European Environment Agency

Floodplains: Indispensable ecosystems and extenuators of flood risk

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Draft key messages

- Floodplains are an important part of rivers. They are largely in poor condition. Improving their condition is important for achieving objectives of the Water Framework, Floods, Habitats and Birds Directives.
- Presently, floodplains are recognised in the context of the Water Framework Directive, but they are not systematically assessed as part of river basin management plans, although an ecosystem based perspective suggests this could be highly relevant.
- A more overarching strategic approach for the protection and restoration of floodplains, also encompassing objectives of the Floods Directive, the Habitat and Birds Directives, the EU 2020 Biodiversity Strategy, the Green Infrastructure initiative, and the EU Climate Change Adaptation Strategy, could be taken.
- Natural water retention measures are cost effective and viable alternatives to structural flood protection. In addition, they support multiple ecosystem functions and services needed to achieve the objectives of several EU policies. Such solutions enable achieving multiple environmental policy goals: they enhance the delivery of ecosystem services and in return for this improvement they support the delivery of good ecological status, good conservation status and improved flood risk management.
- Shifting the management focus towards natural retention measures represents a transition towards ecosystem-based management and needs to be incorporated into river basin and flood risk management plans, conservation plans and climate change adaptation plans. Once implemented, natural water retention measures deliver valuable regulating & maintaining ecosystem services and high quality cultural services.
- Restoration requires public support, investment and time. EU and national funding instruments are available to support restoration.
- In spite of the obvious benefits of floodplain protection and restoration, the analysis points to a fragmented management approach that would benefit from some streamlining across Europe, in order to better achieve the value of restoration efforts. Relevant measures for achieving cross-policy objectives can often be the same.
- As most restoration projects involve using land differently, it is very important to secure citizen engagement in the planning process and to allow enough time to negotiate the best possible solutions. The results are, however, often greatly appreciated by the public because of the recreational qualities achieved.

Executive summary

This report provides an overview of the multiple policy benefits that can be achieved by including floodplains more systematically into future assessments and planning in River Basin and Flood Risk management plans. It also points to a fragmented information base that would benefit from some streamlining across Europe, in order to understand the true value of river restoration efforts.

In the recent reporting of the second river basin management plans under the Water Framework Directive, it is clear that across Europe, Member States are not achieving at least good ecological status for their waterbodies. On average, approximately 40 % of Europe's surface water bodies achieve good ecological status (EEA, 2018). Similarly, an analysis of the conservation status of 37 floodplain habitats listed in the Habitats Directive shows that the vast majority are in either inadequate or bad conservations status. Across Europe, only 14 % of floodplain habitats and species are in good conservation status.

Although difficult to quantify, there is a link between the amount of natural floodplains and achieving the key objectives of European policies, in particular in the context of the Water Framework, Floods, Habitats, and Birds Directives. Floodplain management or protection is encouraged but only indirectly required under European environmental policies, but floodplain health is important for achieving multiple European policy objectives. Many of these policies have not reached their objectives to date.

Because of the multiple benefits provided by natural floodplains, EU policies encourage restoration based on natural water retention measures, as well as conservation of existing natural floodplains, to be adopted in river basin or flood risk management plans, conservation plans or climate change adaptation plans. To this end, the link between the Water Framework and Floods Directives is essential. It provides a clear incentive to base flood risk management on natural water retention measures.

Natural water retention measures refer to initiatives where flood protection is provided, while at the same time the natural properties of the floodplain and its connection to the river are restored. As such, these measures are an integral part of ecosystem-based management; they can include both structural changes to the river and floodplain, and changes that involve managing land use within the floodplain. Using natural water retention measures and green infrastructure has been found to be a cost effective alternative to structural measures (EEA, 2017). The European Union promotes the increased use of natural water retention measures as part of its Green Infrastructure initiative and has co-financed restoration projects through the LIFE programme. Most countries also report on using nature based solutions as measures in their Flood Risk Management plans (EC, 2019).

An approach to securing recognition and prioritisation of multiple benefits of floodplain and river restoration could be developed by using an approach rooted in ecosystem-based management when developing river basin and flood risk management plans. Such an approach would secure that the multiple benefits of potential restoration measures are considered, devising solutions suitable for meeting all environmental objectives set across policies.

