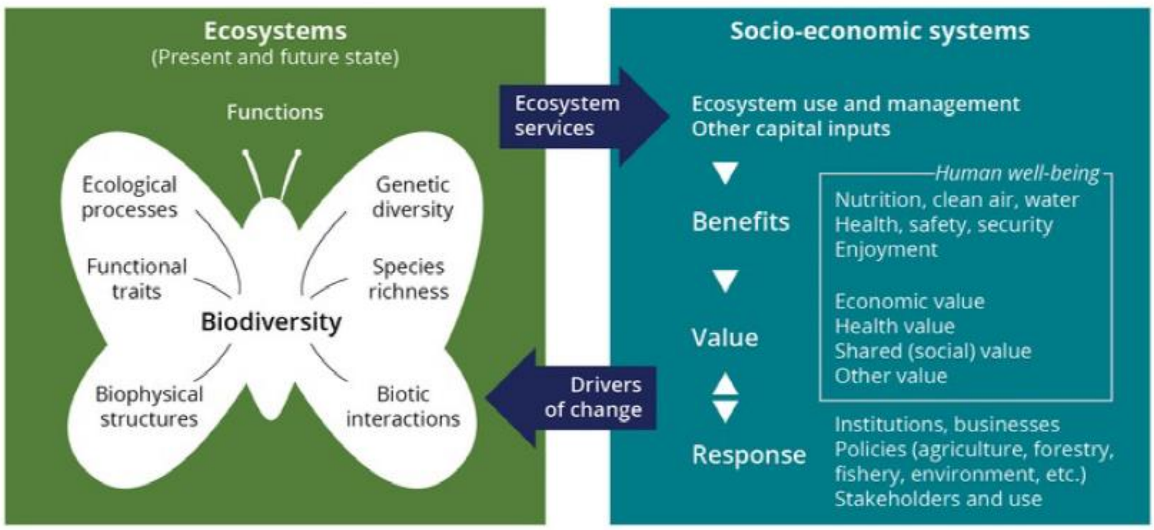
(a) See http://projects.eionet.europa.eu/eea-ecosystem-assessments/library/draft-ecosystem-map-europe online. Floodplains are not a type of ecosystem but overlap and can be part of almost all ecosystem types and subtypes. In the freshwater pilot, (inland) wetlands were included but these overlap only partly with floodplains (see section 2.3).

Figure 3.6 Basic ecosystem services of rivers and floodplains



Source: (Millennium Ecosystem Assessment 2005)

Figure 3.7 Conceptual framework for ecosystem assessments



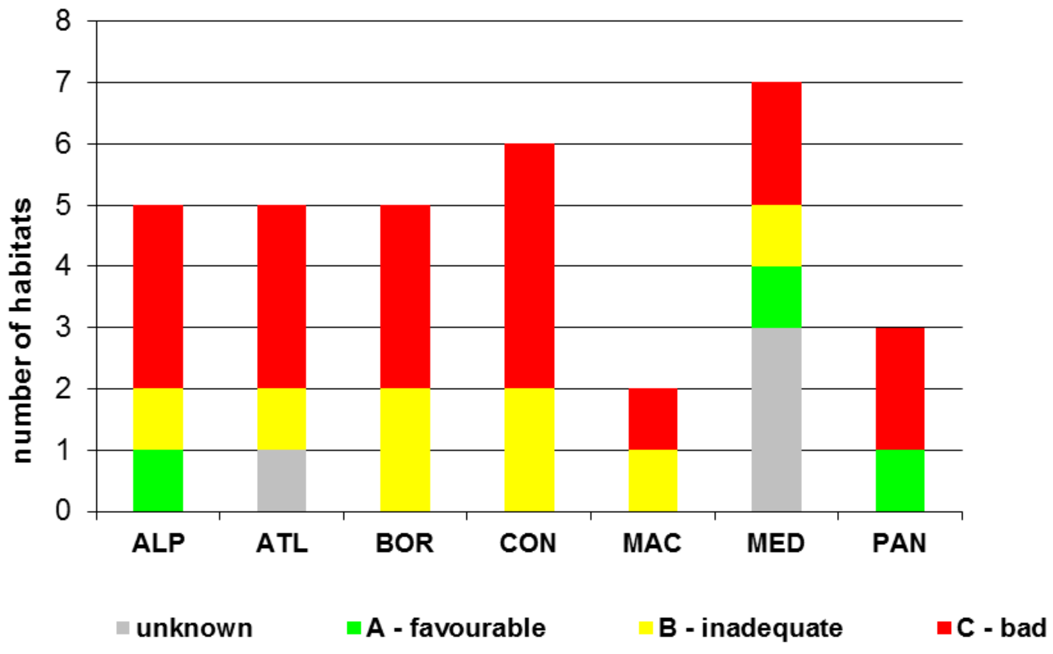
Source: (EC 2013f) and (EEA 2015c)

3.4.1 Protection of floodplains

Remaining floodplains are important to fulfil the goals of different European directives like the WFD, the FD or the BHD (see Chapter 4). The riparian zones are important biological quality components to assess the ecological structure and status. According to FD most countries in Europe have designated flood retention areas which are very often legally protected to manage flood events and to avoid unsuitable land uses. Because of the high biodiversity values, many of these flood retention areas are at the same time overlapping with protected sites for nature conservation, like the Natura 2000 network.

Floodplains contain a high diversity in habitats and species (section 2.3 and 3.1) and most of the natural or semi-natural floodplain habitats are listed in the annexes of the HD (EU 1992). Floodplain habitats are not only covered in the category of freshwater habitats, but can also be found in the categories of bogs and mires, grasslands and forest. Nearly all natural floodplain forest types are nowadays listed in the Annex 1 of the HD and are protected at national level. Nevertheless, in most biogeographic regions the conversation status (EU 1992, Art. 17) still remain in unfavourable condition, being classified as “bad” or at least ”inadequate”(EEA 2015d) (Figure 3.8).

Figure 3.8 Floodplain forest habitats in Natura 2000 Assesment (*)



Note: for EU27 and per biogeographic region; Results of 9 forest type assessments have been aggregated.

Source: Data aggregated from Eionet – ETC/BD 2015: Online report on Article 17 of the Habitats Directive (2001-2006) http://bd.eionet.europa.eu/article17/reports2012/.

(*) Figure to be updated in final version based on most recent data, plus explanation of abbreviations. Conclusions remain.

Besides restoration of the former floodplains and habitats (see subsection 3.4.2), protection of the valuable areas that are left must be assured and remain a priority as no restoration can reach the level of ESs provided as the intact reference landscape does (Rey Benayas, et al., 2009; Scholz et al., 2012, Schindler, et al., 2014). The interventions in floodplains and the effects on biodiversity lead to the conclusion that there is often a mismatch in spatial and temporal scales between scattered scientific evidence and the holistic approach needed by decision makers (Schindler, et al., 2013). These spatial aspects go beyond areal requirements (minimum area) needed to deliver a certain level of ESs, but also include spatial composition (patterns of different ecosystems) and spatial configuration like buffer strips, connections and corridors (Bastian, et al., 2012). The same goes for the time dimension, where there are minimum time requirements for the generation of a particular ES as well as complex sequences in the utilization of an ES to enhance the benefits and time lags between the supply and demand or use of an ES (Bastian, et al., 2012).

Where the water storage role of floodplains and wetlands gets increased attention as an ES, ecology-based measures get rarely only positive feedback from different stakeholders (Grygoruk, et al., 2013). Flooding, normally naturally and regularly occurring in lowland floodplains becomes a limiting factor for agricultural activities and an obstacle for economic development. Drainage as a pressure is increasing with broad-scale degradation of the fresh-water dependent ecosystems. The true economic dimension of water storage in floodplains is however more profitable for a broad range of stakeholders and potentially affected people than it appears negative for agriculture (Grygoruk, et al., 2013).

In economic terms, the benefit of water storage in the floodplain is often compared with the benefit of storage in artificial reservoirs. Although, the total picture need to include other ESs as well, having their own economic value as well as the value of the synergies between ESs. In doing so, the monetary or economic value of water storage on a unit of land cannot be substituted by flood-related losses, but become one element in balanced calculations of whether to drain or keep the floodplain (Grygoruk, et al., 2013). Such an ecologic-economic assessment – extensively studied nowadays (e.g. (Bateman, et al., 2013; Burkhard, et al., 2013; Maes, et al., 2012; Sullivan, 2012)) - is a basic requirement for sustainable development and a necessity for environmental management at country level (Lawton, and Rudd, 2013).

A sustainable management of floodplains could at least minimize eco-toxicological effects of pollutants by e.g. uptake through plants, restricting agricultural use and by widening the active floodplain areas in terms of connecting rivers to their adjacent floodplains. This is highly important as floodplains fulfil several ecosystem functions and services. Water purification is one of them; floodplains may retain several pollutants and nutrients from river water during inundation events or phases of high groundwater levels (Hoffmann, et al., 2009; Natho, et al., 2013). Consequently, an increase of pollutant and nutrient retention in floodplains supports the efforts undertaken to fulfil the aims of the WFD.

The sum of all inundated floodplains in Germany can retain up to 42 000 tons of nitrogen and 1200 tons of phosphorus per year. This equals a yearly purification service of 500 million Euros, being the avoided costs for water treatment in sewage plants (Natho, 2014; Scholz, et al., 2012).

3.4.2 Floodplain restoration in Europe

Floodplain restoration refers to the creation of ecosystems that are typical for floodplains, which exhibit a hydrological link between the river and the adjacent land. The term restoration as we use it in this report only refers to rehabilitation or enhancement of the ecological functions of rivers and their floodplains (Moss, et al., 2008). Restoration and rehabilitation of floodplains showed enhanced ESs provided and a consistently increased multifunctionality of the area (Schindler, et al., 2014). Floodplain restoration is an important measure to give more rooms for rivers, especially to reduce flood hazards aiming to prevent them from becoming disasters.

Natural flood plain management requires a specific set of measures to reduce flood risk and improve natural floodplain functioning at the same time. These measures can be aimed at both reducing the flooding probability and minimising the potential damage. Natural flood risk reduction measures contribute to the restoration of the characteristic hydrological and geomorphological dynamics of rivers and floodplains and ecological restoration for biodiversity. Especially in highly and/or long time developed areas, it is (almost) impossible to go back to a complete natural state. Still, natural water retention measures (NWRMs) (see Box 3.5) like artificial wetlands, even on a small scale, help to keep farmland soil out of rivers and reduce river pollution by nutrients (Ockenden, et al., 2014).

Where structural measures mainly deal with flood control, natural flood risk reduction measures comprise flood control, use and retreat, regulation, financial stimulation and compensation measures (Pichler, et al., 2009). However, the whole discussion has to focus on ESs that are provided and the co-benefits provided by natural flood risk retention measures (EEA and ETC/ICM 2015) rather than on the somewhat arbitrary distinction between structural and non-structural measures or grey and green measures. A ring dike around a floodplain is longer than a straight dike along the river. Nevertheless, the previous is leaving more room for water retention, self-purification, sediment accumulation, recreation, and many other ESs. Case studies in the UK (Pettifer, and Kay, 2012) support the 'intermediate disturbance hypothesis'; where sites that are frequently and never flooded are less diverse in terms of biodiversity than those that are sometimes disturbed. This calls for sustainable flood risk management approaches with measures that work with natural processes to allow intermediate levels of flooding.

Changes in land use are often needed for the implementation of these measures. Therefore spatial planning and stakeholder involvement are of vital importance when implementing a natural flood defence scheme (Moss, et al., 2008). The protection of existing naturally functioning river and floodplain systems also can be regarded as an important natural flood risk reduction measure.

Box 3.5 Natural Water Retention Measures

Natural Water Retention Measures (NWRMs) are a nature-based approach to pursue the objectives of water management, providing a variety of co-benefits in terms of biodiversity enhancement, greenhouse gas mitigation, energy saving or rural development opportunities (EC, 2015a). These co-benefits create opportunities to involve different stakeholders and require cooperation between policy areas like agriculture, forestry, energy or tourism but also includes the possibility that no one might be interested in taking the initiative as the benefits are varied and sparsely distributed.

Natural water retention is explicitly mentioned in the EU Floods Directive (EU 2007) and the maximisation of its use forms part specific objectives of the Water Blueprint (EC 2012c). Other restoration measures for natural areas, like re-meandering of natural ponds are (indirectly) recommended by a note on better environmental options for flood risk management (EC 2011d), and seen as a better environmental option and alternative for hard (grey) infrastructure. "Flood risk management should work with nature, rather than against it (EC 2011d). Where the Water Framework Directive (EU 2000) has the water body as a central concept, limited attention is given to riparian zones which might hinder the implementation of NWRMs to its full potential (EC, 2015b). NWRMs call for an integration, not only in between WFD and FD but also nature legislation and all policy fields where water and land planning needs careful coordination (EC, 2015b).

Most of the NWRMs have a long term horizon, where the effectiveness and benefits of a measure only become visible after some time and they need a large spatial scale of implementation, like a catchment to be effective, so one needs to find space on land that is often already serving another purpose (EC, 2015b). This can be challenges or even barriers for implementation, as society can feel less concerned about long-term impacts and benefits that are more uncertain than short term costs (EC 2012b). In addition, the fact that several NWRMs require a commitment for regular management and maintenance can be an additional challenge.

Financing NWRMs can be challenging as there are many beneficiaries and the financing sources used for traditional flood risk management based on infrastructure works are not always available. Even when NWRMs are more cost-efficient than "grey" infrastructure providing the same flood protection, funding for the implementation and maintenance still has to be found (EC, 2015d). In section 4.1, some of the financing sources available for NWRMs are discussed in more detail.

On the other hand, there is a strong evidence base that NWRMs can be effective and cost-beneficial, especially in win-win situations where costs and benefits are distributed amongst several stakeholders

(EC, 2015b). Spatial planning activities could provide the appropriate room to bring the different needs and constraints of stakeholders together (Parrod, 2014).

Choosing the right NWRM in connection to one objective is already far from straightforward, and adding multiple objectives makes it even more complicated (EC, 2015c). The mix of NWRMs with other structural and non structural measures will always need to be site-specific and robust to changing conditions, including climate change (Santato, et al., 2013). Many NWRMs are low-regret measures regarding climate change adaptation (Borchers, 2014), yielding benefits even in the absence of climate change and are flexible to be adapted to new insights on a later stage. A single NWRM is unlikely to change significantly the flood risk in a catchment of the status of a water body. Nevertheless, the widespread use of NWRMs can make significant contributions to meet flood risk objectives, water quality objectives and nature objectives, while improving financing possibilities, finding the best adapted solution for the local situation, increasing public acceptance and overcoming concentration on individual policies (EC, 2015c).

For more information, see http://www.nwrm.eu online

Efficiency and effectiveness of water retention measures

NWRM and other non-structural measures like flood forecasting and early warning are integral part of a modern integrated flood risk management (Pichler, et al., 2009). NWRM and the changes in land use that come with them are important to reach substantial flood risk reductions, but decision makers keep coming back to water managers with the question about their efficiency and effectiveness. Effectiveness, a term also used in the WFD is a result–based term and describes the degree of goal achievement in terms of risk reduction or effects towards risk reduction. Efficiency is a yield-based term and describes how economically an intended risk reduction or an effect towards risk reduction has been achieved. This later one is related to a cost-benefit analysis, and is a key concept in the programme of measures for the floods directive (EEA 2012c; Pichler, et al., 2009)

In general, the potential additional water storage capacity during floods of NWRMs like microponds or afforestation is rather limited. As smaller and more frequent floods can still have a large contribution to the total risk, the risk reduction capacity of NWRMs can be higher than expected from the hazard reduction (EEA 2012c; Francés, et al., 2008; Pichler, et al., 2009).

When assessing the efficiency and effectiveness of NWRMs, two issues have to be kept in mind: the complexity and the competitiveness. Complexity refers to the fact that NWRMs are not implemented to reach one single goal, e.g. flood protection, but come with a range of benefits. One should not forget that this can impose constraints on some sectors as well, because they perceive that their interests were better served by the former practices than by NWRM (Ungvári, 2014). The competitiveness addresses the issue that NWRMs and nature-based solutions have to deliver comparable sector level results on natural effectiveness, economic efficiency and being able to be implemented.

Box 3.6 Restoration projects in Europe

During the 1990s interest in river restoration increased all across Europe. Initially restoration was mainly focused on the river channel itself and on aquatic ecology, but since the FLOBAR2 project (Hughes, et al., 2003) and the establishment of a European Centre for River Restoration (ECRR) in 1995 floodplain restoration got increased attention as an essential part of sustainable water management. A RiverWiki-database of the RESTORE project contains almost 1000 river restoration case studies but only a minority of the completed measures is directly related to floodplain restoration; being mainly floodplain reconnections, riparian tree planting, removal of exotic plants as well as wetland and backwater creation.

Also in the NWRM initiative (see Box 3.5) a catalogue with around 125 case studies can be found, including measures focussing on floodplain restoration that mainly can be found under the hydromorphology measures: river wetland and floodplain restoration and management, restoration and reconnection of seasonal streams or oxbow lakes, elimination of riverbank protection, re-naturalisation of polder areas etc.

Sources: http://www.ecrr.org/, https://restorerivers.eu/wiki/, http://www.nwrm.eu/list-of-all-case-studies

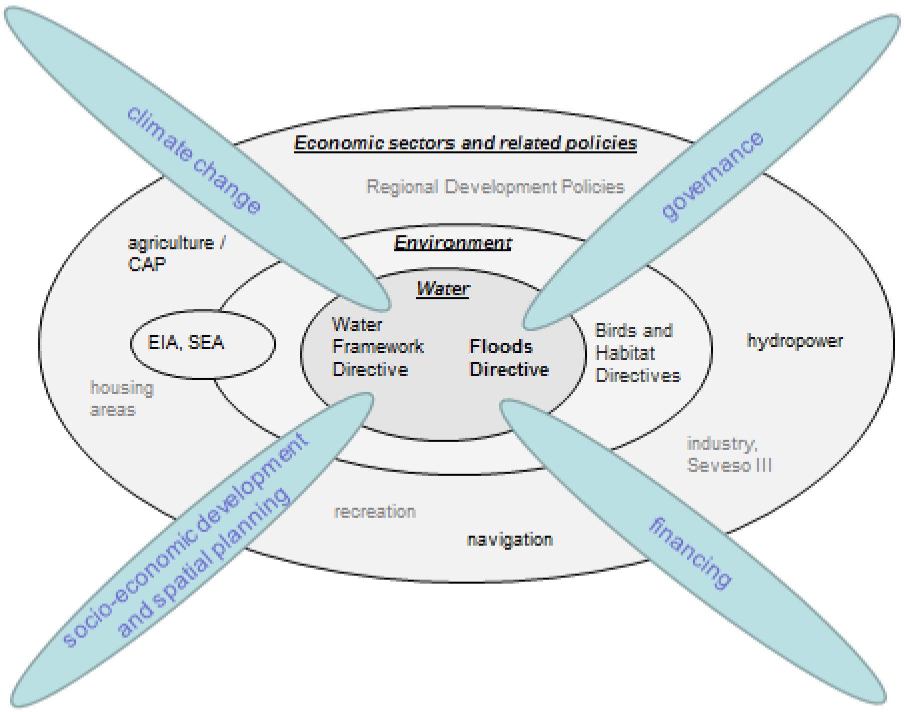
4 Policy developments and implementation

The management of flood plains and river catchments at large has many objectives. Keeping flood risks at an acceptable level must be combined with the needs of other societal, economic and ecological functions. Agriculture, inland navigation, hydropower, forestry, recreation, housing and industry are amongst the most prominent socio-economic activities found in flood plains. Mapping the demands of these sometimes conflicting interests, including their relative influence, and reconciling them with environmental protection and restoration to increase the ecosystem services delivered, is an increasingly relevant and complex task.

The focus of this chapter is on highlighting recent developments and insights in EU policy and in research, as far as relevant for the overlapping areas of flood risk management, flood vulnerability and its environmental impacts. Our objective is not to provide full summaries of these policies and research projects, but from all these initiatives we picked those elements which focus on the interlinkages between water, environment and economic policies and sectors.

Figure 4.1 gives a schematic overview of the contents of this chapter. The directly water-related directives and the water-related sectoral policies are discussed in section 4.1, the cross-cutting issues - including driving forces like climate change or spatial planning but also aspects as governance - that are of special interest for at least several policy fields in are described in section 4.2.

Figure 4.1 Schematic overview of the contents of Chapter 4.



Disaster Risk Reduction

Disaster risk reduction is the concept and practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters. Reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment, and improving preparedness and early warning for adverse events are all examples of disaster risk reduction (see also Figure 2.1).

In March 2015, the third United Nations World Conference on Disaster Risk Reduction was held in Sendai, Japan. The conference adopted the Sendai Framework for Disaster Risk Reduction 2015-2030 (UN 2015). This Framework aims for *'The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries*.' The Sendai Framework sets four specific priorities for action:

- understanding disaster risk;
- strengthening disaster risk governance;
- investing in disaster risk reduction for resilience and enhancing disaster preparedness; and
- "Build Back Better" in recovery, rehabilitation and reconstruction.

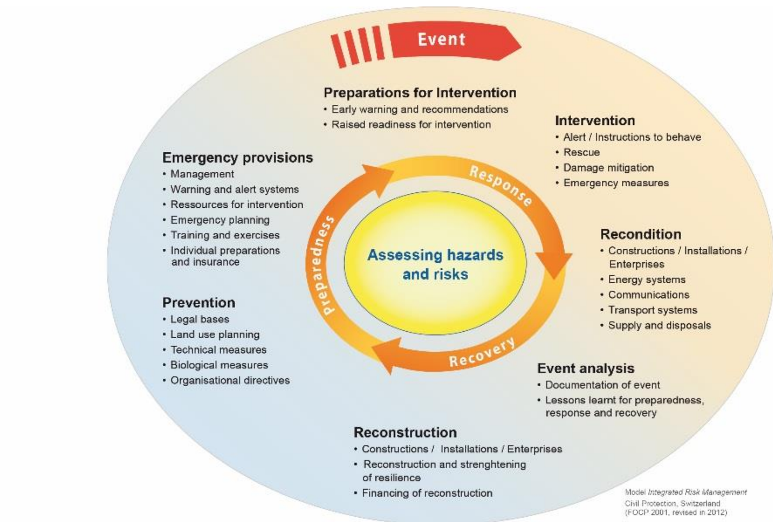
To support the assessment of global progress in achieving the outcome and goal of the Sendai Framework, seven global targets have been agreed, aimed at reducing the impacts of disasters, at enhancing preparedness, at enhancing international cooperation and at development and improved access to early warning systems.

The Sendai Framework attributes a primary role to reduce disaster risk to the state, although this responsibility should be shared with other stakeholders. It defines resilience as a priority and emphasises the importance of locally-driven solutions. It pays attention to social vulnerability and recognises social processes and weak institutional arrangements as drivers of risk. It furthermore pays ample attention to environmental aspects. There is a strong recognition that reconstruction of eco-systems and nature-based solutions are crucial in the protection against disasters.

Disaster Risk Reduction and the Floods Directive

There are obvious differences in scope and legal status between the Sendai Framework and the FD, but they show many similarities as well.

Figure 4.2 The Disaster Risk Reduction Cycle



Source: Swiss Federal Office for Civil Protection (FOCP s.d.)

The FD deals with all aspects of the DRR cycle in Figure 4.2, although it focuses on prevention, protection and preparation (the 'reducing vulnerability' part of the cycle, or the pre-event in Figure 4.2). Many of the new elements of the Sendai Framework are already included in the FD: stakeholder involvement, the importance of governance, ecosystems and eco-based solutions. Climate change is acknowledged in the Sendai Framework as a driver of disaster risk. In the Flood Risk Management Plans (FRMPs), climate change is getting increasing attention. The Sendai Framework offers little guidance to governments to link DRR and adaptation planning and funding mechanisms. Actions highlighted include the use of climate change scenarios to inform risk assessments and maps, and collaboration across institutions for DRR and adaptation at all scales, as also promoted under the FD.

4.1 European policies influencing the management of floods and floodplains

An efficient and effective flood risk management planning cannot be based on the floods directive only. In terms of process, many links are made with the Water Framework directive (WFD), but more important are the content links for a sustainable flood risk management: first of all with the WFD and wider water legislation but also with the nature legislation. In addition, many thematic policies have an impact and are impacted by flood risk management. These influences differ from place to place and can change over time. As agricultural policies are important to look at almost all over Europe, they are discussed separately.

4.1.1 Floods Directive

After indicating the units of management – which are, except for Italy and Ireland the same as the river basin districts under the WFD – and the competent authorities responsible for the implementation of the FD, the first analysis was done by EU Member States in the Preliminary Flood Risk Assessment The first reporting (PFRA), which were due in December 2011.

A large majority (roughly two-third) of reported events is related to fluvial flooding, followed by surface water flooding from heavy rainfall and coastal water floods. Over 40% of records are from floods for flood events from the year 2000 onwards (EC 2015a). The PFRA not only made information available about the physical flood characteristics of significant past floods like the source, mechanism and characteristics, but also about the consequences. When looking at the impacts, it becomes clear that the economic damage is reported less frequently as ‘not applicable’ than the Environmental impact. It is unclear if this is because environmental damage occurs less frequently or explained by an inherent bias in the data as economic impact were traditionally recorded in more detail (Kjeldsen, et al., 2013).

Where the PFRA made more information on the impacts of flooding available in a structured way (although often not quantified or in monetary terms), it is at the same time obvious that the PFRA reporting in itself is insufficient to act as the single database on floods and flood impacts in Europe (ETC/ICM 2015). As significant differences are found in the way countries reported past flood events. The next reporting cycle, with a PFRA due by the end of 2018, could benefit from additional guidance in order to obtain more homogeneous information across member states (Kjeldsen, et al., 2013). Examples are the non-uniformity in the criteria to declare flood events beings ‘significant’, or the term ‘not applicable’ which is sometimes used as 'was checked and was not observed' and in other cases in the sense of 'we do not know because there are no data available'.

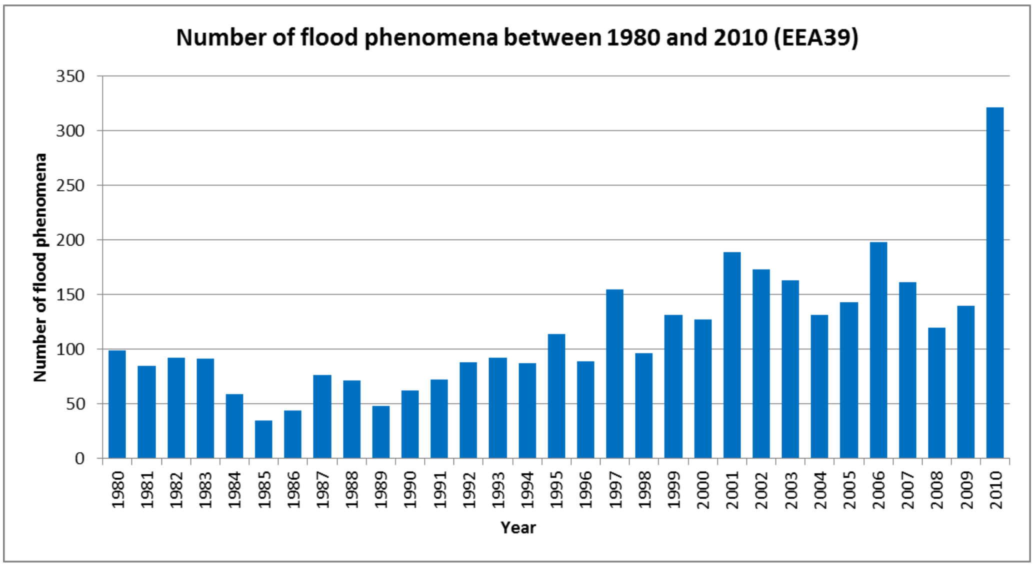
Box 4.1 The European Floods Directive

The purpose of the Floods Directive (FD) (EU 2007) is 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. The FD defines a series of process steps to be taken, including associated efforts on data collection and reporting, but it does not include specified targets e.g. in terms of flood risk levels to be reached. The FD follows a 6-year cycle similar to the WFD (EU 2000). The first cycle will be completed by the end of 2015 when the member states are scheduled to adopt and make available the first round of Flood Risk Management Plans (FRMPs).

Using the information about past floods reported by member states and combining that information with available data from global datasets on floods and additions by national authorities on a voluntary basis, provides already a more complete overview of European floods. Between 1980 and 2010, 3 552 distinct flood phenomena (floods) were evidenced in 37 European countries. As shown in Figure 4.3, the highest number of floods is reported for the year 2010 (321 floods), when 27 countries were affected. This number is associated with the “Central European floods” which occurred across several central European countries during May and June 2010. In Poland, more than 20 people lost their lives, approx. 3 400 km^2 of land have been inundated by the floods and the total damage cost by floods have been assessed to more than 2 billion Euro. Germany, Slovakia, Hungary, Republic of Serbia, Bulgaria, France and other countries were affected as well (ETC/ICM 2015). The apparent increase of the number of reported floods has not been crosschecked with the natural flooding of the rivers. Therefore, based on Figure 4.3 no one can make any conclusion about trends or patterns of flooding in Europe as, besides the length of time series, reporting bias (see also (EEA 2012a) (*))the reporting across Europe is not homogeneous.

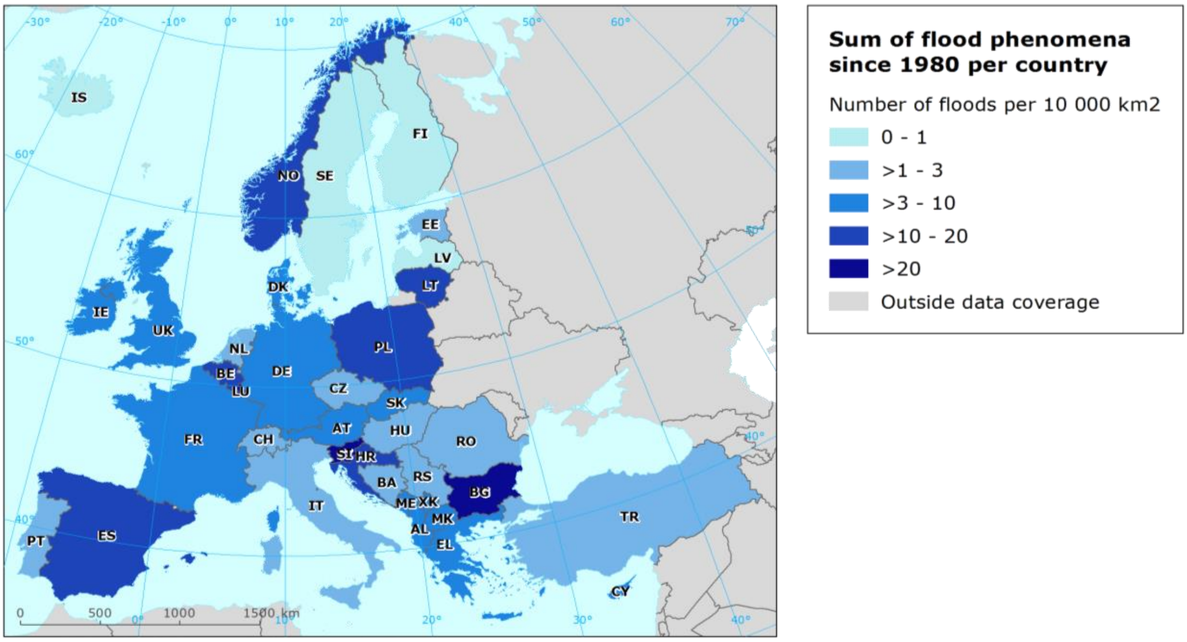
(*) to be updated for final version

Figure 4.3 Flood phenomena between 1980 and 2010.



Map 4.1 shows the number of flood phenomena since 1980 which are weighted in respect to country areas.

Map 4.1 Flood phenomena per country (since 1980)



Source: National boundaries: EEA; Flood phenomena database: EEA.
Note: Country areas calculated using national boundaries spatial data.

Although the structured way of reporting these impacts in categories is relatively rough it contains information on human health (fatalities) and economic impacts as well as impacts on the environment and cultural heritage that can be used in European overviews. Making this information available to the public is essential in raising awareness of flood risks ([11]).

After the delineation of Areas of Potential Significant Flood Risk (APSFR) (EU 2007, Art. 5), EU Member States had to develop on Flood Hazard and Risk Maps (FHRMs), which were due for the end of 2013. While the in-depth review is ongoing in 2015, a partial overview (including the FHRMs of 32 units of management (UoMs)) shows that international coordination is lagging behind. From a subset of 18 UoMs, all being part of an international River Basin District (RBD), 11 of them presented flood hazard and flood risk maps for the area that is shared. In addition, only in five of them it is clear that co-ordination in the development of the maps has been achieved (WRc 2015).

The Member States' reporting of the FHRMs suggests almost 4500 industrial installation are potentially affected by pluvial floods. In roughly half of the EU Member States fluvial flooding with a probability of 1% per year can be overlaid with protected areas (Kavvadas, 2015) as defined in the directives on drinking water (EU 1998), birds (EU 2010) and habitats (EU 1992), urban wastewater treatment (EU 1991), and the WFD (EU 2000).

The development of a Flood Risk Management Plan (FRMP). FRMPs are to be adopted and available in December 2015 and will be reported to the European Commission by March 2016. However, as FRMPs should be developed with the active involvement of interested parties (EU 2007, Art. 10) draft FRMPs were available when this report was produced in 2015.

While keeping in mind only the draft FRMPs were available, a screening of them reveals that over 90% of the plans included objectives for flood risk management and objectives to reduce flood risks (WRc 2015). However, these objectives are only specific and measurable in 25% of the plans. Only in a very small minority of the plans, objectives for the use of preventive and protective measures were

[11] For links to the European database on past floods: see chapter 2

listed while, in contrast, almost 80% of the plans included objectives on preparedness measures. Still lacking in many cases is the underpinning of how the individual measures contribute to the overall objectives set to reduce flood risk and towards more general water policy (environmental) objectives (WRc 2015). Nevertheless, the proposed measures themselves are rather evenly distributed over the four types ([12]). As the FD has a framework approach, its success is dependent on the ambition of the Member States for its implementation and measuring the progress (EC 2015b). The development of a European database on flood impacts (see chapter 2) and initiatives like disaster loss data recording guidelines (De Groeve, et al., 2013, 2014) are important for the measurement of success.

Co-ordination between Member States on objectives and measures has been achieved in half of the RBDs/UoM that are part of international RBDs/UoM, so – as for the FHRMs - there seems to be ample room for further improvements. The same is true for climate change and socio-economic changes (and resulting pressures e.g. changing land use) and especially for the quantification of these future impacts as they are key elements of flood risk management (EC 2015b).

With the first cycle of implementation for the FD almost ending with the availability of the FRMPs, a preliminary evaluation of where the implementation of this directive leads us to can be made. In general it is clear that the improved estimations (and in a way prioritization within Member States) of areas with potential significant floods and the values at risk became publicly available. Although difficult to quantify, it is expected that this lead to an increased flood risk awareness among the general public.

Given the importance of synergies with the WFD and other policies (see subsection 4.1.2) various types of measures are explored, and there's an increased awareness for the potential programmes of measures where prevention, protection, preparedness, and recovery and review measures are combined. Steps towards the integration of flood risk management with nature, environment and water quality objectives by multiple use of the same datasets have been made but can be further improved.

All Member States are – for the first time - concurrently taking action, under the same framework, to prevent or reduce social, economic and environmental damage from flood risk. The detailed information form the FHRMs should direct decision makers and authorities towards (programmes of) measures aimed at reducing flood risks in an effective and sustainable way for the aquatic environment and societies (EC 2015b).

4.1.2 Interlinkages between the Floods Directive, the Water Framework Directive and the Birds and Habitat Directives

The Floods Directive (FD) is linked to the Water Framework Directive (WFD) in all stages of the planning cycle: from problem identification to implementation and monitoring. The main benefits of this mutual coordination are the improved efficiency when communicating with the public, better information exchange between those working on floods and water (quality) management, and achieving common synergies in the environmental objectives of FD and WFD (EC 2014d).

These commonalities are not an end point, as there's room for further improvements (EC 2012c). Part of the current implementation gap in the WFD can be attributed to challenges that are linked to flood risk management. First, the cost-effectiveness of the Programmes of Measures (PoMs) is not always clear and it can be assumed that it is difficult to attract funding for large-scale restoration projects. Second, there is a lack of integration and coherence with other policy domains, including the common

[12] Measures are divided in four categories: Prevention, Protection, Preparation and Recovery/Review (EC 2013a)

agricultural policy and regional and urban policies. And third, it is necessary to improve governance, amongst others by addressing ineffective water planning and management in order to tackle coordination problems (EC 2012a).