1 Introduction

1.1 Scope of theme: Why care about floodplains?

Rivers are much wider than the channels we associate them with. The areas next to rivers, which are only covered by water during floods, are also part of the river system, acting as the interface between the catchment and the river. Known as floodplains, in their natural condition they are an important ecological part of this system: they filter and store water, secure both natural flood protection and the healthy functioning of river ecosystems, and help sustain the high biological diversity present there. Floodplains are an important part of Europe's natural capital, covering 8 % of the continent's area and up to 30 % of its terrestrial Natura 2000 site area. Because they flood regularly, floodplains are naturally highly fertile areas. This combined with the use of rivers for transport has historically made them ideal sites for human settlement and agriculture. Many of Europe's major cities are located on floodplains and agriculture is linked with an average of 55 % of land use activities there. While they are home to multiple protected species and habitats, they are also now home to 8 % of Europe's population; in the Netherlands and Hungary this figure rises to more than 20 %.

Moreover, in parts of Europe, climate change projections suggest high-intensity rainfall will increase, while in others drought could become more frequent, further affecting the condition of floodplains. In either case, improved ecological integrity is becoming increasingly important and natural floodplains will become key to achieving important policy objectives. These changes have also made floods more damaging — flood waves became higher and now travel faster down the straightened rivers. They also carry larger amounts of fine sediments creating larger deposits than would have been the case under more natural conditions. Further damage has been introduced through the combined desire for flood control, water supply and hydroelectricity, which increased the development of hydroelectric dams and water storage reservoirs, and the control of water flow in rivers.

The drive for increased urbanisation and economic growth, and a bigger agricultural area continue to drive change in Europe's river systems. Public safety from flooding through drainage and flood protection has developed throughout the last centuries, especially after World War II. In addition, Europe's large rivers are also important transport corridors, supporting trade over large distances. Improvements in navigation have led to rivers being straightened by cutting off meanders and forcing the flow into a fixed channel. These changes have also served as land reclamation projects in which floodplains were drained for greater agricultural production and security of food supply. While these changes have supported both economic growth and flood protection, they have also had serious environmental consequences. The solutions put in place have contributed greatly to disconnecting rivers from their floodplains, greatly reducing their critical roles in flood and drought mitigation, as habitats, and in water quality protection.

Estimates made on the Danube, Ebro and Seine rivers and some German rivers suggest that today 70-90 % of Europe's floodplains are ecologically degraded (EEA, 2016). These changes are of such magnitude that many scientists talk of a regime shift for the ecological functioning of many rivers since the introduction of manmade pressures. Moreover, in the future, high-intensity rainfall is anticipated to become more frequent because of climate change, meaning some countries will be faced with an increased demand for flood protection. In other parts of

Europe, the frequency of droughts will increase. During droughts, the water stored in natural floodplains mitigates ecosystem impacts.

In 2018, the results of the second river basin management plans were published, among others showing that currently only 42 % of Europe's rivers achieve good ecological status (EEA, 2018b). Hydromorphological and diffuse pollution pressures are the two main reasons for rivers failing to achieve good ecological status. Both pressures can be reduced through improved floodplain condition. This report provides an overview of the multiple policy and natural resource management benefits that can be achieved by including floodplains more systematically into future assessments and planning in River Basin and Flood Risk Management Plans. We also introduce the notion of ecosystem based management as a unifying concept for managing across policy boundaries.

In this first chapter we describe our assessment system and describe the Global and European policy framework that encompasses floodplains. In chapter 2 we provide basic characteristics of the floodplain-river system, and how land use and population in the floodplain is distributed among EEA-39 countries. In chapter 3 we describe some of the key ecosystem services provided by floodplains that support good condition in rivers and of biodiversity together with approaches to river and floodplain restoration and examples of successful restoration projects. In chapter 4 we discuss conditions for successful implementation. Over all the analysis points to a fragmented management approach that would benefit from some streamlining across Europe, in order to better achieve the value of river restoration efforts.

This report builds on other publications undertaken by the EEA, in particular EEA, 2016 and EEA, 2017.

1.2 The catchment-river-floodplain ecosystem and policies

In their natural condition, rivers and floodplains are laterally connected, exchanging water and nutrients in a shared ecosystem. Thus, floodplains act as a buffer between the catchment and the river; its quality is closely linked to conditions in the river as well as within the catchment. Many of the human activities that develop pressures on rivers and the floodplain need to be managed at catchment scale, while the specific impacts are observed in the river and floodplain. Changes in river flow, sediment input, forestation, agricultural activities, and urbanization all have the ability to change conditions in the river and in the floodplain, ultimately affecting both aquatic and floodplain habitats (Schulz et al., 2015). In addition several studies have shown that if ecosystem improvements occur in the river system, it will also lead to improvements in the floodplain (Januschke et al., 2011; Hering et al., 2015; Göthe et al., 2016). This inter-connectedness underlines the importance of considering the catchment-floodplain-river ecosystem as a whole.