The Floods Directive is related to EU nature legislation by the requirement to include protected areas in the flood risk maps (EU 2007, Art. 6 §5(c)) and by a specific mentioning of the need to take into account nature conservation in the flood risk management plans (EU 2007, Art. 7 §3). The Floods Directive also recognises the opportunities created by giving rivers more space by the maintenance or restoration of floodplains in flood risk management.

Through the links to the WFD, all activities under the FD must be in line with the requirements of the BHDs as well, e.g. when flood protection measures potentially affect one or more Natura 2000 sites (EU 1992, Art. 6). Neither the WFD nor the FD change any of the requirements for the BHDs, but they provide a joint framework for the implementation of measures in water-dependent Natura 2000 sites (EC 2011c). Therefore, it is recommended that water bodies, as the basic unit for the WFD, are delineated as far as possible taking into account the protected areas from the BHDs, because these protected areas introduce additional objectives (EC 2003). The restoration of healthy ecosystems, e.g. through Natura2000 networks, can be a very effective way of preventing and mitigating floods, and will in addition be an important tool in adapting to climate change. However, conflicts between the directives can occur as well, e.g. when increasing the dynamics in floodplains (as a measure to support flood risk management). This may have negative consequences for existing environmental values protected under the BHDs. This can arise when human intervention has modified a water body and, as a result of the modification, some valuable protected habitats and/or species have developed in the modified environment. The observed conflicts can be solved by early cooperation, negotiation and well informed choices using the flexibilities that the Directives provide (Summary Report 2015).

In the 2014 workshop on coordinated implementation of nature, biodiversity, marine and water (NBMW) policies (Workshop preparatory committee 2014) it was stressed once more that successes in water, nature (or marine) policies invariably depend on the progress in all other areas. A coordinated implementation is rewarding as the joint implementation of water and nature policies achieves a higher quality of our environment and promote better regulation at European and national level, including avoiding burdensome duplication of work (Workshop preparatory committee 2014). There are no objective obstacles preventing from working together efficiently and exploit synergies of NBMW policies, as there is no essential contradiction in objectives between them. Nevertheless, a full harmonisation is not possible (Summary Report 2015).

Notwithstanding the different contexts in which the BHDs, WFD and FD are developed, and the different objectives they aim to achieve, creating different instruments, there are plenty good examples on a more coordinated approach of the policy processes, e.g. on monitoring and reporting and on the development of programmes of measures and public consultation (Workshop preparatory committee 2014). The comparison of some management aspects, indicating similarities and differences between the FD, WFD and BHDs, can be found in Table 4.1. Examples of potential synergies and conflicts at different scales, related to the hydrology and physical processes can be found in Table 4.2. The importance of potential conflicts became clear once more when assessing the state of Europe’s nature: besides agriculture the modification of natural conditions of water bodies is seen as a major pressure and also pollution remains an issue (EEA 2015d). The proportion assessments which are unfavourable and deteriorating is particularly high for species and habitats associated with wetlands, alluvial grassland, riparian forests and freshwater (EEA 2015d).

There was a large consensus that there is the need to further define a common agenda, building further on the basis of the NBMW workshop (Summary Report 2015). It will be followed by an event under the Luxembourg Presidency in November 2015 (*).

(*) in final version to replace by ‘past time’ and some key messages.

Table 4.1 Comparison of some management aspects of FD, WFD and BHDs

Directive(s)	FD	WFD	BHDs
Objectives	Assessment and management of flood risk reduce adverse consequences (human health, the environment, cultural heritage and economic activity)	Good Status (ecological and chemical status for surface water, chemical and quantitative status for groundwater) No Deterioration Exemptions	Favourable Conservation Status of protected habitats and species No Deterioration
Scale	RBD (UoM) APSFR country	RBD (and sub-units) Water Body (WB) and WB types specified at biogeographical scale country	Biogeographical region, country, site Habitat Type Species
Instruments	PFRA FHRM FRMP	RBMP Programmes of Measures Normative Definitions (Type, Reference, Intercalibration)	Network of Protected Areas for Habitats/Species Habitats and wild fauna and flora Appropriate Assessment Management Plans
Schedule	6-year management cycle ending 2015, 2021 etc.	6-year management cycle ending 2015, 2021 etc.	6-year reporting cycle ending 2013, 2019 etc.

Source: based on (Workshop preparatory committee 2014) for BHDs and WFD objectives and scale

Table 4.2 Interlinkages and potential synergies between the FD, WFD and BHDs.

scale (A)	hydrological processes of interest for the FD (B)	physical processes, related to (B), of interest for the WFD (C)	physical processes as abiotic habitat determinant, related to (B), of interest for the BHDs (D)	potential synergetic measures and potential conflicts (E)
catchment	- infiltration - retention - storage	- nutrient control - natural hydromorphology of small water bodies ([a])	- groundwater in- and outflow - natural groundwater level fluctuations - temporal pluvial and groundwater floods in low-lying areas	- restoration of buffering capacity of agricultural land and forests - NWRM - land use planning, securing functions and ESS
floodplain / APSFR	- storage - attenuation of flood waves (upstream stretches) - increase of discharge capacity (downstream stretches)	- nutrient retention - natural hydromorphology of water bodies in floodplains ([a])	- connectivity in natural degrees - continuity - inundation depths at natural levels - natural erosion and sedimentation processes	- increasing or re-activating floodplains - land use planning, excluding certain developments, keeping storage / discharge capacities intact, - increase floodplain area - protection of Natura 2000 from adverse effects of flood risk management - green infrastructure to support the multi-functionality
river bed	- fast discharge of flood water	- natural hydromorphology ([a])	- continuity - environmental flow	- sediment management

(a) Hydromorphological elements supporting the biological elements: hydrological regime, quantity and dynamics of water flow, connection to groundwater bodies, river continuity, morphological conditions, river depth and width variation, structure and substrate of the river bed and structure of the riparian zone

4.1.3 Potential conflicts with thematic policies

Without diluting the importance of reaching the good status for all water bodies in Europe and a sustainable flood risk management, it is clear that many other (environmental) objectives of the EU are using the same (scarce) resources: water and the adjacent land areas: to secure food production, fertile arable land is needed, to reduce CO_2 emissions renewable energy needs increased and less fuel used per ton and km of goods transported.

The renewable energy directive (EU 2009), which includes hydropower, and the white paper on transport (EC 2011e), stimulating the integration of inland waterways into the transport system in their support for multimodal transport, are two examples of thematic policies aiming to improve Europe’s environmental quality, hence potentially conflicting with the aims of the WFD, the FD and the BHDs. A successful implementation of all these agendas is only possible when there’s a sufficient level of coordination and cooperation. Amongst the tools available to encourage a more integrated approach – linking socio-economic issues with environmental aspects - are the strategic environmental assessment directive (EU 2001) and the environmental impact assessments directive (EU 2012b, 2014a).

Agriculture

Under the rural development policy of the EU (Pillar 2 of the Common Agircultural Policy, CAP), are 2 development priorities defined that are of direct relevance for water quantity and flood risk management (EU 2013b):

- restoring, preserving and enhancing ecosystems - improving water management, including fertiliser and pesticide management (priority 4b); and
- resource efficiency and shift towards a low carbon and climate resilient economy - increasing efficiency in water use by agriculture (priority 5a).

Under these priorities measures affecting the occurrence, timing or extend of flooding can be included and this both in the floodplain as well as in the wider catchment.

The most common example in the floodplain is the promotion of land use changes which reduce the hydraulic resistance. In the catchment this can be done by promoting land use modifications which increase infiltration and delay run-off (e.g. by adapted cropping patterns or reforestation). Alternatives are the provision of additional or reinforced ecosystem services (e.g. by allocating parcels for water storage during floods) or by taking water conservation measures.

The effects of measures in the floodplains are more likely to be directly visible. The effect of measures taken in the catchment will to a large degree depend on the spatial scale of measures compared to the catchment area. Furthermore such measures can have a long lead time before their effects can be demonstrated in hydrological measurements.

The Rural Development Programmes (RDPs) ([13]) 2014-2020 are very relevant for water management, as they define largely how agriculture pressures will be addressed in the WFD RBMPs to be available

[13] 56 out of 118 Rural Development Programmes are adopted, covering 63,2% of the EU rural Development Funds (Status as of 3/07/2015), http://ec.europa.eu/agriculture/rural-development-2014-2020/country-files/common/overview-map-adopted-rdp_en.pdf (status to be updated in final version of report)

by the end of 2015. In addition, the RDPs represent 20% of the CAP budget. However, integration of the two fields remains difficult in practice.

The draft RDPs were screened with regard to their efforts to contribute to achieve the ecological functioning of water bodies and taking into account the flood protection requirements. In addition it was checked how they align with the WFD implementation and contribute to the restoration of water bodies (Fresh Thoughts Consulting 2014). In many of the RDPs there's an emphasis on hard defences like dikes and reservoirs, rather than giving priority to natural water retention measures. Explicit references to maintain and not degrade are scarce and so are the links to the floods directive (Fresh Thoughts Consulting 2014). Although there is improvement in the adopted RDPs compared to the draft versions it – in general – remains a missed opportunity to strengthen the links between CAP and water policies.

Hydropower

An overview of the impacts of hydropower generation on water management can be found in "Towards efficient use of water resources in Europe" (EEA 2012b). The impacts are plentiful and the altered flow regimes and water-level fluctuations as well as the sediment transport an retention affect floodplains (EEA, 2012b). The Renewable Energy Directive (EU 2009) does not set legally binding national targets for hydropower specifically but does so for electricity and transport for renewable sources in general. Where this directive makes a general reference to ecosystem services and the Ramsar Convention (Ramsar Convention Secretariat 2014) in the preambles, there is no specific reference to the Water Framework Directive or any other specific European water or nature legislation.

Where most RBMPs in the first cycle of implementation of the WFD (by 22/12/2009) do not make a reference to the exemptions for the environmental objectives (EU 2000, Art. 4§7) there seems to be a lack of integration between water and energy policies (EC 2012c). Nevertheless, there are several examples on sustainable hydropower development, like in Austria (Koller-Kreimel, 2015) where a catalogue for water protection and use sets national criteria for new hydropower projects (BMLFUW 2012) and was developed in cooperation with 9 regional governments and stakeholders. Also for the Danube River Basin, guiding principles are adopted (ICPDR 2013), with attention for both existing and newly developed power plants. But up till today both water sector and energy sector are at risk to fail achieving the objectives and legal compliance without a cross-sectoral dialogue (Mair, 2015).

Inland navigation

Natural water retention measures and giving room to rivers and other flood risk management measures working with natural processes may influence flow patterns (and erosion-sedimentation processes) during normal conditions and these projects often aim at increasing the biodiversity. This may have an impact on inland water transport (IWT) (PIANC 2009). Measures taken for the benefit of navigation can be divided into (PIANC 2009):

- maintenance measures, like extractive dredging, sediment feeding and management or vegetation maintenance;
- construction measures, like groynes, dikes and revetments, sills and armoured layers, rock blasting, locks and barrages or flow regulation; and
- operational measures, like terminal and port facilities, or river information services.

Where the maintenance and operational measures in general affect the physical characteristics of the flood wave only to a limited extent, it is also true that maintenance measures like extractive dredging, sediment management or vegetation management can have significant effects on the ecosystem services in the riverbed and floodplain. This is even more true for construction measures for navigation and in addition they may influence probability, magnitude and duration of flooding.

Construction of levees and flow diversions have the largest impacts on ecosystem services, but at the other hand can be reversed easier (e.g. by dike-openings) than modifications of the river itself (PIANC 2009).

However, it needs to be mentioned that of the many grey river engineering measures reducing the natural storage of floodwaters, only some of the developments can be attributed to navigation, mainly:

- river regulation causing an increased flood wave propagation which is leading to increased flooding downstream; and
- excessive levee construction or channelling that accelerates flood peaks and wave heights (PIANC 2009)

While developed originally within different communities, an ecosystem based flood risk management and navigation needs are not incompatible. A joint statement for the river Danube (ICPDR 2007) was made based on integrated planning, defining goals and ensuring comparability of alternatives, applying EIAs and with respect for and contributing to the RBMPs (Mair, 2015) and further specified in a manual (ICPDR 2010) and with a yearly follow-up and exchange of good practices. To maximise synergies between transport needs, WFD, FD and BHDs, also in terms of (co-)funding, an integrated planning approach is necessary, e.g. by integrating river restoration initiatives into IWT sector plans (EC 2012d).

4.1.4 Environmental Assessments

The Strategic Environmental Assessment Directive (SEA) (EU 2001) aims to encourage a more integrated and efficient approach to territorial planning where environment, including biodiversity considerations, are taken into account much earlier on in the planning process and at a much more strategic level. This should lead to fewer conflicts further down the line at the level of individual projects.

An SEA is mandatory for a variety of plans and programmes dealing with land use changes including for agriculture or forestry, energy, or water management. An SEA should also be carried out on any plan or programme, which, in view of the likely significant effect on sites, have been determined to require an assessment pursuant to the Habitats Directive (EU 1992, Art. 6 §3).

An SEA sets the framework for future development consent of projects listed in the Environmental Impact Assessment Directive (EIA) (EU 2012b, 2014a). While the SEA process operates at the level of plans and programmes, the EIA Directive operates at the level of individual public and private projects. Thus, development consent for projects ([14]) which are likely to have significant effects on the environment should be granted only after an assessment of its likely environmental effects has been carried out.

Flood relief works in general are not amongst the projects for which an EIA is mandatory. They do however require a screening by member states, in order to decide about the necessity of an EIA. For dams and reservoirs, which may play a role in flood control, an EIA is mandatory. Also for many types of projects that may cause negative environmental impacts as a consequence of floods, such as the construction of oil refineries, chemical installations, power plants and quarries, an EIA is mandatory.

[14] The jurisprudence of the Court in relation to the concept ‘project’ is summarized in (EC 2015d)

Flood risk reduction measures to be implemented as part of the currently devised FRMPs are thus likely to require a screening and potentially an SEA or EIA, the results of which are to be included in the FRMP. In such cases, the two may profit from each other's databases and public consultation processes. The drafting process of an SEA or EIA may raise awareness of potential adverse environmental impacts of proposed FRMP measures and foster a creative process to devise better-balanced measures.

4.2 Flood risk management, climate change adaptation and disaster risk reduction

Besides the specific links between water and nature policies on the one hand and thematic policies like CAP, energy (hydropower) or transport (IWT) on the other, there are also cross-cutting issues that need special attention as they – by their very nature – have an impact on all activities. To take them into account is a prerequisite for a successful integrated planning between involved different policy domains.

4.2.1 Climate change and adaptation in European Directives

In Europe, policy for adaptation to climate change has been developed at many levels: from local to a European-wide scale. There is limited systematic information on current implementation or effectiveness of adaptation measures or policies. Some adaptation planning has been integrated into coastal and water management, as well as disaster risk management (IPCC 2014, Chapter 23: Europe). A Europe-wide state of play for adaptation activities on a national scale is presented in (EEA 2014c)

Water Framework Directive and the Water Blueprint

Climate change and adaptation are not mentioned explicitly in the Water Framework Directive (EU 2000). Nevertheless, in the first RBMPs (2009) future climate change scenarios were mentioned in almost 70% of the plans (EC, 2012). The four most often cited climate change threats are: flooding, changes in water demand and availability, threat of drought, and impacts on water quality and biodiversity.

The subject was discussed intensively over the last years as climate change pressures are exacerbated by human and economic activities and climate change poses an additional threat to the flow regime of water ecosystems (EEA, 2012c). The step-wise and cyclical approach of river basin management described in the WFD makes the process well suited to adaptively manage climate change impacts (EC 2009). Climate-related threats and adaptation planning should be incorporated in the river basin management plans from the second planning cycle (for WFD 2009-2015) onwards. As a minimum it should be demonstrated how climate change projections have informed the assessment of pressures and impacts, how the monitoring programmes are configured to detect climate change impacts, and how selected measures are robust to projected climate conditions (EC 2009).

The Water Blueprint Communication (EC 2012c) reviewed the most important water policy processes in the light of resource efficiency, including the water related part of Europe’s climate change vulnerability and adaptation policy (EEA 2012b). In the Blueprint, climate change together with land use and economic activities are depicted as the main causes having a negative impact on Europe’s water status. Adapting to climate change and building resilience to disasters are presented as key activities for a sustainable water management and good qualitative and quantitative status for water bodies in Europe and worldwide. The Blueprint communication explicitly refers to the (by that time upcoming) EU adaptation strategy (EC 2013b).

Floods Directive

The effect of climate change on flood risk is still uncertain, but under a SRES A1B scenario (IPCC 2000) roughly two-thirds of the modelled increase is due to economic growth and one-third can be attributed to climate change by the middle of this century (Jongman, et al., 2014).

In the Preliminary Flood Risk Assessment (PFRA) reporting in the first cycle of implementation of the Floods Directive (EU 2007), only one third of Member States explicitly considered climate change or socio-economic changes as long-term developments. This surprised the assessors based on the substantially increase of flood losses in Europe over decades due to increasing wealth located in flood-prone areas and climate change (EC 2015b). However, only from the second cycle of implementation onwards (2016-2021) the likely impact of climate change is mandatory to include in the PFRA.

The climate change impacts mentioned in the PFRA so far are mainly changes in precipitation and to a lower extent changes in temperature, sea level rise, increase in extreme events and change in run-off. Changes in snowmelt, wind direction and wind speed and surface flow are only mentioned for a few Units of Management (UoM).

For the Flood Hazard and Risk Maps (FHRMs), no explicit reference to climate change is made in the Floods Directive. However, in the reporting guidance (EC 2013a) a summary text on the methods used to include climate change in the FHRM scenarios can be reported as optional information.

Flood Risk Management Plans (FRMPs) are produced by the end of 2015, including a programme of measures. The likely impact of climate change on the occurrence of floods has to be taken into account but for the review of FRMPs only. So strictly spoken, the floods directive does not ask for it in the first cycle of implementation. At least from the screening of the draft FRMPs doesn’t seem fully considered or it is unclear if taken into account (WRc 2015).

The shifts in the extremes, rather than the trend in the averages are likely to be the biggest challenge for adaptation (EEA 2012c; IPCC 2012)and likely to be the cost drivers for adapting the infrastructure (OECD 2013). While the strategies for disaster risk management developed within the context of climate change requires measures that are specific to the local circumstances, including a sustainable land management and spatial planning (IPCC 2012), the river basin approach avoids passing on negative consequences further downstream and for international river basin districts both the water framework directive and floods directive it has to be ensured that relevant information is exchanged and the plans are coordinated. Transboundary river basins pose especially complex challenges for building adaptive capacity.