Natural, undisturbed floodplains are areas of very high biodiversity; they support habitats and species that have adapted to the unique environmental conditions provided by the cycle of flooding and drying, and they provide intermittent habitats for water dependent species. Flooding and water-logged soils are important properties of a natural wetland. Both water and substrate properties are highly dynamic, creating a multitude of ecological niches in permanent exchange with the river and its catchment area and act to form ecological resilience over time (Fuller et al., 2019).

In Europe, almost all rivers and their floodplains have been disturbed by artificial interventions. Adjustments happen in a multitude of ways that depend on conditions in the particular river basin, and often continue over years, calling for both increased focus on river basin management. The need for management and restoration of the catchment-river-floodplain system is, however, widely recognised in EU policies. The overview provided in Table 1 shows the many policies that either depend on restoration to achieve their objectives, or encourages restoration through specific mechanisms such as green infrastructure. The Water Framework Directive, with its objective of reaching good ecological status for biological quality elements linked to aquatic fauna and flora, and its recognition of hydromorphology as a pressure, is a very important driver for such improvements.

The Water Framework Directive also operates with hydromorphology as a supporting quality element, i.e. for surface water bodies not achieving good ecological status, hydromorphology needs to be assessed, and significant hydromorphological pressures are identified. Moreover, important policy instruments are already in place to secure that new initiatives in rivers and floodplains do not negatively affect the status of environmental objectives.

Both the Water Framework Directive and the Habitats Directive provide provisions for preventing further degradation. The Water Framework Directive article 4(7) requires that only new projects that do not risk altering the waterbody status are authorised. New projects that involve e.g. hydromorphological alterations or alterations of the groundwater level must be developed in a way that waterbody status is not lowered. Similarly, new projects that could impact protected sites (e.g. Natura 2000 sites) designated under the Habitats and Birds Directives also need an appropriate assessment of impacts according to article 6(3) of the Habitats Directive, and primarily only plans that do not adversely impact the site of concern can be approved. Europe’s Floods Directive requires all EU member states to develop flood risk management plans that include an assessment of areas of potential flood risk, and evaluation of assets at risk with the specific objective of reducing the adverse effects associated to human health, the environment, cultural heritage, and economic activities.

As a cross policy initiative, Target 2 of EU 2020 biodiversity strategy requires restoring at least 15 % of degraded ecosystems by 2020, and increasingly, implementing restoration approaches based on green infrastructure principles is seen as best practice solutions. Such solutions enable achieving multiple environmental policy goals: they enhance the delivery of ecosystem services and in return for this improvement they support the delivery of good ecological status, good conservation status and improved flood risk management. Hence, the Water Framework, Floods, Birds and Habitats Directives in combination act as drivers for river and floodplain restoration efforts, even if their management plans are developed with differing objectives in mind. More recently, the importance of river restoration has been acknowledged at the global level with the adoption sustainable development goal 6.6.

Table 1: Overview of policy objectives and targets of policies that would either benefit from or support achieving improved floodplain condition. Further explanation of the objectives is provided in Annex 1.

Policy Objectives & Targets	Sources	Target Year	Agreement type
Policy objectives that benefit from improved floodplain condition			
Protect and restore water related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	SDG 6.6	2030	Non-binding global commitment

Nitrates Directive. Reduces nitrogen input and provides a provision for establishing bufferstrips in the floodplain.	**EU Nitrates Directive (1991/676/EEC)**		**Legally binding EU commitment**
Conservation and protection of Annex I&II listed habitats and species	**EU Habitats and Birds Directives (1992/43/EEC & 2009/147/EC)**		**Legally binding EU commitment**
Achieve good ecological status of all waterbodies in Europe	**Water Framework Directive (2000/60/EC)**	**2015**	**Legally binding EU commitment**
To assess and manage flood risks, aiming at the reduction of the adverse consequences for human health, environment, & cultural heritage.	**Floods Directive (2007/60/EC)**	**2015**	**Legally binding EU commitment**
Maintain and enhance ecosystems and their services by establishing green infrastructure and restoring at least 15 % of degraded ecosystems	EU Biodiversity Strategy, target 2 (COM/2011/244)	2020	Non-binding EU commitment
Mitigation and prevention of pressures from agriculture and flood protection using buffer strips, … and using, whenever possible, green infrastructure such as the restoration of riparian areas, wetlands and floodplains to retain water, support biodiversity and soil fertility, and prevent floods and droughts.	EU Blueprint to Safeguard Europe's Water Resources (COM/2012/673)		Non-binding EU commitment
Establishment of green infrastructure	Green Infrastructure (GI) — Enhancing Europe’s Natural Capital (COM/2013/0249)		Non-binding EU commitment
Measures such as the reconnection of the floodplain to the river, remeandering, and the restoration of wetlands can reduce or delay the arrival of flood peaks downstream while improving water quality and availability, preserving habitats and increasing resilience to climate change.	The Water Framework Directive and the Floods Directive: Actions towards the 'good status' of EU water and to reduce flood risks (COM/2015/120)		Non-binding EU commitment
Adaptation of flood risk management to climate change	EU climate change adaptation strategy and disaster risk reduction (COM/2013/0216) & and rescEU on strengthening EU Disaster Management (COM/2017/779)		Non-binding EU commitment

While the policy overview shown in Table 1 is comprehensive, it is also fragmented with many different approaches taken to managing environmental concerns within the catchment-floodplain-river ecosystem. Presently, floodplains are recognised in the context of the Water Framework Directive, but they are not systematically assessed as part of river basin management plans, although an ecosystem based perspective suggests this could be highly relevant.

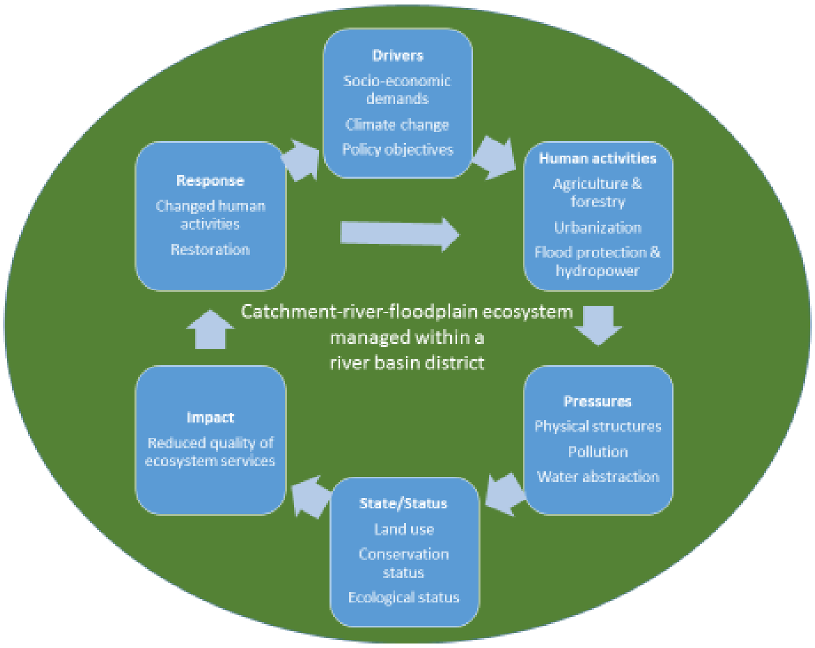
Ecosystem based management refers to a system for managing multiple human activities and their pressures, that aims to ensure that the ecosystem is healthy and resilient while at the same time delivering the services that people want and need (McLeod and Leslie, 2009). Defining the catchment – floodplain – river ecosystem provides a unifying concept for managing across the policies listed in Table 1. It also demonstrates that there are benefits to including a broader perspective on the notion of rivers than currently captured in river basin management plans.

Because floodplains are at the interface between the river and the remaining catchment, their condition is critical for the over-all ecosystem health, i.e. as status of water in the river, for flood protection and water retention, and for biodiversity.

Some of these principles have already transpired into European legislation. The management units of the Water Framework and Floods Directives are river basin districts, which to a very large extent overlaps with catchment boundaries. However, biodiversity management, takes a different approach, operating at the geographical scale of biogeographic regions. Many habitat types and species, however, also depend on water and wetland availability which is often associated with rivers and floodplains; 50-60% of the terrestrial Natura 2000 sites are found within floodplains. For these habitat types and species, relevant management actions for their improved conservation, could benefit from being linked to an overall approach to water management.

To make ecosystem based management work, it needs to also encompass collaboration between all institutions that have governance responsibilities for human activities together with transparent stakeholder and adaptive management processes (Rouillard et al., 2018). As captured by the drivers-pressures-state-impact-response framework (Figure 1.1), it is not enough to identify environmental pressures, state and impact, a shared plan for their solution also needs to be developed, evaluated, and readjusted over time. This planning establishes the need to reconcile many different priorities for human activities while maintaining a healthy ecosystem as key to environmental management decisions. Solutions for achieving the multiple policy objectives listed in Table 1, can often be the same, and often need to be established in floodplains. If well planned they can lead to over-all improvement of ecosystem health in rivers, floodplains, and eventually the entire catchments. Measures, however, often aim at addressing specific human activities, but to achieve societal buy-in to implementation, the overall link to socio-economic demands also needs to be addressed.