Nature legislation

While in the Birds and Habitats Directives (EU 1992, 2010) climate change and adaptation aren’t mentioned at all, it has a strong presence in the Biodiversity 2020 strategy (EC 2011a). Although Climate change is not having a major impact at present, it is expected to have an increasing impact in the future. Nevertheless, climate change is relatively infrequently reported as a pressure or threat in the 2007-to-2012 Habitat Directive Article 17 reports (in 3% of habitat and 2% of Member State species assessments it is reported as a pressure, and 5% and 4%, respectively, as a threat) (EEA 2015d).

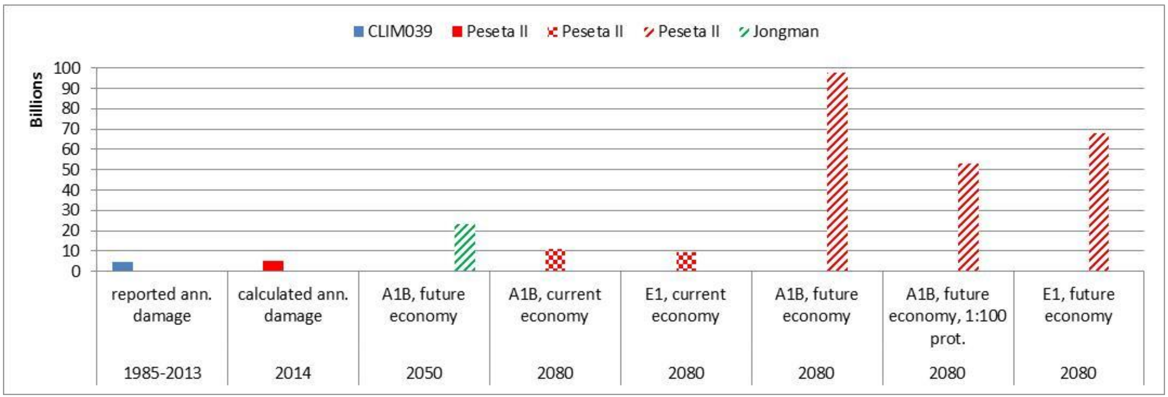
Adapting the Natura 2000 network to climate change based on current policy requires voluntary action by the Member States, which may not be timely or ambitious enough (Verschuuren, 2010). A targeted guidance document specifically on climate change and Natura 2000 was published, to optimally address the impacts of climate change in managing the network's protected sites (EC 2013e).

4.2.2 Socio-economic change, land use change and spatial planning

Flood risk management is related to socio-economic development by two mechanisms. The first and most important mechanism is that as a result of socio-economic development the economic value of the assets in floodplains increases. This in turn increases the justifiable investments for protection measures.

Recent estimates of calculated future flood losses are presented in Figure 4.4. With all uncertainties inherent to these data, the picture is clear that flood losses can be expected to increase 5-fold by 2050 and up to 17-fold by 2080. The major share of this increase (70 to 90%) is due to socio-economic development, the remainder (10 to 30 %) to climate change (Ciscar, et al., 2014; Jongman, et al., 2014).

Figure 4.4 Annual flood losses for 2050 and 2080 compared to the 'actual situation'



Note: For SRES scenarios A1B and E1 and for current and future economy. The SRES scenarios cover a wide range of the main driving forces of future emissions, from demographic to technological and economic developments (IPCC 2000; van der Linden, and Mitchell, 2009)

Sources: (EEA 2012a) (*)(Ciscar, et al., 2014; Jongman, et al., 2014)
(*) reference to be updated after update of CLIM039

The second mechanism is that the change in land use that results from socio-economic development may lead to changes in the hydrological characteristics of a catchment, which in turn may cause an increase in peak floods. This effect, however, is difficult to demonstrate in real data, and only becomes significant in small catchments with large-scale changes in land use.

The methods to quantify socio-economic changes like urban sprawl and soil sealing land use and especially their potential future impacts on water management should be further improved (EC 2015b). Whether or not land use change significantly affects flood risks depends first on the location of the land use change. Land use changes in the floodplains have a direct impact on flood risk because they affect the invested values at risk, and they may also increase water levels during floods. The effects of changes in the wider catchment depend on the scale of changes relative to the scale of the catchment (e.g. (ICPR 2006)).

Guiding land use change can, it least in theory, be realised by spatial planning policies. However, Spatial planning is not subject to EU regulation, except at sea under the Maritime Spatial Planning Directive (EU 2014b). In practice, the implementation of planning policies is often incomplete due to a lack of specific instruments and measures for implementation in practice (Mickwitz, et al., 2009; Swart, et al., 2009; IPCC 2014, Chapter 23: Europe)(. In addition, spatial planning and water management have for a long time been viewed as separate management problems (EEA 2012c), where the interests of flood risk management are sometimes valued lower than those of competing economic functions such as agriculture (see also text box 4.5), housing (ARUP 2011) or infrastructure.

At European level there is no regulation in place to organise a process to timely signal the effects that land use changes may have on flood risk management or water body status and to take mitigating measures. This could be a role of the SEA and EIA directives (see subsection 4.1.4).

4.2.3 Financing instruments

River restoration and flood risk management projects are mostly financed from national funds. With public budgets under pressure (e.g. (EC 2012c; Despotovic, 2015; EEA et al., 2015; Morse, 2014)). There is a tendency within at least some of the competent authorities to focus their spending on their core tasks, i.e. flood protection. An example is the Dutch Flood protection programme (Hoogwaterbeschermingsprogramma 2013), which only subsidizes 'sober and efficient' protection measures. This trend is contradictory to the trend to adopt more integrative solutions to meet the complex interests involved in floodplains. As a result, the additional investments required to implement integrative measures rather than sectoral measures are not directly or fully covered by national funds. Additional funding by other stakeholders, e.g. NGO's, national or local authorities is then required.

Innovative ways that may help to cover these expenses are Payment for Watershed Services (PWS) and Water Funds. PWS belong to the wider category of Payments for Ecosystem Services (PES) and are voluntary mechanisms to maintain or enhance the provision of ESs (EC, 2015d). Water Funds are innovative ways to finance water management, to ensure the supply of environmental services from a healthy watershed and promote integrated and participated watershed management based on a long-term work plan (EC, 2015d).

At EU level, EU-LIFE program is the EU's financial instrument to support environmental, nature conservation and climate action projects throughout the EU. By then end of 2014, searching in the life project databases with the keyword “wetland”, which includes floodplains, 239 projects popped-up, and with the keyword “aquatic ecosystems”, where riparian zones and floodplains are an integral part, 54 projects were shown.. The new LIFE+ Integrated Projects offer funding possibilities for nature-based solutions and NWRM.

A core issue in these solutions is that a stronger case than presently available is needed to underpin the cost- effectiveness of integrative nature-based solutions. The Ecosystem Services approach is an important instrument in this respect, but cases based on 'willingness to pay' are not considered strong enough to hold in court (EEA et al., 2015); although in other cases, this approach has been welcomed by policy makers for making such services visible. Promising services are those that lead to cost savings on maintenance. Building stronger cases will not only be instrumental in attracting funds, but also and in parallel in building up institutional and public support.

Where most of the nature-based solutions for flood risk management can be found in the prevention and protection of flooding (see also the introduction of chapter 4), necessary to reduce the overall flood losses, the FD in addition focusses on preparedness with (often non-structural) measures like flood forecasting and flood warning. However, one may not forget that – as total protection does not exist – financial instruments also need to be in place for the response and recovery phases (during and after a flood). Because people and their goods are threatened, decisions have to be taken under high uncertainty and time pressure they often have less attention for ecosystem services or nature-based solutions. Their scale of applicability ranges from international solidarity (like the European Union Solidarity Fund, see Box 4.2), up to individual initiatives (like flood insurance, see Box 4.3).

Box 4.2 The EU Solidarity Fund

In the aftermath of the exceptional floods along the Elbe and Danube rivers in August 2002, the EU Solidarity Fund (EUSF) was set up as a new EU financial instrument. The EUSF was established in an unusually short time and equipped, over and above the ordinary appropriations in the Multiannual Financial Framework (MFF), with up to 1 billion (1000 million) Euros annually.

Since 2002, the European Commission (EC) took major efforts to make the EUSF more responsive and applicable for a broader scope. A new proposal, to reform the EUSF, was presented in July 2013. It is less ambitious and more acceptable to the EU member states (MS) than previous suggestions that didn't pass the European Council. The new MFF (2014-2020) halved the annual ceiling of the EUSF but set its limit in constant 2011 Euro value (EU 2013a). The administration of the applications was simplified as well. As before, the EUSF can be used for national and regional natural disasters, and for neighbouring countries affected.

By choosing to reinstall the absolute damage threshold criterion of 3 billion Euro in 2011 instead of 2002 prices, the legislator made it easier for the largest (six) EU economies to access the post-disaster solidarity aid, while the relative threshold of 0.6 per cent of the gross national income (GNI) remained unchanged. The reform of the EUSF has made a clearer definition of the terms under which the solidarity aid can be provided for regional natural disasters, causing damage below these thresholds but disproportionally affecting the regional economies. The initially unspecified regional dimension has been equated with the second level statistical subdivisions (NUTS2) which in many but not all EU MSs tally the administrative division.

For flood related disasters only, the total damage registered since 2002 amounted to 51.5 billion Euro (2014 Euro prices). Around 2.1 billion Euros, ca 50% of the total EUSF resources, has been mobilised to assist a total of eighteen countries to cope with the impacts of floods. Only 417 million Euros (ca. 20% of the total aid) has been disbursed for other than major (flood) events. The countries affected by the 2002 and 2013 Central European floods (Germany, Austria, Czech Republic) are among the largest recipients of the solidarity aid, followed by United Kingdom who applied only once for the aid from the EUSF in the aftermath of the 2007 floods.

The EUSF has attracted little attention in scientific literature. (Hochrainer, et al., 2010a) analysed legitimacy, viability and efficiency of the Fund, using normative and quantitative assessment criteria. Focussing on flood risk only, and assuming spatial independence of the risk, they found that with probability of 8% that solidarity aid claims will exceed the annual ceiling (for all disbursement of the EUSF meant to cover all hazards), at that time still set to 1 billion Euro. So even if dedicated entirely to post-flood disaster assistance, would be depleted without covering all solidarity assistance quests every 12 years on average (this probability increases to 10% for the maximum case). (Jongman, et al., 2014) found a significant and positive correlation between the flood probabilities across 63% among 1 007 European sub-basins. They estimated the annual average demand for the EUSF's assistance to 258 million Euro and the probability that the Fund would be depleted without satisfying all claims amounting to 5%. The latter would increase to 9% as a result of projected climate change until 2050.

Box 4.3 Flood insurance

Uninsured risks are a source of concern, as they negatively affect the wellbeing of people and the economy. Of all flood losses 1980-2013, approximately 23% is insured. This is much less than for storms (where more than half of the losses are insured) but more than for all other natural hazards (EEA 2012a) (*)

Insurance and banking face problems related to accurate pricing of risks, shortage of capital after large loss events, and by an increasing burden of losses that can affect markets and insurability, within but also outside the European region (Botzen, et al., 2010). Accurate information on the joint occurrence of flooding in different river basins is essential for insurers and public consultation schemes (Jongman, et al., 2014). Nowadays, the efforts to reform flood compensation mechanisms are solely focussed on the financial losses after an event without attention for managing and reducing the underlying flood risks (Surminski, et al., 2015). The financial sector can adapt through adjustment of premiums, restricting or reduction of coverage, further risk spreading, and importantly incentivising risk reduction. Government intervention is however often needed to provide compensation and back-stopping in the event of major losses (Aakre, and Rübbelke, 2010).

Many policies related to insurance and compensation are guided at EU level. The Green Paper on disaster insurance (EC 2013d) builds upon existing evidence to create a better understanding needed for potential actions by private and public actors involved and to increase market penetration, but wasn't followed until now by a formal response to the green paper consultation and it remains unclear what decisions (if any) will be made in this area (Surminski, et al., 2015). While the Green Paper (EC 2013d) hinted a state-mandated insurance scheme as a way to harmonize practices across Europe, the European Parliament (EP 2014) made a critical review and concluded that disaster insurance harmonization is not prudent because insurance should remain voluntary and the market as flexible as possible to come up with products tailored to local requirements.

(*) to be updated in final version

4.2.4 Governance

The available evidence of the progress made in the implementation of both the WFD and the FD indicates that governance-related issues will need continued attention. According to the EU Strategy on Adaptation to Climate change (EC 2013b), an important challenge is in the coordination across the various levels of planning and management. A similar hint can be derived from the screening of the draft RBMPs, provisionary as it is, when it states that international coordination seems to lag behind, that co-ordination of the setting of objectives has only been achieved in less than half of the UoMs investigated, and that public consultation on these objectives only took place a little over half of the RBDs/UoMs (WRc 2015). These numbers can improve in the final reporting for 2015, but for the moment there seems to be a discrepancy between the generally accepted benefit of early involvement and the apparent late reporting on public participation (WRc 2015).

The NWRM report on Policy coordination (EC 2014c) sketches a varying picture of governance arrangements for the WFD (which also affects NWRM), stating that in many countries the structures for the WFD implementation built on the existing structures. As these were different across the EU before the WFD, they are different until now. As some governance-related elements are shared between the FD and the WFD like appointing competent authorities, defining river basin districts units of management, organising public participation, or ensuring international coordination where appropriate, governance offers potential synergies between the two.

Also the (IPCC 2014) identifies weaknesses in present governance arrangements, such as a lack of concrete instruments beyond a general level of policy formulation and a lack of institutional frameworks to support (climate) adaptation.

From experiences from France, Germany, Great Britain, the Netherlands, Poland, Romania and Sweden one can conclude that the FD is implemented differently across the EU, and even within one country (van Eerd, et al., 2015; Głosińska, 2014; Hartmann, and Spit, 2015; Hedelin, 2015; Heintz, et al., 2012; Vinke-de Kruijf, et al., 2015). Differences within a country may occur when the responsibilities for implementation are positioned at the regional or local level (e.g. federal states in Germany or municipalities in Sweden). Five more general issues for implementing the FD were identified:

1. Capacity: the FD introduces new tasks to governmental organisations. Their capacities may not be up to these tasks, such as: thinking in a river basin perspective, designing space for the river measures, mapping flood risks, engaging with stakeholders.

2. Timing: the tight deadlines of the Directive are seen as a mismatch with implementation of the ambitious aim to change from flood control to flood risk management.

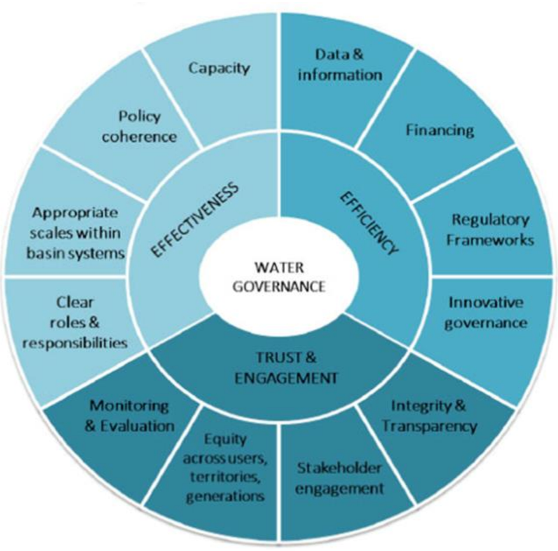
3. Vertical coordination: the Directive requires coordination across national and regional authorities, yet this is not necessarily in place or the responsibilities are not well defined.

4. Stakeholder engagement: stakeholder engagement is necessary for implementation and support of local actors, yet remains difficult to be put into practice.

5. Institutional change: depending on (a) the ambitions a region has to change its flood policy and (b) its current institutional structure, changes in institutions and legislation are required to implement the EU Floods Directive.

The OECD recently developed a tool for the analysis of governance arrangements (OECD 2015), which give a complete list of elements to be taken into consideration. Figure 4.5 represents a summary overview, for further explanation we refer to the source document.

Figure 4.5 Overview of Governance Principles

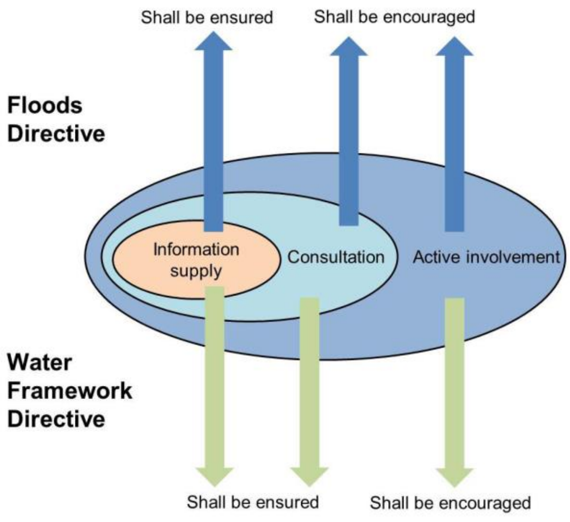


Source: (OECD 2015).

The interlinkages between the FD and the WFD with respect to public participation are visualised in figure 4.6. Key success factors for public participation in water management, and its relation with the wider governance isin water management, is presented in a recent EEA report based on eight case studies (EEA 2014e). Synergy in public participation and information exchange may also be found with the Seveso III directive (EU 2012c) which puts much emphasis on providing information to the public.

Evaluation of the public participation process for the FD – where they shall encourage active involvement of interested parties for the FRMP, while the PFRA/APSFR and FHRM are simply 'made available' to the public - is not yet considered. A joined approach for WFD and FD may prove to be beneficial. The evaluation must include a clear definition of the goals of the process. These are formulated in the FD, but also other more generally stated objectives for example as formulated in the case studies (EEA 2014e) or by OECD (Buckle, 2015) may be included.

Figure 4.6 Source of flooding for historic flood events reported under the PFRA



Source: (EC 2014d)

How the different governance principles are combined into a specific governance model, depends on the local situation: the key issues (and most important links to other activities and legislation), the stakeholder composition, previous experiences, administrative set-up …. The Governance Principles were used in interviews with experts from two European river basins, the Guadiana and the Rhine (text boxes 4.4 and 4.5), answering to which extent each of the principles is present in their river basin with regards to the FD implementation.