Figure 1.1 DPSIR analysis framework for floodplain ecosystems



Notes: The drivers-pressures-state-impact-response framework, is used qualitatively to highlight links between human activities, environmental impacts or benefits in the floodplain. It is shown as a cycle because changes in one part potentially influences others.

Compartments that characterise response, drivers and human activities are a consequence of our human interaction with the ecosystem whereas pressures, state and impact refer to the ecosystem itself.

The drivers-pressures-state-impact-response framework outlined in Figure 1.1 is used for reference throughout the remaining report.

2 Floodplains under pressure

2.1 Floodplain characteristics and extent

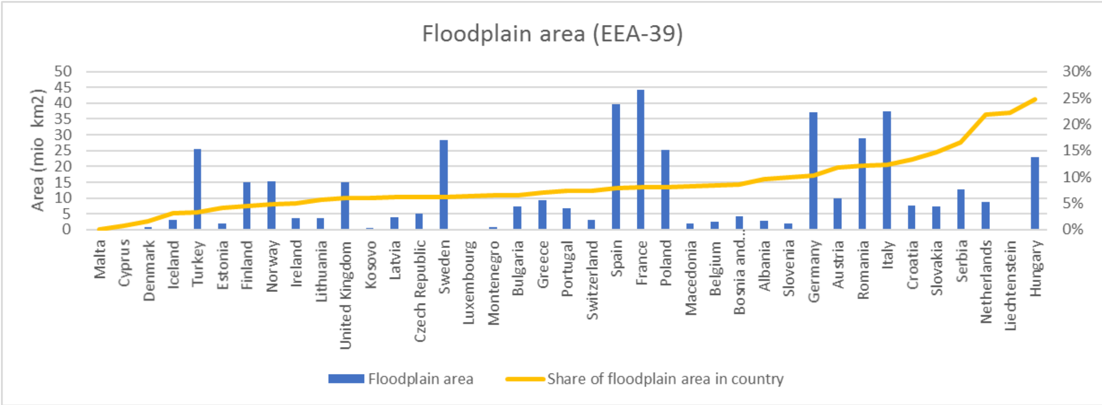
For the purpose of this report, we have defined the *potential* floodplain extent as the lateral extent of a flood that has a return period of once every 100 years. As part of the Copernicus Land Monitoring Service, a riparian zone local component has been developed. It provides a high resolution geographical database of ecosystems found the riparian zone in Europe[1]. The floodplain area has been selected from this database, and has been used to calculate key statistics for EEA-39. Copernicus is a European system for monitoring the Earth using earth observation satellites and in-situ sensors (Copernicus, 2019).

On average, 8% of the EU is covered by floodplain. Countries with more than 15% floodplain area include Slovakia, Serbia, the Netherlands and Hungary (Figure 2.1). The Scandinavian countries, Iceland, Norway, Finland and Sweden have less than 25% of their area covered by cropland, grassland and urban ecosystems, whereas in Germany, Denmark, Slovakia, Hungary and the Netherlands, more than 80% of the area is covered by these ecosystem types (

[1] The riparian zone product provides a detailed land cover dataset of ecosystem types in EEA-39 countries (Copernicus, 2019). Approximately 525.000 km² is mapped, covering rivers of Strahler level 3 to 8 with 100m grid size (GAF, 2015). The floodplain ecosystems are classified using eight MAES ecosystem types (EC, 2014). At level 1, the eight ecosystem types are: urban, croplands, woodland and forest, grassland, heathland and scrub, sparsely vegetated land, and rivers and lakes.