Box 4.4 Recommendations to implement the FD in the Rhine basin – a water governance perspective

Since the FD came into force much has happened to implement it in the Rhine basin. The roles and responsibilities had to be allocated for the three implementation steps of making PFRAs, FHRMs and FRMPs. Many of these tasks are carried out by the regional and local governments, whereas flood control used to be the responsibility of a national government. The implementation process is going well: discussions take place on new strategies to change from flood control to managing flood risks; maps are prepared at the local level resulting in an improved understanding of the local flood risk situation; member states are pushed to be transparent since they engage with stakeholders and present their flood risk management plans.

However, there are also issues that require attention for the next 6-year implementation cycle of the FD. These issues are discussed and complemented with lessons learnt from the Space for the River programme, a programme that implements 34 projects that integrate flood control with spatial quality along the Dutch Rhine branches.

The first issue relates to transferring responsibilities to the regional and local governments. These governments do not always have sufficient technical capacity to develop flood risk management measures and maps. Moreover, public administration staffs are reduced across the river basin, making it difficult to conduct the required work for the FD. Insights from the Space for the River programme suggest that tasks should be matched with the expertise and capacity of an organisation rather than imposing new tasks on them. Integration across different levels of government is reached by initiating (and maintaining) region specific Steering Committees where administrators of different levels meet. Another lesson is that responsibilities should not only be well defined across governmental organisations, but also within one organisation since flood risk management covers multiple departments.

The second issue is budget. Securing budget for flood risk management measures becomes increasingly difficult since countries reduce budgets. The FD neither provides budget for funding nor recommends how to arrange funding for the implementation of measures. In the Space for the River programme budget was secured at the national level for the full programme. The budget is spent in local projects by regional and local governments. External accountants closely monitor their spending.

The third issue is cross-sectoral integration and policy coherence. Agriculture, industry and urban areas are in competition with space reservations for flood retention areas along the River Rhine. Space for the River projects realise measures that integrate interests of flood risk management, agriculture, industry, nature and urban expansion. The Space for the River case suggests that connections between these sectors should be included in policies from the very start, and that budget should be allocated for measures that integrate various functions. Much time should be devoted to exploring integrated options at the local scale since insights are gained on the ambitions of actors from different sectors and governments (local and regional).

The fourth issue is whether the outcomes of the Directive are reached. The Directive is ambitious since it aims to change policies from flood control to flood risk management. However, member states may become afraid of sanctions when they do not reach too ambitious goals. Instead regions may opt for ‘form’ instead of content and merely present plans that do not differ much from the current flood policy. For instance, (Heintz, et al., 2012) report that the German Federal States of Hesse and Saxony adapted the tasks of the FD to their existing routines in a ‘pro-forma’ implementation process. These routines fitted the flood security approach that is characterised by top-down sectoral planning by the water authority

Box 4.5 Recommendations to implement the FD in the Guadiana basin – a water governance perspective

Various aspects of water governance are well organised in the Guadiana river basin. Roles and responsibilities for policy making are well defined and water is managed both at the basin and the local scale. Many data are available and used to inform decisions regarding dam regulation and water allocation. In relation to implementing the FD, the Spanish have developed a well-conceived plan. It is clear on the roles and responsibilities of various water authorities and states that coordinated participation of all institutional authorities is fundamental in controlling floods. It is coherent with existing policies and proposes measures that are approved by the responsible authorities.

However, there are also several issues that require attention to implement the FD. The first issue is cross-sectoral coordination. Coordination with other sectors is difficult. Other sectors such as agriculture, industry and spatial planning are much more powerful than water and the environment. They also have more budget. As a result, many activities (e.g. expansion of urban and industrial areas, planting of olive trees) take place in flood prone areas. This complicates the process of space reservations for flood risk management.

The second issue is capacity. Although a proper flood risk management plan may have been developed, the capacity to implement and enforce it is limited. This is already the case with existing water policies. Due to the economic crisis, there is very limited budget for water projects. The implementation of measures of the flood risk management plan will only improve with the availability of new financial resources.

The third issue is that of trade-offs across users and generations. Due to the economic crisis the main focus is on economic development and there is no attention for trade-offs between environmental protection and economic development. The next-generation aspect is also not reflected in the implementation of water programs and projects.

The fourth issue is that of innovative governance. The river basin organisations (Confederaciones) are quite conservative and do not want much to change. Hence there is a big challenge to implement novel measures for flood risk management since the Confederaciones are the governmental water experts and responsible for river basin management.

4.3 Gaps in knowledge and policy integration

Notwithstanding the detailed data and information available at local scale, often covering a wide range of themes, there are gaps to be closed for a better implementation of the floods directive and for a more environmentally focussed flood risk management.

4.3.1 Data

As seen in the reporting on past floods in the PFRA (and in the EFID database) (*), data on the environmental impacts of floods are scarce. The subtypes of consequences foreseen in the reporting for the floods directive (affecting water body status, affecting protected areas and pollution sources) (EC 2013a) seem to cover the most important aspects with the exemption of a subtype on erosion and/or sedimentation.

(*) link to be added in final version

Where floodplains are approximated by the areas with alluvial soil, wetlands, of the hydraulic floodplain for a given return period, it already becomes clear that data on delineations of floodplains are incomplete. At European scale, the data must not be as detailed as for the planning of measures and development of specific areas, but actual data availability does not allow a proper status and trends assessment of Europe’s floodplains.

Two other data gaps are related to this one: detailed information on land use in floodplains and an overview of flood protection measures. Where Europe has good spatial data on land use and protected areas like Corine Land Cover (CLC) (EEA 2014b), Natura2000 (EEA 2015b) or CDDA (EEA 2014d) ([15]), high resolution data needed to estimate potential flood losses or changes in ecosystem services provided are not available, even with the Corine Land Cover changes (EEA 2014a) available on a more detailed scale.

In addition, information on flood protection infrastructure is unavailable across Europe, and these linear infrastructures are not included in land use maps like CLC. In most studies nowadays where most of Europe is covered, simple assumptions as ‘protection against a flood with a return period of 100 years in place’ are used, updated with more detailed values where available but never including local variations (e.g. (Ciscar, et al., 2011; Jongman, et al., 2014; Mokrech, et al., 2015; Rojas, et al., 2013)).

Notwithstanding the large projects on the (methodologies for the) assessments of ecosystem services and attempts to quantify them in a global context like the (Millennium Ecosystem Assessment 2003) (MA) ([16]) or the economics of ecosystems and biodiversity (TEEB) (UNEP 2010) or - on a European scale - in the Mapping and Assessment of Ecosystems and their Services (MAES) (EC 2013f, 2014e), specific data to underpin the economic justification of measures, including benefits from ESs, aren’t always available. The same can be said about green infrastructures (GI), where the need for better data is identified (EC 2013c) to promote GI solutions in spatial planning and flood protection infrastructure decision-making processes.

[15] For more data sets, see http://www.eea.europa.eu/data-and-maps/ online
[16] See for an overview of reports http://www.millenniumassessment.org/en/Reports.html# online

The remaining data gaps must not divert attention from the fact that more and more data are available. Although not generated or assessed specifically for nature based flood protection measures, they are very useful, especially at project level. As with measures to adapt to climate change, most of the flood protection measures based on working with natural processes or natural water retention measures are low-regret measures. The missing information must not therefore prevent projects from being implemented. Better fit for purpose information in the future can be expected from the reporting under the floods directive as well as a further integration of management plans on water and nature and beyond (including sectors like spatial planning, agriculture, tourism etc.). Nevertheless, to achieve high effectiveness and efficiency from natural water retention measures, beneficial for flood risk management, water management and nature conservation an assessment based on all information available on catchment or river basin district scale remains necessary.

4.3.2 Knowledge and methodology

It remains difficult to quantify, not to speak about monetarize, all the costs and benefits related to Natural Water Retention Measures, including the opportunity costs like lost yields, required resources, time to implementation or maintenance costs. This constitutes a barrier for financing and thus implementation (EC, 2015b, 2015d).

Where the idea of NWRMs and GI as an essential contribution to sustainable flood risk management gets more and more common, there is still a way to go to select it as the primary choice for implementation. This is related to the uncertainty of costs and benefits over a longer time, but also because uncertainty on maximising the benefits for all economic sectors. A single goals solution has less of these uncertainties, but at the same time almost ever delivers the same potential for ESs and other co-benefits.

The lack of reported data on environmental flood impacts may partially be attributed to knowledge gaps in the underlying mechanisms. The guidance documents for reporting under the floods directive (EC 2013a) require an update and explanation to have replies more comparable throughout Europe restressing the link with the WFD and making the link to nature policies more obvious.

The impact of socio-economic developments on future flood losses is large. The question is if these developments will be adequately accounted for in the FRMPs.

Where the Sendai declaration on DRR (UN 2015) talks about improving (environmental) resilience, the focus is on damage and impact reduction of extreme events. Both DRR and FRM more and more look at the whole risk management cycle (see introduction chapter 4); but where a sustainable flood risk management incorporates co-benefits and the maintenance or elaboration of ESs, this topic is largely absent in the DRR community. .

4.3.3 Policies

As stated in the water Blueprint (EC 2012c) there remains a need for a better implementation of water policies and mainstreaming the water policy objectives into other policies. In a report for the European Parliament it is stated that, especially with regard to floodplain restoration, the implementation of measures is hindered by a lack of effective tools to design the most cost-efficient measures (Zandstra, 2015). The delayed floodplain restoration across Europe leads to a cost that can be avoided by better implementation of legislation of over 15 billion Euros per year (Zandstra, 2015).

Where water quality and pollution issues are dealt with in many European policies, like WFD, but also UWWTD, DWD, BWD IPPC or SEVESO, quantitative management of water in general requires an unanimous decision of the European Council according to the EU treaty (EU 2012a). The revised CAP includes water use measures, but the decision to add the WFD to the list of issues for cross-compliance was postponed.

Floodplains are under pressure from activities like urban settlement, infrastructure works or agricultural developments, both existing and further developing. Spatial planning instruments linking flood risk management to agricultural practices and urban development are lacking or not enforced. The lack of coherence between sector-specific and water policies is hindering an effective achievement of water policy goals an integrated management of floodplain areas where ESs are maximized.

There is not only a role for EU policies, in domains like agriculture, energy or navigation to better coordinate with water policies. A (potential) role can also be seen for financial instruments like the Cohesion Funds when implementing measures relevant for flood risk management and with consequences for the spatial configuration and connectivity of the floodplain. Many planning processes are not steered from an EU-level, but are national or local regulations and policies. The coordination during the implementation of measures can only be framed on a European level (e.g. by imposing stakeholder involvement or cross-compliance) but have to be implemented on a catchment level.

5 Conclusions

“*More than any other environmental hazard, floods bring benefits as well as losses*” (Smith, 1996).

Floods serve as ecological ‘reset’ buttons because of the drastic way they alter the landscape. Considerable volumes of sediment are moved during flood events: eroded from soils on the banks, sorted and transported sediments from the bed and deposited in floodplains and other areas where the flow velocity is low. These sedimentation processes serve to create and rejuvenate habitats.

Where flooding as such is beneficial for the environment, hard/grey flood protection measures to safeguard industries, infrastructure, settlements and agricultural land often have a negative impact on the environment. In this regard, the floods directive differs from the WFD and BHDs, where measures have a primary focus on improving the environment; some flood protection measures have a negative impact on the quality and amount of ecosystem services provided. NWRMs and other nature-based solutions must bring the necessary flood protection and maintain, restore and improve the ESs delivered by the river and floodplains. However, this will not be possible everywhere and in the neighbourhood of cities, power plants, infrastructure and industries hard flood defences will remain necessary in the interest of the community. There is no binary switch in between grey and green infrastructure, so even when flood defences protecting against the extremes are seen as a societal necessity the idea of *greening the grey* can be adopted to maintain protection with minimal loss of habitat and ESs.

5.1 Data on floods and floodplains

At first glance, many data on floods and flooding are available throughout Europe, especially on the flood hazard. Water levels, discharges, flooded areas are better known and more easily comparable than the impacts of flooding. A hydrological analysis of interdepence and correlation of floods in adjacent groups of river basins will support the incorporation of the EU dimension in the estimates and impacts of floods. The catchment approach has proved useful but has its limitations when larger-scale processes become important, as is most obvious for climate change (Merz, et al., 2014).

Quantitative information on the impacts of flooding, being it fatalities, affected people or (direct) economic damages is much more difficult to have available on a European scale. Not to speak about impacts on cultural heritage or the environment, where the reporting for the PFRA (EU 2007, Art. 4) showed large gaps across Europe. Further development of the database on past floods (EFID), filling gaps and enhancing homogeneity of data by additional guidance on definitions and reporting, will promote the use and increase usability of the data.

Data can also be generated by computer modelling. Modelling exercises for Europe (Ciscar, et al., 2014; Dankers, et al., 2008; Rojas, et al., 2013) have the advantage of a more homogeneous methodology used across Europe to increase the comparability of results compared to natural map inventories, but lack in information on remaining and former floodplains, actual flood protection standards and on the actual technical state of flood protection infrastructure. This level of detail is needed when monitoring and evaluating the status, impact and effectiveness of adaptation efforts (EC 2013b). Research into the underlying mechanisms of flooding (e.g. advective versus convective precipitation, snowmelt versus rain), to improve future projections of flood frequencies, timing and depths and thus be helpful in estimating the effects of flooding on the environmental quality remains recommended (Merz, et al., 2014). Comparing this information with information on damages and impacts from floods contributes to our knowledge on adaptation and the effectiveness of NWRM measures. Where the data on European level aim at showing an overview picture, based on more or less homogeneous data, this hotspot analysis is not there to compete with detailed mapping on national level, being the one needed for detailed catchment scale assessments and the implementation of measures.

The reporting by the EU Member States on past floods, as well as the voluntary exercise organised by EEA ([17]) has resulted in a valuable database at EU level and detailed information at member state and basin level, available for the public (link to final version of EFID database). There's a learning process related to the implementation of the FD and some elements in the reporting need further clarification in the next reporting cycle, but there definitely is a concerted action and more consistent and detailed outcomes can be expected in future. The next round of reporting will benefit from additional guidelines to further harmonise the approaches across the EU. Based on the draft FRMPs (WRc 2015), a preliminary conclusion is that the international coordination requires additional efforts.

5.2 Floodplains in Europe

Large parts (up to 80 or even 90 %) of the previously intermittently inundated lands next to rivers are nowadays disconnected from the river channel and do not act as active floodplains any longer. Main pressures are the economic developments in the low-lying areas, the regulation of water levels, and loss of connectivity due to flood protection measures.

Land use changes from natural, mainly forested, vegetation into agriculture, housing development and industries turn irregular but rather frequent inundations into undesired phenomena because of the economic damage caused. When at the same time the water level is regulated for navigation or hydropower and areas are protected by hard flood protection measures, the remaining active floodplains are inundated with higher water levels. Nevertheless, remaining floodplains are biodiversity hotspots and play a key role in sustainable flood risk management as these are the locations where NWRMs can be implemented most efficient and effective.

NWRMs will especially be beneficial for smaller flood events. As these happen more regularly, they still contribute significantly to the reduction of flood risk. In addition, their capacity to maintain and improve a multitude ESs should be taken into account when making a societal-environmental cost-benefit analysis, as well as their role in climate change adaptation (and mitigation as CO_2 and CH_4 sinks).

The uncertainties about their effectiveness, especially during extreme flood events, and the variety of beneficiaries make it hard to make the step from 'in principle agreeing' on NWRMs towards their implementation. Examples of good practice and successful projects can be shared but one of the characteristics is their context dependency making any case different. Stakeholder involvement however is a key for all of them. Where working with nature is impossible due to the socio-economic values to be preserved, the alternative must not always be the classical hard engineering infrastructure. By 'greening the grey' and making a network of green infrastructures the necessary protection levels are combined with a minimum loss of habitat and preserving the remaining ESs to the extent possible.

5.3 Coordination of flood risk management with adjacent policy fields

Many efforts have already been devoted to the coordination of different policy instruments at the European, national and local level within the water area and with other policy fields. Nevertheless, there's room for further improvement, mainly by better implementation (EC 2012c). A common definition of goals and objectives from the initiating of projects onwards and with the active

---

[17] See http://forum.eionet.europa.eu/nrc-eionet-freshwater/library/country-review-european-floods-impact-database-2015 online for details

involvement of stakeholders (EEA 2014e) makes the potential synergies in between activities competing for and on the same area visible and creates opportunities for innovative financing and a governance model that combines socio-economic with environmental goals.

The interlinkages between the FD, WFD, BHDs and CAP take place (amongst others) through measures that modify land use, e.g. by afforestation or by frequently storing excess precipitation. An improved hydrological modelling at catchment scale could reduce the uncertainty about the effectiveness of separate small-scale measures. Subsequently, linking many small-scale measures together to make a real impact on flood risk management requires long-term and deliberate spatial planning.

A fully integrated approach between policies considered in this report would require a nexus approach. Elements to be implemented on the short term could be the adoption of a harmonized set of scenarios for climate change and socio-economic development, procedures for using them, and early identification of the effects of planned land use change on hydrology and flood risk management. The latter could be implemented by adding a ‘hydrological paragraph’ to the SEA and EIA.

Interlinkages between topics and policies

There are strong interlinkages between the FD and the WFD, both in procedures and in the programmes of measures, but further improvements in the integration are possible at different levels. At the level of measure implementation, the integration is realised due to the stakeholder participation, but at national and EU-level the directives are seen separated. The interlinkages between the FD and the BHDs are to be found in a limited number of procedural arrangements, and in field measures that contribute to water retention while protecting environmental values. The effectiveness of these measures is known in theory but may differ depending on field conditions and lack of monitoring. The scale of the measures as compared to the scale of the catchment or floodplain is an important factor.

For the interlinkages between the FD and CAP, the interlinkages are in most cases secondary as compared to WFD and BHDs. Natural Water Retention Measures (NWRMs) offer an opportunity to support water, nature and agriculture policies. The assessment of the effectivity of these measures for flood risk management requires dedicated hydrological studies. There is no 'one size fits all' solution. A recent development in the hydropower sector is the recognition of the role that dams can have in flood risk management. This offers opportunities that in an integrated approach may lead to changes in dam management.

Spatial planning is not subject to EU regulation, except at sea under the MSPFD (EU 2014b). However, without spatial planning and effective enforcement, many types of measures will be excluded as a result of socio-economic developments, because the necessary room will simply be occupied by competing uses.

Working with natural processes

The implementation of measures is where of all the above comes together. Bottlenecks that were identified in the implementation of Green rather than Grey Infrastructure are:

- technical: strength of green infra for flood protection; hydrological effectiveness of NWRM, in short and long term;
- economic/financial: underpinning of cost-effectiveness and cost-efficiency of measures ; and
- governance and practical guidelines for implementation.