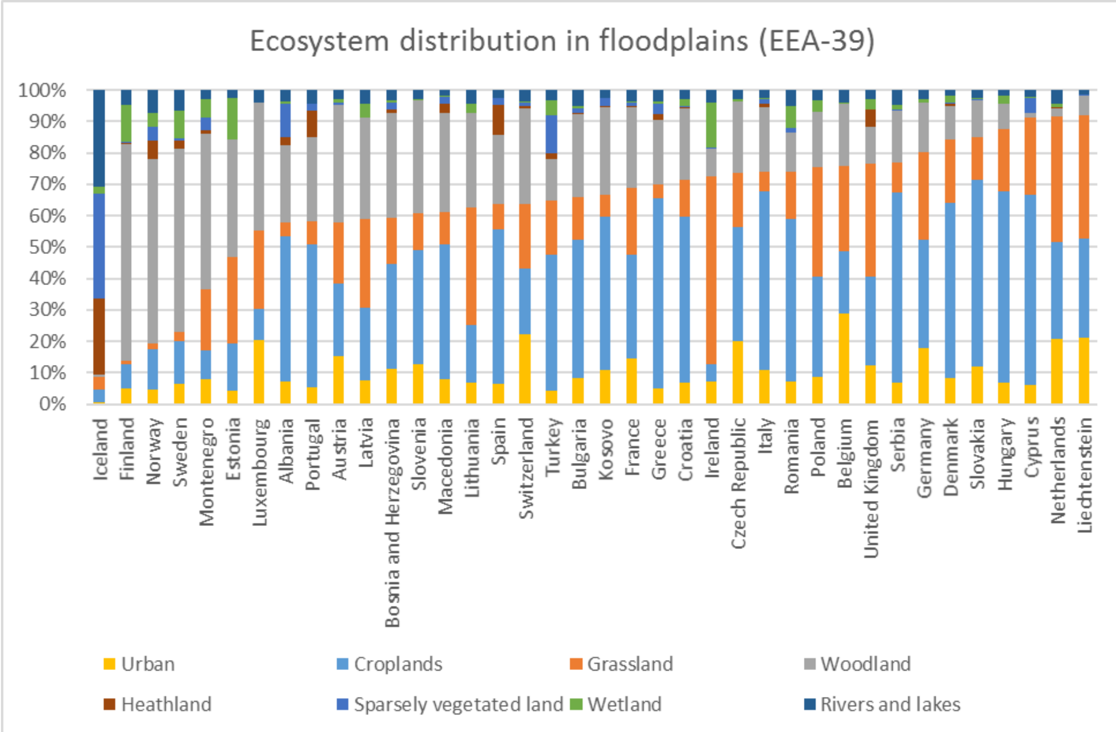
Figure 2.2). More than 25% of the population in Netherlands, Slovakia and Austria, Bosnia and Herzegovina, and Lichtenstein live in the floodplain (Figure 2.3). On average 11% of Europe’s Natura 2000 area is in floodplains, with Hungary having designated the largest share of the network in the floodplain. Natura 2000 sites are designated for protection of species and habitats listed under the Habitats and Birds Directives.

Figure 2.1: Floodplain area



Note: Country coverage is EEA-39. In EU-39, 8% of the area is in the floodplain.
Source: (EEA, 2019b)

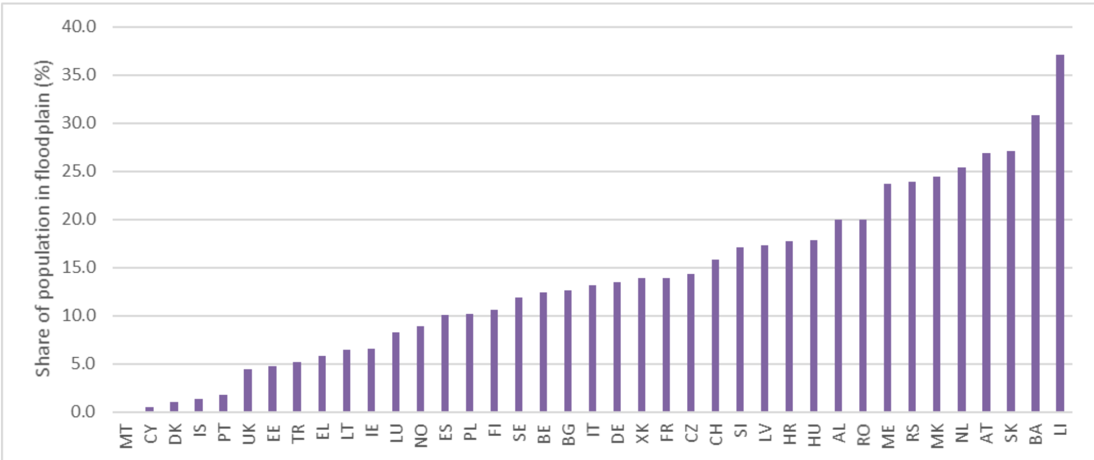
Figure 2.2: Ecosystem distribution in floodplains



Note: Country coverage is EEA-39. In EU-39, 64% of the floodplain area is used by croplands, grass lands and urban areas. Extent of coastal floods is not considered.