A wide variety of structural (where infrastructure is build) and non-structural measures is at hand and could be applied when implementing the FD. Emerging knowledge and technologies should be applied. NWRMs aim to maintain and improve ESs and are part of a wider group of measures working with natural processes. Measures working with natural processes are not only applied along rivers and in floodplains but also in an urban context (e.g. green roofs or rain gardens) or in coastal areas. Here an example of a measure working with natural processes but not aiming to increase retention is the ‘sand motor’ (or sand engine): an innovative way of coast protection and maintenance. Wind, waves and currents will spread the sand naturally along the coast and nature is used to build and maintain natural coastal defences.

Ecosystem-based adaptation and green infrastructure are in many cases key part of a cost-effective way to deal with scenario uncertainty by delaying or avoiding lock-in to classical infrastructure-building water management to provide safety while providing manifold co-benefits for the environment (e.g. environmental objectives of the WFD) and the different water-using sectors (EEA 2012b; OECD 2013). To overcome the bottlenecks for the implementation of measures working with natural processes, the flexibility of the measures needs to be mentioned. These measures, contrary to most hard defences and engineering works can be adapted with progressive insights. Even when each case is unique and other pressures and key stakeholders are involved, there are many lessons to learn from projects already implemented. Therefore, additional guidelines and examples of successes and failures are recommended.

An appropriate role for inherent uncertainties

Actual flood risk management is surrounded by a multitude of uncertainties. Changes in flood regimes (mean annual discharges, maximum discharges, and their timing) show a mixed pattern across Europe. However, even in those cases where a trend in flow regime is visible, it is difficult to separate a potential climate change signal from other drivers of change (land use, infrastructure). There are indications that the increase in reported flood damage should mainly be attributed to economic development as well as to better reporting, and that an increased flood frequency because of climate change remains uncertain. Nevertheless, climate change deserves priority, because the lead-time for measures to adapt is often very long. Scenarios and foresight studies are recommended as tools. Scenarios must differ by the main uncertainties, and the uncertainties communicated in a suitable way (Hall, et al., 2014).

Sustainable solutions look beyond the protection of flood risk management measures, but link it to the overlapping areas of vulnerability, environmental quality and the delivery of ESs. Driving forces and pressures, like socio-economic and political developments on all scales (from local to European and global) can only be estimated with a certain level of detail. This has implications for land use, protection of floodplains, or the available funding.

Guiding principles for next steps in flood risk management

Flood risk management, linking economic, social, environmental and cultural aspects, will have to be based on social-environmental cost-benefit approaches, balancing the needs of the environmental and the sustainability of ESs with the needs of a multitude of sectors. Whatever the names used: NWRMs, building with nature, room for the river, green measures etc., working with natural processes is a key process to maximize the common goals and objectives of water management, economic development, nature conservation and ESs. These objectives start from an integrated approach on RBD level, requiring improved reporting and implementation practices under the FD to make the hotspot analysis and European overview.

In a following step, the European and RBD-level overview has to be translated into national flood risk objectives.

Notwithstanding the different context in countries, the discussion on sustainable flood risk management seems, judging from the evidence presented in this report, to converge on the ambition to apply the following principles underlying the choice of measures:

- Consider cost-effective investments as part of a system at appropriate scale(s) (OECD 2015);
- Go beyond the economic benefits and include environmental and societal benefits in the assessment of (programmes of) measures (EU 2007, Art. 7 §3);
- Use the framework of Ecosystem Services to identify societal costs and benefits of measures (COWI 2014);
- Use the principles of nature-based solutions to identify infrastructural measures in order to serve multiple purposes;
- Use Green Infrastructure and Natural Water Retention Measures where possible, but combine them with more traditional types of measures where needed;
- Minimise investment needs; this supports the adaptive capacity of water managers and reduces the chances of lock-in situations (OECD 2015);
- Avoid building unnecessary future liabilities, apply adaptive management approaches where feasible;
- Identify the weakest links. This may for instance imply that before technical measures are designed in great detail, efforts should be directed towards improving governance arrangements.

[to be complemented with roles of different stakeholders to make the cross-cutting approaches work: role of national, local authorities, role of stakeholders, role of private sector including the insurance industry etc. Good examples, preferably applicable on a large part of Europe are welcomed during the consultation period]

References

Aakre, S. and Rübbelke, D. T. G., 2010, 'Adaptation to climate change in the European union: efficiency versus equity considerations', *Environmental Policy and Governance* 20(3), 159–179 (DOI: 10.1002/eet.538).

Aarts, B. G. W., Van Den Brink, F. W. B. and Nienhuis, P. H., 2004, 'Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: the transversal floodplain gradient', *River Research and Applications* 20(1), 3–23 (DOI: 10.1002/rra.720).

Acreman, M. C., Blake, J. R., Booker, D. J., Harding, R. J., Reynard, N., Mountford, J. O. and Stratford, C. J., 2009, 'A simple framework for evaluating regional wetland ecohydrological response to climate change with case studies from Great Britain', *Ecohydrology* 2(1), 1–17 (DOI: 10.1002/eco.37).

Acreman, M. C., Harding, R. J., Lloyd, C., McNamara, N. P., Mountford, J. O., Mould, D. J., Purse, B. V., Heard, M. S., Stratford, C. J. and Dury, S. J., 2011, 'Trade-off in ecosystem services of the Somerset Levels and Moors wetlands', *Hydrological Sciences Journal* 56(8), 1543–1565 (DOI: 10.1080/02626667.2011.629783).

Amoros, C. and Bornette, G., 2002, 'Connectivity and biocomplexity in waterbodies of riverine floodplains', *Freshwater Biology* 47(4), 761–776 (DOI: 10.1046/j.1365-2427.2002.00905.x).

Antrop, M., Brandt, J., Loupa-Ramos, I., Padoa-Schioppa, E., Porter, J., Van Eetvelde, V. and Pinto-Correia, T., 2013, 'How landscape ecology can promote the development of sustainable landscapes in Europe: the role of the European Association for Landscape Ecology (IALE-Europe) in the twenty-first century', *Landscape Ecology* 28(9), 1641–1647 (DOI: 10.1007/s10980-013-9914-9).

ARUP, 2011, *Analysis of How Land Use Planning Decisions Affect Vulnerability to Climate Risks - Final Report*, Adaptation Sub-Committee of the Committee on Climate Change, London.

Balon, E. and Holčík, J., 1999, 'Gabčíkovo River Barrage System: The Ecological Disaster and Economic Calamity for the Inland Delta of the Middle Danube', *Environmental Biology of Fishes* 54(1), 1–17 (DOI: 10.1023/A:1007576103855).

Bastian, O., Grunewald, K. and Syrbe, R.-U., 2012, 'Space and time aspects of ecosystem services, using the example of the EU Water Framework Directive', *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(1-2), 5–16 (DOI: 10.1080/21513732.2011.631941).

Bateman, I. J., Harwood, A. R., Mace, G. M., Watson, R. T., Abson, D. J., Andrews, B., Binner, A., Crowe, A., Day, B. H., Dugdale, S., Fezzi, C., Foden, J., Hadley, D., Haines-Young, R., Hulme, M., Kontoleon, A., Lovett, A. A., Munday, P., Pascual, U. et al., 2013, 'Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom', *Science* 341(6141), 45–50 (DOI: 10.1126/science.1234379).

Bertoldi, W., Gurnell, A., Surian, N., Tockner, K., Zanoni, L., Ziliani, L. and Zolezzi, G., 2009, 'Understanding reference processes: linkages between river flows, sediment dynamics and vegetated landforms along the Tagliamento River, Italy', *River Research and Applications* 25(5), 501–516 (DOI: 10.1002/rra.1233).

BfG, 2013, *Länderübergreifende Analyse des Juni-Hochwassers 2013*, Bericht BfG-1797, Koblenz.

Blackbourn, D., 2007, *The conquest of nature: water, landscape and the making of modern Germany*, Pimlico, Pimlico, London.

BMLFUW, 2012, *Österreichischer Wasserkatalog Wasser schützen – Wasser nutzen: Kriterien zur Beurteilung einer nachhaltigen Wasserkraftnutzung*, BMLFUW-UW.4.1.2/0004-I/4/2012, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, Austria.

BMU and BfN, 2009, *Auenzustandsbericht Flussauen in Deutschland*, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit and Bundesamt für Naturschutz, Berlin, Bonn.

Borchers, T., 2014, 'Linkages between NWRM and relevant EU directives/policies', presentation given at: Pilot Project on Natural Water Retention Measures 2nd Regional Workshop (Western Network), 1-2 July 2014, Strasburg, 1 July 2014.

Botzen, W. J. W., van den Bergh, J. C. J. M. and Bouwer, L. M., 2010, 'Climate change and increased risk for the insurance sector: a global perspective and an assessment for the Netherlands', *Natural Hazards* 52(3), 577–598 (DOI: 10.1007/s11069-009-9404-1).

Brakenridge, G. R., 2015, 'Global Active Archive of Large Flood Events' (http://floodobservatory.colorado.edu/Archives/index.html) accessed 18 August 2015.

Bravard, J.-P., 2002, 'Les réponses des systèmes fluviaux à une réduction des flux d’eau et de sédiments sous l’effet du reboisement en montagne', *La Houille Blanche* (3), 68–71 (DOI: 10.1051/lhb/2002046).

Brunotte, E., Amberge, P., Günther-Diringer, D., Koenzen, U. and Mehl, D. (eds), 2009, *Flussauen in Deutschland: Erfassung und Bewertung des Auenzustandes*, Naturschutz und biologische Vielfalt, Bundesamt für Naturschutz, Bonn-Bad Godesberg.

Buckle, S., 2015, 'Water policy in the context of Green and Blue Growth: an OECD Perspective', presentation given at: 4th European Water Conference, Brussels, 24 March 2015.

Burkhard, B., Crossman, N., Nedkov, S., Petz, K. and Alkemade, R., 2013, 'Mapping and modelling ecosystem services for science, policy and practice', *Ecosystem Services* 4, 1–3 (DOI: 10.1016/j.ecoser.2013.04.005).

Capon, S. J., Chambers, L. E., Mac Nally, R., Naiman, R. J., Davies, P., Marshall, N., Pittock, J., Reid, M., Capon, T., Douglas, M., Catford, J., Baldwin, D. S., Stewardson, M., Roberts, J., Parsons, M. and Williams, S. E., 2013, 'Riparian Ecosystems in the 21st Century: Hotspots for Climate Change Adaptation?', *Ecosystems* 16(3), 359–381 (DOI: 10.1007/s10021-013-9656-1).

Ciscar, J. C., Feyen, L., Soria, A., Lavalle, C., Raes, F., Perry, M., Nemry, F., Demirel, H., Rozsai, M., Dosio, A., Donatelli, M., Srivastava, A., Fumagalli, D., Niemeyer, S., Shrestha, S., Ciaian, P., Himics, M., Van Doorslaer, B., Barrios, S. et al., 2014, *Climate Impacts in Europe: The JRC PESETA II Project*, JRC Scientific and Policy Reports EUR 26586 EN, JRC87011, European Commission – Joint Research Centre Institute for Prospective Technological Studies, Institute for Environment and Sustainability.

Ciscar, J.-C., Iglesias, A., Feyen, L., Szabo, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O. B., Dankers, R., Garrote, L., Goodess, C. M., Hunt, A., Moreno, A., Richards, J. and Soria, A., 2011, 'Physical and economic consequences of climate change in Europe', *Proceedings of the National Academy of Sciences* 108(7), 2678–2683 (DOI: 10.1073/pnas.1011612108).

Clerici, N., Weissteiner, C. J., Paracchini, L. M. and Strobl, P., 2011, *Riparian zones: where green and blue networks meet : pan-European zonation modelling based on remote sensing and GIS.*, JRC Scientific and Technical Reports, European Commission - Joint Research Centre: Institute for Environment and Sustainability, Ispra.

Clerici, N., Weissteiner, C. J., Paracchini, M. L., Boschetti, L., Baraldi, A. and Strobl, P., 2013, 'Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data', *Ecological Indicators* 24, 211–223 (DOI: 10.1016/j.ecolind.2012.06.002).

Copernicus Land Monitoring Services, 2015, 'Wetlands' (http://land.copernicus.eu/pan-european/high-resolution-layers/wetlands) accessed 6 August 2015.

COWI, 2014, *Support Policy Development for Integration of Ecosystem Service Assessments into WFD and FD Implementation*, Resource document 08/ contract 070307/2012/637505/D1, COWI A/S in cooperation with DHI and ARUP, Copenhagen.

Craft, C. B. and Casey, W. P., 2000, 'Sediment and nutrient accumulation in floodplain and depressional freshwater wetlands of Georgia, USA', *Wetlands* 20(2), 323–332 (DOI: 10.1672/0277-5212(2000)020[0323:SANAIF]2.0.CO;2).

Dankers, R. and Feyen, L., 2008, 'Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations', *Journal of Geophysical Research* 113, D19105 (DOI: 10.1029/2007JD009719).

Despotovic, J., 2015, 'Floods in the Sava River Basin in May 2014', presentation given at: EEA Expert Workshop: “Environmental effect of floods and flood protection measures, 28-29 May 2015, Copenhagen, 28 May 2015.

Dufour, S., Provansal, M. and Raccasi, G., 2008, 'Can flood risk management restore eco-geomorphologic functioning of fluvial margins along the lower Rhône river (France, SE)?', conference paper presented at: International Conference on River Restoration. 4., 16-19 Jun 2008, Venice, Italy, 2008.

EC, 2003, *Common Implementation Strategy for the Water Framework Directive (2000/60/EC) Guidance document - No. 2 Identification of Water Bodies*, European Commission - Directorate General Environment, Luxembourg.

EC, 2008, *Management models for habitats in Natura 2000 Sites. 6440 Alluvial meadows of river valleys of the Cnidion dubii*, European Commission, Brussels.

EC, 2009, *Common Implementation Strategy for the Water Framework Directive (2000/60/EC): river basin management in a changing climate (Guidance document No 24).*, European Commission - Directorate-General for the Environment, Brussels.

EC, 2011a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Our life insurance, our natural capital: an EU biodiversity strategy to 2020, COM (2011) 244 final, Brussels, 03.05.2011.

EC, 2011b, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Regional policy contributing to sustainable growth in Europe 2020, COM(2011) 17 final, Brussels, 26.01.2011.

EC, 2011c, *Links between the Water Framework directive and Nature Directives: Frequently Asked Questions*, European Commission Directorate General Environment, Brussels.

EC, 2011d, Note by DG Environment: Towards Better Environmental Options for Flood risk management, DG ENV D.1 (2011) 236452, Brussels, 08.03.2011.

EC, 2011e, White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, COM(2011) 144 final, Brussels, 28.03.2011.

EC, 2012, Commission Staff Working document European Overview (2/2) Accompanying the document Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC) River Basin Management Plans, SWD(2012) 379 final, Brussels, 14.11.2012.

EC, 2012a, Commission Staff Working Document Executive Summary of the Impact Assessment Accompanying the document 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Blueprint to Safeguard Europe's Water Resources', SWD(2012) 381 final/2, Brussels, 13.12.2012.

EC, 2012b, Commission Staff Working Document Impact Assessment Accompanying the document 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Blueprint to Safeguard Europe's Water Resources', SWD(2012) 382 final/2, Brussels, 13.12.2012.

EC, 2012c, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Blueprint to Safeguard Europe's Water Resources, COM (2012) 673 final, Brussels, 14.11.2012.

EC, 2012d, *Guidance document on Inland waterway transport and Natura 2000 Sustainable inland waterway development and management in the context of the EU Birds and Habitats Directives*, European Commission Directorate General Environment, Brussels.

EC, 2013a, *A compilation of reporting sheets adopted by water directors common implementation strategy for the Water Framework Directive (2000/60/EC) Guidance document No 29.*, European Commission, Brussels.

EC, 2013b, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - An EU Strategy on adaptation to climate change, COM(2013) 216 final, Brussels, 16.04.2013.

EC, 2013c, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Green Infrastructure (GI) — Enhancing Europe's Natural Capital, COM(2013) 249 final, Brussels, 06.05.2013.

EC, 2013d, Green paper on the insurance of natural and man-made disasters, COM (2013) 213 final, Brussels, 16.04.2013.

EC, 2013e, *Guidelines on climate change and Natura 2000 dealing with the impact of climate change, on the management of the Natura 2000 network of areas of high biodiversity value.*, European Commission - Directorate-General for the Environment, Brussels.

EC, 2013f, *Mapping and Assessment of Ecosystems and their Services:: An analytical framework for ecosystem assessment under Action 5 of the EU Biodiversity Strategy to 2020*, European Commission - Directorate General Environment, Brussels.

EC, 2014a, *A guide to support the selection, design and implementationof Natural Water Retention Measures in Europe:: Capturing the multiple benefits of nature-based solutions,* European Commission Directorate General for Environment, Brussels.

EC, 2014b, 'Commission joins forces with European cities to promote urban adaptation to climate change - European Commission' (http://ec.europa.eu/clima/news/articles/news_2014031901_en.htm) accessed 27 August 2015.

EC, 2014c, *EU policy document on natural water retention measures by the drafting team of the WFD CIS Working Group Programme of Measures (WG PoM)*, European Commission - Directorate-General for the Environment, Brussels.

EC, 2014d, *Links between the Floods Directive (FD 2007/60/EC) and Water Framework Directive (WFD 2000/60/EC) resource document*, European Commission - Directorate General Environment, Brussels.

EC, 2014e, *Mapping and Assessment of Ecosystems and their Services:: Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020*, European Commission - Directorate General Environment, Brussels.

EC, 2015a, Commission Staff Working Document - Report on the progress in implementation of the Floods Directive Accompanying the document 'Communication from the Commission to the European Parliament and the Council: The Water Framework Directive and the Floods Directive: Actions towards the "good status" of EU water and to reduce flood risks', SWD (2015) 51 final, Brussels, 9.3.2015.

EC, 2015b, Communication from the Commission to the European Parliament and the Council: The Water Framework Directive and the Floods Directive: Actions towards the "good status" of EU water and to reduce flood risks, COM(2015) 120 final, Brussels, 09.03.2015.

EC, 2015c, *Ecological flows in the implementation of the Water Framework Directive (Guidance Document No. 31)*, European Commission - Directorate-General for the Environment, Brussels.

EC, 2015d, *Interpretation of definitions of project categories of annex I and II of the EIA Directive*, European Commission - Directorate-General for the Environment, Brussels.

EC, 2015a, *Synthesis document n°8 'Windows of opportunities' for Natural Water Retention Measures*, NWRM SD8, European Commission Directorate General Environment and NWRM project team, Brussels.

EC, 2015b, *Synthesis document n°9 Barriers and success factors for Natural Water Retention Measures*, NWRM SD9, European Commission Directorate General Environment and NWRM project team, Brussels.

EC, 2015c, *Synthesis document n°10 Policy coordination linked to Natural Water Retention Measures: Which integration with different European Directives*, NWRM SD10, European Commission Directorate General Environment and NWRM project team, Brussels.

EC, 2015d, *Synthesis document n°11 Financing NWRM - How can NWRM be financed?*, NWRM SD11, European Commission Directorate General Environment and NWRM project team, Brussels.

EC and EEA, 1995, *CORINE land cover Technical Guide*, European Commission Directorate General Joint Research Centre and European Environment Agency.

EEA, 2011, *Mapping the impacts of natural hazards and technological accidents in Europe*, Technical report 13/2010, European Environment Agency, Copenhagen.

EEA, 2012a, *Climate change, impacts and vulnerability in Europe - An indicator-based report*, European Environment Agency, Copenhagen, Denmark.

EEA, 2012a, 'Damages from weather and climate-related events (CLIM 039)' (http://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-1/assessment) accessed 13 August 2015.

EEA, 2012b, *EEA Water 2012 Report: European waters — assessment of status and pressures*, European Environment Agency, Copenhagen, Denmark.

EEA, 2012c, *Europe's water resources: Current Status and Future Challenges: Synthesis*, EEA Report 9/2012, European Environment Agency, Copenhagen, Denmark.

EEA, 2012b, *Towards efficient use of water resources in Europe*, EEA Report 1/2012, European Environment Agency, Copenhagen.

EEA, 2012c, *Water resources in Europe in the context of vulnerability: EEA 2012 state of water assessment*, EEA Report 11/2012, European Environment Agency, Copenhagen.

EEA, 2014a, 'Corine Land Cover 2000 - 2006 changes' (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-3) accessed 17 August 2015.

EEA, 2014b, 'Corine Land Cover 2006 seamless vector data' (http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-3) accessed 17 August 2015.

EEA, 2014c, *National adaptation policy processes in European countries - 2014.*, Publication 4/2014, European Environment Agency, Copenhagen.

EEA, 2014d, 'Nationally designated areas (CDDA)' (http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-9) accessed 17 August 2015.

EEA, 2014e, *Public participation, contributing to better water management experiences from eight case studies across Europe*, Publication 3/2014, European Environment Agency, Copenhagen.

EEA, 2014f, 'River Mur recognised for effective river basin management' (http://www.eea.europa.eu/highlights/river-mur-recognised-for-effective) accessed 28 August 2015.

EEA, 2015a, 'Freshwater quality' (http://www.eea.europa.eu/soer-2015/europe/freshwater) accessed 11 August 2015.

EEA, 2015b, 'Natura 2000 data - the European network of protected sites' (http://www.eea.europa.eu/data-and-maps/data/natura-6) accessed 17 August 2015.

EEA, 2015c, 'Natural capital and ecosystem services' (http://www.eea.europa.eu/soer-2015/europe/natural-capital-and-ecosystem-services) accessed 24 August 2015.

EEA, 2015d, *State of nature in the EU: Results from reporting under the nature directives 2007–2012,* EEA Technical Report 2/2015, European Environment Agency, Copenhagen.

EEA, 2015e, *The European environment — state and outlook 2015: Synthesis report*, State of the environment report, European Environment Agency, Copenhagen, Denmark.

EEA and ETC/ICM, 2015, 'Final minutes', conference paper presented at: Environmental effect of floods and flood protection measures, Copenhagen, 28 May 2015.

van Eerd, M. (M. C. J. ., Dieperink, C. and Wiering, M. (M. A. ., 2015, '‘A dive into floods’: exploring the Dutch implementation of the floods directive', *Water Policy* 17(2), 187 (DOI: 10.2166/wp.2014.025).

EM-DAT, 2015, 'The International Disaster Database' (http://www.emdat.be/) accessed 18 August 2015.

EP, 2014, European Parliament resolution of 5 February 2014 on the insurance of natural and man-made disasters, 2013/2174 (INI), Strasbourg, 05.02.2014.

ETC/ICM, 2015, *Flood phenomena database – structure and assessment*, European Topic Centre on Inland, Coastal and Marine Water, Magdeburg.

EU, 1991, Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC), OJ L135, 30.05.91, p. 40-52.

EU, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, OJ L206, 22.07.1992, p. 7-50.

EU, 1998, Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

EU, 2000, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L327, 22.12.2000, p. 1-73.

EU, 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, OJ L 197, 21.07.2001, p.30-37.

EU, 2007, Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, OJ L288, 06.11.2007, p.27-34.

EU, 2009, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, OJ L 140, 5.6.2009, p. 16–62.

EU, 2010, Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version), OJ L20, 26.01.2010, p. 7-25.

EU, 2012a, Consolidated version of the Treaty on the Functioning of the European Union, OJ C 326, 26.10.2012, p. 47–390.

EU, 2012b, Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment, OJ L 26, 28.01.2012, p. 1–21.

EU, 2012c, Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC, OJ L 197, 24.7.2012, p. 1–37.

EU, 2013a, Interinstitutional Agreement of 2 December 2013 between the European Parliament, the Council and the Commission on budgetary discipline, on cooperation in budgetary matters and on sound financial management, OJ C373, 02.12.2013, p. 1-11.

EU, 2013b, Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 december 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005, OJ L347, 20.12.2013, p. 487-548.

EU, 2014a, Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment, OJ L 124, 25.04.2014, p. 1–18.

EU, 2014b, Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning, OJ L 257, 28.08.2014, p. 135–145.

Evers, M. and Nyberg, L., 2013, 'Coherence and inconsistency of European instruments for integrated river basin management', *International Journal of River Basin Management* 11(2), 139–152 (DOI: 10.1080/15715124.2013.811416).

FOCP, s.d., 'PLANAT National Platform for Natural Hazards - Information platform on natural hazards in Switzerland :What has to be done?' (http://www.planat.ch/en/specialists/risk-management/what-has-to-be-done/) accessed 1 September 2015.

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 CRUE Research Report No I-6, CRUE Flooding ERA-NET.

Fresh Thoughts Consulting, 2014, '2014-2020 Rural Development Plans - Opportunities for Flood Management', presentation given at: 16th meeting of the Working Group on Floods, Rome, 9 October 2014.

Frohne, T., Diaz-Bone, R. A., Laing, G. Du and Rinklebe, J., 2015, 'Impact of systematic change of redox potential on the leaching of Ba, Cr, Sr, and V from a riverine soil into water', *Journal of Soils and Sediments* 15(3), 623–633 (DOI: 10.1007/s11368-014-1036-8).

Gautier, E., Corbonnois, J., Petit, F., Arnaud-Fassetta, G., Brunstein, D., Grivel, S., Houbrechts, G. and Beck, T., 2009, 'Multi-disciplinary approach for sediment dynamics study of active floodplains', *Géomorphologie : relief, processus, environnement* (1/2009) (DOI: 10.4000/geomorphologie.7506).

Gierk, M., 2013, 'Flood Event June 2013 Germany', presentation given at: 14th meeting of the Working Group on Floods, Brussels, 17 October 2013.

Glaeser, J. and Wulf, M., 2009, 'Effects of water regime and habitat continuity on the plant species composition of floodplain forests', *Journal of Vegetation Science* 20(1), 37–48 (DOI: 10.1111/j.1654-1103.2009.05282.x).

Globevnik, L. and Mikoš, M., 2009, 'Boundary conditions of morphodynamic processes in the Mura River in Slovenia', *CATENA* 79(3), 265–276 (DOI: 10.1016/j.catena.2009.06.008).

Głosińska, E., 2014, 'Implementation of Flood Directive in Poland in the context of floodplain development', *Quaestiones Geographicae* 33(1) (DOI: 10.2478/quageo-2014-0002).

De Groeve, T., Poljansek, K. and Ehrlich, D., 2013, *Recording disaster losses recommendations for a European approach.*, European Commission - Joint Research Centre: Institute for the Protection and the Security of the Citizen, Ispra.

De Groeve, T., Poljansek, K., Ehrlich, D. and Corbane, C., 2014, *Current status and best practices for disaster loss data recording in EU Member States*, European Commission - Joint Research Centre: Institute for the Protection and the Security of the Citizen, Ispra.

Grygoruk, M., Mirosław-Świątek, D., Chrzanowska, W. and Ignar, S., 2013, 'How Much for Water? Economic Assessment and Mapping of Floodplain Water Storage as a Catchment-Scale Ecosystem Service of Wetlands', *Water* 5(4), 1760–1779 (DOI: 10.3390/w5041760).

Hall, J., Arheimer, B., Borga, M., Brázdil, R., Claps, P., Kiss, A., Kjeldsen, T. R., Kriaučiūnienė, J., Kundzewicz, Z. W., Lang, M., Llasat, M. C., Macdonald, N., McIntyre, N., Mediero, L., Merz, B., Merz, R., Molnar, P., Montanari, A., Neuhold, C. et al., 2014, 'Understanding flood regime changes in Europe: a state-of-the-art assessment', *Hydrology and Earth System Sciences* 18(7), 2735–2772 (DOI: 10.5194/hess-18-2735-2014).

Haraszthy, 2001, 'The floodplain forests in Hungary', in: Klimo, E. and Hager, H. (eds), *The floodplain forests in Europe: current situations and perspectives*, European Forest Institute research report, Brill, Leiden ; Boston, pp. 17–24.

Hartmann, T. and Spit, T., 2015, 'Implementing the European flood risk management plan', *Journal of Environmental Planning and Management*, 1–18 (DOI: 10.1080/09640568.2015.1012581).

Hausammann, A., Gsteiger, P., Roulier, C., Righetti, A. and Thielen, R., 2005, *Inventaire des zones alluviales*, Dossier Zones alluviales: fiches Fiche zones alluviales 11:, Office fédéral de l’environnement OFEV, Bern, Switzerland.

Hedelin, B., 2015, 'The EU floods directive in Sweden: opportunities for integrated and participatory flood risk planning: The Floods Directive in Sweden', *Journal of Flood Risk Management*, n/a–n/a (DOI: 10.1111/jfr3.12162).

Heintz, M. D., Hagemeier-Klose, M. and Wagner, K., 2012, 'Towards a Risk Governance Culture in Flood Policy—Findings from the Implementation of the “Floods Directive” in Germany', *Water* 4(4), 135–156 (DOI: 10.3390/w4010135).

Herold, C. and Mouton, F., 2011, 'Global flood hazard mapping using statistical peak flow estimates', *Hydrology and Earth System Sciences Discussions* 8(1), 305–363 (DOI: 10.5194/hessd-8-305-2011).

Hochrainer, S., Linnerooth-Bayer, J. and Mechler, R., 2010a, 'The European Union Solidarity Fund: Its legitimacy, viability and efficiency', *Mitigation and Adaptation Strategies for Global Change* 15(7), 797–810 (DOI: 10.1007/s11027-009-9209-2).

Hochrainer, S., Linnerooth-Bayer, J. and Mechler, R., 2010b, 'The European Union Solidarity Fund - Its legitimacy, viability and efficiency', *Mitig Adapt Strateg Glob Change*.

Hoffmann, C. C., Kjaergaard, C., Uusi-Kämppä, J., Hansen, H. C. B. and Kronvang, B., 2009, 'Phosphorus Retention in Riparian Buffers: Review of Their Efficiency', *Journal of Environment Quality* 38(5), 1942 (DOI: 10.2134/jeq2008.0087).

Hohensinner, S., Habersack, H., Jungwirth, M. and Zauner, G., 2004, 'Reconstruction of the characteristics of a natural alluvial river–floodplain system and hydromorphological changes following human modifications: the Danube River(1812–1991)', *River Research and Applications* 20(1), 25–41 (DOI: 10.1002/rra.719).

Hoogwaterbeschermingsprogramma, 2013, *Projectenboek 2014*, Ministerie van Infrastructuur en Milieu and Unie van Waterschappen, Den Haag.

Hughes, F., Richards, K., Girel, J., Moss, T., Muller, E., Nilsson, C. and Rood, S., 2003, *The Flooded Forest: Guidance for policy makers and river managers in Europe on the restoration of floodplain forests*, FLOBAR2, Department of Geography, University of Cambridge, Cambridge (UK).

ICPDR, 2007, *Development of Inland Navigation and Environmental Protection in the Danube River Basin - Joint Statement on Guiding Principles*, International Commission for the Protection of the Danube River, Vienna, Austria.

ICPDR, 2010, *Manual on Good Practices in Sustainable Waterway Planning*, Platina project, International Commission for the Protection of the Danube River, Vienna, Austria.

ICPDR, 2013, *Sustainable Hydropower Development in the Danube Basin: Guiding Principles*, International Commission for the Protection of the Danube River, Vienna, Austria.

ICPDR, 2014, *Floods in June 2013 in the Danube River Basin: Brief overview of key events and lessons learned*, International Commission for the Protection of the Danube River, Vienna, Austria.

ICPR, 2006, *Nachweis der Wirksamkeit von Maßnahmen zur Minderung der Hochwasserstände im Rhein infolge Umsetzung des Aktionsplans Hochwasser bis 2005*, Abschlussbericht IKSR-Bericht Nr. 153d, International Commission for the Protection of the Rhine, Koblenz.

IEEP, 2013, *Report on the influence of EU policies on the environment*, Institute for European Environmental Policy, London, Brussels.

IPCC, 2000, *Emissions scenarios. a special report of IPCC Working Group III*, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

IPCC, 2012, *Managing the risks of extreme events and disasters to advance climate change adaption: special report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, New York, NY.

IPCC, 2013, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014, *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014, *Climate change 2014: impacts, adaptation, and vulnerability. Part B, Regional aspects*, Cambridge University Press, Cambridge.

Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J. C. J. H., Mechler, R., Botzen, W. J. W., Bouwer, L. M., Pflug, G., Rojas, R. and Ward, P. J., 2014, 'Increasing stress on disaster-risk finance due to large floods', *Nature Climate Change* 4(4), 264–268 (DOI: 10.1038/nclimate2124).

JRC, 2008, 'Catchment Characterisation and Modelling (CCM)' (http://ccm.jrc.ec.europa.eu/php/index.php?action=view&id=23) accessed 1 September 2015.

Kavvadas, I., 2015, 'The Floods Directive Implementation Progress (status: December 2014)', presentation given at: 4th European Water Conference, Brussels, 23 March 2015.

Kjeldsen, T., Wolters, H. and Vanneuville, W., 2013, *Historic flood events in Europe: European case studies based on the reporting under the Floods directive*, ETC/ICM Technical Report, European Topic Centre on Inland, Coastal and Marine Water, Prague.

Klaneček, M., 2013, 'Poplave 5. novembra 2012 v porečju Drave. 5. November floods in the Drava River Basin', *Ujma* 27, 62–61.

Klimo, E. and Hager, H. (eds), 2001, *The floodplain forests in Europe: current situations and perspectives*, European Forest Institute research report, Brill, Leiden ; Boston.

Koenzen, U., 2005, *Fluss- und Stromauen in Deutschland – Typologie und Leitbilder*, Angewandte Landschaftsökologie 65.

Koller-Kreimel, V., 2015, 'Sustainable hydropower development in Austria', presentation given at: JASPERS Networking Platform Workshop on the implementation of the Water Framework Directive in projects, Brussels, 9 June 2015.

Kriegner, C. J., Chiarello, R. P. and Buelow, K. W., 2015, 'Wetland Delineation: Accuracy Is Not Precision', *Journal of Water Resources Planning and Management* 141(7), 02515001 (DOI: 10.1061/(ASCE)WR.1943-5452.0000542).

Langanke, T., 2013, *GIO land (GMES/Copernicus initial operations land) High Resolution Layers (HRLs) – summary of product specifications*, European Environment Agency, Copenhagen.

Lasda, O., Dikou, A. and Papapanagiotou, E., 2010, 'Flash Flooding in Attika, Greece: Climatic Change or Urbanization?', *AMBIO* 39(8), 608–611 (DOI: 10.1007/s13280-010-0050-3).

Lawrence, D. and Hisdal, H., 2011, *Hydrological projections for floods in Norway under a future climate Norwegian*, Norwegian Water Resources and Energy Directorate, Oslo, Norway.

Lawton, R. and Rudd, M., 2013, 'Strange Bedfellows: Ecosystem Services, Conservation Science, and Central Government in the United Kingdom', *Resources* 2(2), 114–127 (DOI: 10.3390/resources2020114).

Lazowski, W. and Schwarz, U., 2014, *Auenland: Das Aueninventar als Grundlage einer österreichweiten Auenstrategie*, Arge Naturschutz and Naturschutzbund, Salzburg.

Leyer, I., 2004, 'Effects of dykes on plant species composition in a large lowland river floodplain', *River Research and Applications* 20(7), 813–827 (DOI: 10.1002/rra.795).

van der Linden, P. and Mitchell, J. F. B., 2009, *ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project.*, Met Office Hadley Centre, Exeter.

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., Grizzetti, B., Drakou, E. G., Notte, A. L., Zulian, G., Bouraoui, F., Luisa Paracchini, M., Braat, L. and Bidoglio, G., 2012, 'Mapping ecosystem services for policy support and decision making in the European Union', *Ecosystem Services* 1(1), 31–39 (DOI: 10.1016/j.ecoser.2012.06.004).

Magdaleno Mas, F., 2011, Evolución hidrogeomorfológica del sector central del río Ebro a lo largo del siglo XX: implicaciones ecológicas para su restauración, Doctoral, E.T.S.I. Montes (UPM), Madrid, Spain.

Mair, R., 2015, 'Inter-sectoral cooperation in the Danube Basin: Joint Statement Inland Navigation and Guiding Principles on Sustainable Hydropower', presentation given at: JASPERS Networking Platform Workshop on the implementation of the Water Framework Directive in projects, Brussels, 9 June 2015.

Matella, M. K. and Jagt, K., 2014, 'Integrative Method for Quantifying Floodplain Habitat', *Journal of Water Resources Planning and Management* 140(8), 06014003 (DOI: 10.1061/(ASCE)WR.1943-5452.0000401).