Source: (EEA, 2019b) and (Copernicus, 2019)

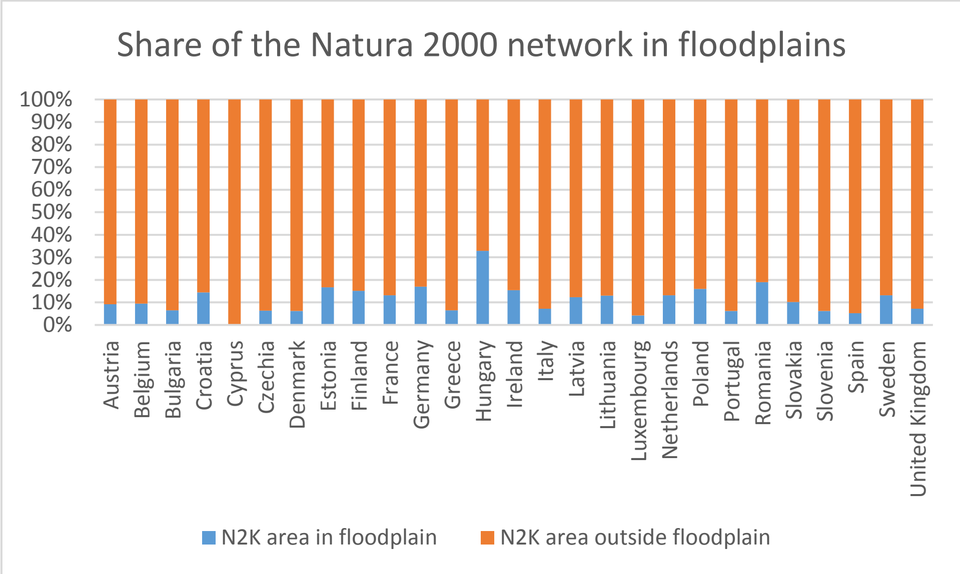
Figure 2.3: Share of population living in floodplains



Note: Country coverage is EU-39. In EU-39, 12% of the population lives in floodplains. Lichtenstein comes out with a very high value because it is a small country with a high proportion of floodplain.

Source: (EEA, 2019b)

Figure 2.4: Share of Natura 2000 network area in floodplain



Note: Country coverage is EU-28. In EU, 11% of the Natura 2000 network area is located in floodplains.
Source: (EEA, 2019b)

2.2 Current floodplain status in Europe

The loss of floodplains in Europe has not been assessed using a uniform Europe wide approach, but those studies that have been carried out suggests it is considerable. An overview of floodplain loss in Europe was presented in EEA, 2016. Depending on the river, 70-100% of the floodplain had been lost. Of the rivers shown, the best preserved floodplains were the Danube Delta and the Middle Ebro River in Spain. The worst were the Tisza, Seine, Rhine and Meuse Rivers where close to 100% of the natural floodplain area had been lost.