Merz, B., Aerts, J., Arnbjerg-Nielsen, K., Baldi, M., Becker, A., Bichet, A., Blöschl, G., Bouwer, L. M., Brauer, A., Cioffi, F., Delgado, J. M., Gocht, M., Guzzetti, F., Harrigan, S., Hirschboeck, K., Kilsby, C., Kron, W., Kwon, H.-H., Lall, U. et al., 2014, 'Floods and climate: emerging perspectives for flood risk assessment and management', *Natural Hazards and Earth System Science* 14(7), 1921–1942 (DOI: 10.5194/nhess-14-1921-2014).

Mickwitz, P., Beck, S., Jensen, A., Pedersen, A. B., Görg, C., Melanen, M., Ferrand, N., Kuhlicke, C., Kuindersma, W., Máñez, M., Reinert, H. and van Bommel, S., 2009, 'Climate policy integration as a necessity for an efficient climate policy', *IOP Conference Series: Earth and Environmental Science* 6(58), 582017 (DOI: 10.1088/1755-1307/6/58/582017).

Millennium Ecosystem Assessment (ed), 2003, *Ecosystems and human well-being: a framework for assessment*, Island Press, Washington, DC.

Millennium Ecosystem Assessment (ed), 2005, *Ecosystems and human well-being: synthesis*, Island Press, Washington, DC.

Mokrech, M., Kebede, A. S., Nicholls, R. J., Wimmer, F. and Feyen, L., 2015, 'An integrated approach for assessing flood impacts due to future climate and socio-economic conditions and the scope of adaptation in Europe', *Climatic Change* 128(3-4), 245–260 (DOI: 10.1007/s10584-014-1298-6).

Mölder, A. and Schneider, E., 2010, 'On the beautiful diverse Danube? Danubian floodplain forest vegetation and flora under the influence of river eutrophication', *River Research and Applications*, n/a–n/a (DOI: 10.1002/rra.1403).

Morse, A., 2014, *Strategic flood risk management: report*, Report by the Comptroller and Auditor General Ordered by the House of Commons to be printed on 4 November 2014 This report has been prepared under Section 6 of the National Audit Act 1983 for presentation to the House of Commons in accordance with Section 9 of the Act, National Audit Office, London.

Moss, T. and Monstadt, J. (eds), 2008, *Restoring floodplains in Europe: policy contexts and project experiences*, IWA Pub, London.

Naiman and, R. J. and Décamps, H., 1997, 'The ecology of interfaces: Riparian Zones', *Annual Review of Ecology and Systematics* 28(1), 621–658 (DOI: 10.1146/annurev.ecolsys.28.1.621).

Naiman, R. J., Décamps, H. and McClain, M. E., 2005, *Riparia: ecology, conservation, and management of streamside communities*, Aquatic ecology series, Elsevier, Academic Press, Amsterdam.

Nanson, G. C. and Croke, J. C., 1992, 'A genetic classification of floodplains', *Geomorphology* 4(6), 459–486 (DOI: 10.1016/0169-555X(92)90039-Q).

Natho, S., 2014, 'Floodplains in Germany - Synergies with nature conservation, WFD and flood protection', presentation given at: Pilot Project on Natural Water Retention Measures 2nd Regional Workshop (Western Network), 1-2 July 2014, Strasburg, 1 July 2014.

Natho, S., Venohr, M., Henle, K. and Schulz-Zunkel, C., 2013, 'Modelling nitrogen retention in floodplains with different degrees of degradation for three large rivers in Germany', *Journal of Environmental Management* 122, 47–55 (DOI: 10.1016/j.jenvman.2013.02.049).

Neuhold, C., 2013, 'Flood 2013 in Austria', presentation given at: 14th meeting of the Working Group on Floods, Brussels, 17 October 2013.

Ockenden, M. C., Deasy, C., Quinton, J. N., Surridge, B. and Stoate, C., 2014, 'Keeping agricultural soil out of rivers: Evidence of sediment and nutrient accumulation within field wetlands in the UK', *Journal of Environmental Management* 135, 54–62 (DOI: 10.1016/j.jenvman.2014.01.015).

OECD, 2013, *Water and Climate Change Adaptation*, OECD Studies on Water, OECD Publishing.

OECD, 2015, *OECD Principles on Water Governance - Welcomed by Ministers at the OECD Ministerial Council Meeting on 4 June 2015*, Organisation for Economic Co-operation and Development, Directorate for Public Governance and Territorial Development, Paris.

Ollero, A., 2010, 'Channel changes and floodplain management in the meandering middle Ebro River, Spain', *Geomorphology* 117(3-4), 247–260 (DOI: 10.1016/j.geomorph.2009.01.015).

Paillex, A., Castella, E. and Carron, G., 2007, 'Aquatic macroinvertebrate response along a gradient of lateral connectivity in river floodplain channels', *Journal of the North American Benthological Society* 26(4), 779–796 (DOI: 10.1899/06-12.1).

Parrod, C., 2014, *Synthesis of the second Western Regional Workshop*, Pilot Project - Atmospheric Precipitation - Protection and efficient use of Fresh Water: Integration of Natural Water Retention Measures in River basin management, ACTeon, Strasburg.

Pavlović, R., 2014, '2014 floods in Serbia', presentation given at: 16th meeting of the Working Group on Floods, Rome, 10 September 2014.

Pettifer, E. and Kay, P., 2012, 'The effects of flood defences on riparian vegetation species richness and abundance: Effects of flood defences', *Water and Environment Journal* 26(3), 343–351 (DOI: 10.1111/j.1747-6593.2011.00294.x).

PIANC, 2009, *Sustainable waterways within the context of navigation and flood management*, PIANC Secrétariat Général - International Navigation Association, Bruxelles.

Pichler, A., Deppe, T. and Jackson, V., 2009, *Syntesis Report adressing the key findings of research related to Risk Assessment and Risk Management: Effectiveness of Non-structural Flood Risk Management Measures*, CRUE Flood Risk Management Research Monograph Series CRUE Synthesis Report No I-2009, CRUE Flooding ERA-NET.

Pitt, M., 2008, *The Pitt Review - Learning the Lessons from the 2007 Floods*, Cabinet Office, London.

Provansal, M., Dufour, S., Sabatier, F., Anthony, E. J., Raccasi, G. and Robresco, S., 2014, 'The geomorphic evolution and sediment balance of the lower Rhône River (southern France) over the last 130years: Hydropower dams versus other control factors', *Geomorphology* 219, 27–41 (DOI: 10.1016/j.geomorph.2014.04.033).

Raccasi, G., 2008, Mutations géomorphologiques récentes du Rhône aval, Recherches en vue de la restauration hydraulique et de la gestion des crues, Université de Provence, Aix-Marseille.

Ramsar Convention Secretariat, 2013, *The Ramsar Convention Manual: a guide to the Convention on Wetlands (Ramsar, Iran, 1971), 6th edition*, Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat, 2014, 'The Ramsar Convention and its mission' (http://www.ramsar.org/about/the-ramsar-convention-and-its-mission) accessed 6 August 2015.

Rey Benayas, J. M., Newton, A. C., Diaz, A. and Bullock, J. M., 2009, 'Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis', *Science* 325(5944), 1121–1124 (DOI: 10.1126/science.1172460).

Robinson, C. T., Tockner, K. and Ward, J. V., 2002, 'The fauna of dynamic riverine landscapes', *Freshwater Biology* 47(4), 661–677 (DOI: 10.1046/j.1365-2427.2002.00921.x).

Rojas, R., Feyen, L., Bianchi, A. and Dosio, A., 2012, 'Assessment of Future Flood Hazard in Europe Using a Large Ensemble of Bias Corrected Regional Climate Simulations', *Journal of Geophysical Research* 117, D17109 (DOI: 10.1029/2012JD017461).

Rojas, R., Feyen, L. and Watkiss, P., 2013, 'Climate change and river floods in the European Union: Socio-economic consequences and the costs and benefits of adaptation', *Global Environmental Change* 23(6), 1737–1751 (DOI: 10.1016/j.gloenvcha.2013.08.006).

Santato, S., Bender, S. and Schaller, M., 2013, *The European Floods Directive and Opportunities offered by Land Use Planning*, CSC Report 12, Climate Service Center, Germany.

Sayers, P., Galloway, G., Penning-Rowsell, E., Yuanyuan, L., Fuxin, S., Yiwei, C., Kang, W., Le Quesne, T., Wang, L. and Guan, Y., 2015, 'Strategic flood management: ten ‘golden rules’ to guide a sound approach', *International Journal of River Basin Management* 13(2), 137–151 (DOI: 10.1080/15715124.2014.902378).

Sayers, P., Yuanyuan, L., Galloway, G., Penning-Rowsell, E., Fuxin, S., Kang, W., Yiwei, C. and Le Quesne, T., 2013, *Flood risks management: a strategic approach*, Asian Development Bank, China General Institute of Water Resources and Hydropower Planning and Design (Ministry of Water Resources), UNESCO and WWF International, Mandaluyong City, Metro Manila, Philippines.

Schindler, S., Kropik, M., Euller, K., Bunting, S. W., Schulz-Zunkel, C., Hermann, A., Hainz-Renetzeder, C., Kanka, R., Mauerhofer, V., Gasso, V., Krug, A., Lauwaars, S. G., Zulka, K., Henle, K., Hoffmann, M., Biró, M., Essl, F., Jaquier, S., Balázs, L. et al., 2013, 'Floodplain management in temperate regions: is multifunctionality enhancing biodiversity?', *Environmental Evidence* 2(1), 10 (DOI: 10.1186/2047-2382-2-10).

Schindler, S., Sebesvari, Z., Damm, C., Euller, K., Mauerhofer, V., Schneidergruber, A., Biró, M., Essl, F., Kanka, R., Lauwaars, S. G., Schulz-Zunkel, C., van der Sluis, T., Kropik, M., Gasso, V., Krug, A., T. Pusch, M., Zulka, K. P., Lazowski, W., Hainz-Renetzeder, C. et al., 2014, 'Multifunctionality of floodplain landscapes: relating management options to ecosystem services', *Landscape Ecology* 29(2), 229–244 (DOI: 10.1007/s10980-014-9989-y).

Schmid-Breton, A., 2015, 'Case study: Flood action programme and role of floodplains in a large river basin', presentation given at: EEA Expert Workshop: “Environmental effect of floods and flood protection measures, 28-29 May 2015, Copenhagen, 28 May 2015.

Schneider, E., 2010, 'Floodplain Restoration of Large European Rivers, with Examples from the Rhine and the Danube', in: Eiseltová, M. (ed), *Restoration of Lakes, Streams, Floodplains, and Bogs in Europe*, Springer Netherlands, Dordrecht, pp. 185–223.

Schneider, E., Dister, E. and Döpke, M. (eds), 2009, *Lower Danube green corridor: an atlas for the lower Danube green corridor*, 2nd ed., WWF Germany, Rastatt.

Scholz, M., Mehl, D., Schulz-Zunkel, C., Kasperidus, H. D., Born, W. and Henle, K., 2012, *Ökosystemfunktionen von Flussauen: Analyse und Bewertung von Hochwasserretention, Nährstoffrückhalt, Kohlenstoffvorrat, Treibhausgasemissionen und Habitatfunktion*, Naturschutz und biologische Vielfalt, Bundesamt für Naturschutz, Bonn-Bad Godesberg.

Scholz, M., Stab, S., Dziock, F. and Henle, K. (eds), 2005, *Lebensräume der Elbe und ihrer Auen*, Konzepte für die nachhaltige Entwicklung einer Flusslandschaft, Weissensee-Verl, Berlin.

Schulz-Zunkel, C. and Krueger, F., 2009, 'Trace Metal Dynamics in Floodplain Soils of the River Elbe: A Review', *Journal of Environment Quality* 38(4), 1349 (DOI: 10.2134/jeq2008.0299).

Schwarz, U., 2010, *Assessment of the restoration potential along the Danube and main tributaries*, Working paper for the Danube River Basin, WWF International Danube-Carpathian Programme, Bucharest, Romania.

Schwarz, U., 2013, *Assessment of the River and Floodplain Restoration Potential in the Transboundary UNESCO Biosphere Reserve 'Mura-Drava-Danube' - Austria, Croatia, Hungary, Serbia, Slovenia*, WWF Austria, Vienna, Austria.

Slokar, M. and Papež, J., 2013, 'Floods on Drava River Basin November 2012 in Slovenia - Lessons learned', presentation given at: Water and Risk Management facing climate change: towards the local adaptation, 10/10/2013, Brescia, 10 October 2013.

Smith, K., 1996, *Environmental hazards: assessing risk and reducing disaster*, 2nd ed, Routledge physical environment series, Routledge, London ; New York.

Španjol, Ž., Tikvić, I. and Baričević, D., 1999, 'Protected sites of floodplain forests ecosystems in the Republic of Croatia', *Ekologia Bratislava* 18(1), 82–90.

Stanners, D., Bosch, P., Dom, A., Gabrielsen, P., Gee, D., Martin, J., Rickard, L. and Weber, J. L., 2007, 'Frameworks for environmental assessment and indicators at the EEA', in: Hak, T., Moldan, B., and Dahl, A. L. (eds), *Sustainability Indicators. A Scientific Assessment*, Island Press, Washington, pp. 127–144.

Stevenson, N. and Frazier, 1999a, 'Review of wetland inventory information in Eastern Europe', in: Finlayson, C. M. and Spiers, A. G. (eds), *Global review of wetland resources and priorities for wetland inventory*, Supervising scientist report, Supervising Scientist, Canberra, pp. 299–355.

Stevenson, N. and Frazier, 1999b, 'Review of wetland inventory information in Western Europe', in: Finlayson, C. M. and Spiers, A. G. (eds), *Global review of wetland resources and priorities for wetland inventory*, Supervising scientist report, Supervising Scientist, Canberra, pp. 357–418.

Sullivan, T., 2012, 'Combining Ecosystem Service and Critical Load Concepts for Resource Management and Public Policy', *Water* 4(4), 905–913 (DOI: 10.3390/w4040905).

Surminski, S., Aerts, J. C. J. H., Botzen, W. J. W., Hudson, P., Mysiak, J. and Pérez-Blanco, C. D., 2015, 'Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union', *Natural Hazards* (DOI: 10.1007/s11069-015-1832-5).

Swart, R., Bernstein, L., Ha-Duong, M. and Petersen, A., 2009, 'Agreeing to disagree: uncertainty management in assessing climate change, impacts and responses by the IPCC', *Climatic Change* 92(1-2), 1–29 (DOI: 10.1007/s10584-008-9444-7).

Syrbe, R.-U. and Walz, U., 2012, 'Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics', *Ecological Indicators* 21, 80–88 (DOI: 10.1016/j.ecolind.2012.02.013).

Tines, R. W., 2013, 'Wetlands', in: *Encyclopedia of Environmental Management*, Taylor & Francis.

Tockner, K., Lorang, M. S. and Stanford, J. A., 2010, 'River flood plains are model ecosystems to test general hydrogeomorphic and ecological concepts', *River Research and Applications* 26(1), 76–86 (DOI: 10.1002/rra.1328).

Tockner, K. and Stanford, J. A., 2002, 'Riverine flood plains: present state and future trends', *Environmental Conservation* 29(03) (DOI: 10.1017/S037689290200022X).

Tockner, K., Uehlinger, U. and Robinson, C. T. (eds), 2009, *Rivers of Europe*, 1. ed, Academic Press, Amsterdam.

Tockner, K., Ward, J. V., Arscott, D. B., Edwards, P. J., Kollmann, J., Gurnell, A. M., Petts, G. E. and Maiolini, B., 2003, 'The Tagliamento River: A model ecosystem of European importance', *Aquatic Sciences - Research Across Boundaries* 65(3), 239–253 (DOI: 10.1007/s00027-003-0699-9).

UN, 2015, Resolution adopted by the General Assembly on 3 June 2015: 69/283. Sendai Framework for Disaster Risk Reduction 2015–2030, A/RES/69/283, General Assembly, 69th session.

UNEP (ed), 2010, *Mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB*, The economics of ecosystems & biodiversity (TEEB), United Nations Environment Programme, Geneva.

UNESCO, 1994, Convention on Wetlands of International Importance especially as Waterfowl Habitat; Ramsar, Iran, 2.2.1971 as amended by the Protocol of 3.12.1982 and the Amendments of 28.5.1987.

Ungvári, G., 2014, 'Thematic issues: Effectiveness, Efficiency and Implementation', presentation given at: Pilot Project on Natural Water Retention Measures WorkShop n°1 - Danube Region, 28-29 January 2014, Szentendre, Hungary, 28 January 2014.

UNISDR, 2015, *Making Development Sustainable: The Future of Disaster Risk Management*, *Global Assessment Report on Disaster Risk Reduction*, United Nations Office for Disaster Risk Reduction, Geneva, Switzerland.

Verschuuren, J., 2010, 'Climate Change: Rethinking Restoration in the European Union’s Birds and Habitats Directives', *Ecological Restoration* 28(4), 431–439 (DOI: 10.3368/er.28.4.431).

Vinke-de Kruijf, J., Kuks, S. M. M. and Augustijn, D. C. M., 2015, 'Governance in support of integrated flood risk management? The case of Romania', *Environmental Development* (DOI: 10.1016/j.envdev.2015.04.003).

Ward, J. V., 1989, 'The Four-Dimensional Nature of Lotic Ecosystems', *Journal of the North American Benthological Society* 8(1), 2 (DOI: 10.2307/1467397).

Willems, P., Olsson, J., Arnbjerg-Nielsen, K., Beecham, S., Pathirana, A., Bulow Gregersen, I., Madsen, H. and Van-Thanh-Van Nguyen (eds), 2012, *Impacts of climate change on rainfall extremes and urban drainage systems*, IWA Publishing, London.

WMO (ed), 2009, *Integrated flood management: concept paper*, WMO Report, World Meteorological Organization : Associated Programme on Flood Management and Global Water Partnership, Geneva, Switzerland.

Workshop preparatory committee, 2014, Workshop on coordinated implementation of nature, biodiversity, marine and water policies, Background document.

WRc, 2015, *Screening Assessment of Draft Flood Risk Management Plans*, UC10757.01, WRc, Wiltshire (UK).

WWF Germany, 2000, 'Oder-Auen-Atlas' (http://atlas.odra.pl/de/index.html) accessed 27 August 2015.

Zandstra, T., 2015, *Water Legislation - Cost on Non-Europe Report*, European Parliamentary Research Service (EPRS), Brussels.

Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L. and Tockner, K., 2015, 'A global boom in hydropower dam construction', *Aquatic Sciences* 77(1), 161–170 (DOI: 10.1007/s00027-014-0377-0).

2015, 'Summary Report', conference paper presented at: Workshop on coordinated implementation of nature, biodiversity, marine and water policies 2-3 December 2014, Brussels, 30 January 2015.