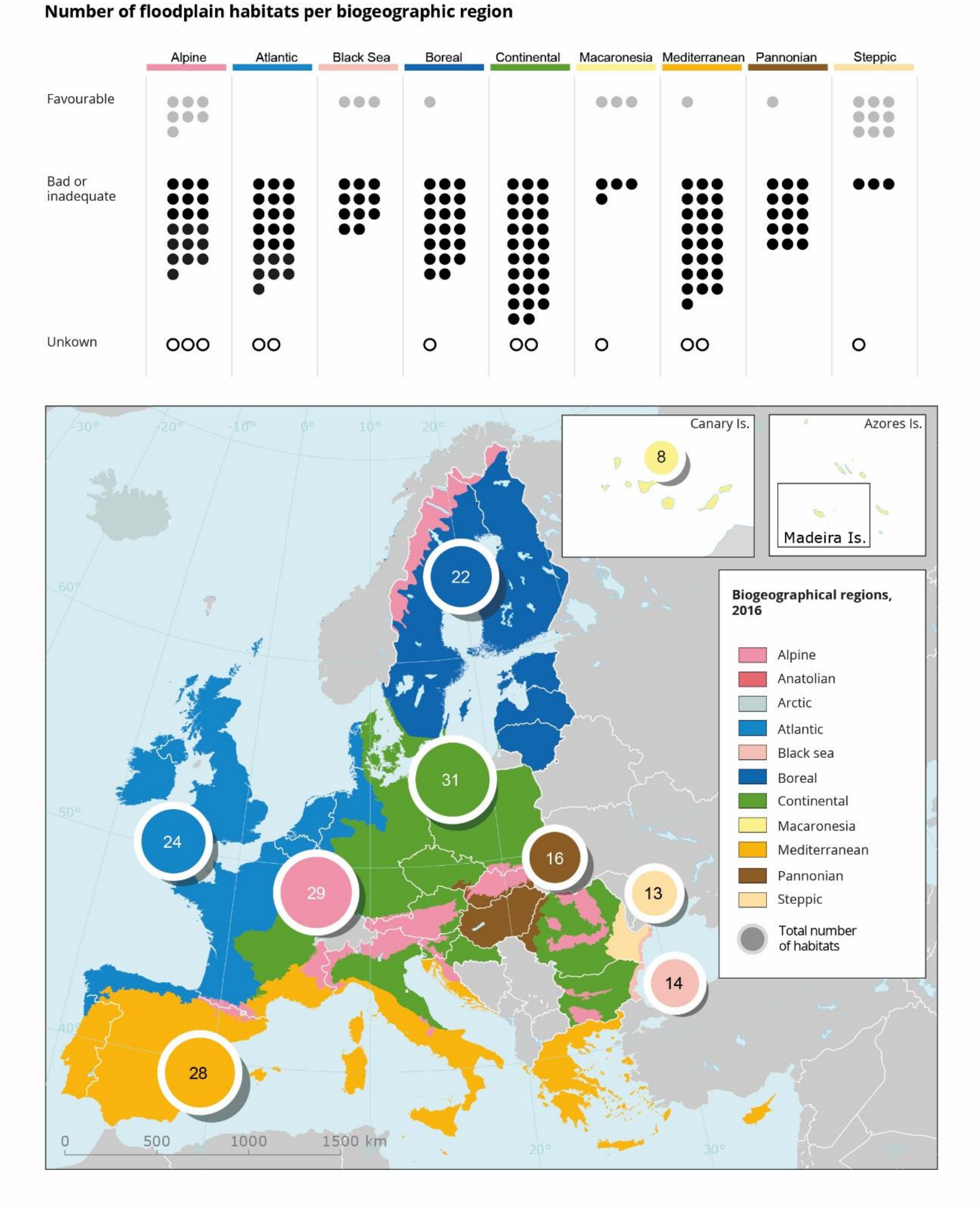
This loss, is reflected in assessments of conservation status carried out under the Habitats Directive (EEC, 1992). An analysis of the conservation status of 37 floodplain habitats shows that the vast majority are in either inadequate or bad conservation status (Figure 2.5). Across Europe, only 14% of floodplain habitats and species are in good conservation status, reflecting the high degree of disturbance to the floodplain ecosystems. The disturbances stems from the multitude of human activities, but especially urbanization and agriculture have had a very large impact.

Box 1: Riparian forests in central Europe

One of the floodplain habitats listed in the Habitats Directive is riparian forest, which is also the natural vegetation of floodplains in Central Europe. Softwood forest is found close to the river where inundation can be up to 180 days per year. Hardwood forest is found further away from the river where groundwater levels are lower and inundation occurs less than 60 days per year. In their natural state floodplain forests provide important habitats for many different species. Because of their nutrient rich soils, water supply and diversely structured forest strata, old hardwood forests host one of the most species-rich and unique bird communities of Central European forests. One study counted more than 200 pairs of breeding birds per 10 hectares in a riparian forest along the Elbe River (Scholz et al., 2012). One of the most prominent bird species of these forests in Central Europe is the Middle Spotted Woodpecker (*Dendrocopos medius*).

Only around 12% of existing riparian forests across Europe achieve favourable conservation status, and many have disappeared altogether.

Figure 2.5 Conservation status of Europe's floodplains across biogeographic regions.



Notes: The analysis encompass nine floodplain forest habitats, nine floodplain grassland habitats, and 19 aquatic floodplain habitats.

Source(s): Data aggregated from [Eionet – ETC/BD 2015: Online report on Article 17 of the Habitats Directive (2007-2012) of Biogeographic Regions.]

2.3 Climate change and altered flood risk

In Europe, global warming is projected to lead to both higher intensity of precipitation and longer dry periods. Projections of extreme precipitation events indicate an increase in the frequency, intensity, and amount of water. Events currently considered extreme are expected to occur more frequently in the future. If all other factors affecting flood risk remain the same, these climatic changes will also lead to increased risk. It is expected that both flood risk and the risk of drought will increase across Europe in the next decades with considerable impacts on society as a consequence (EEA, 2017a).

Flood risk is associated with heavy precipitation events that may come in many forms, ranging from high-intensity but short lived events to long but low-intensity events. Both may lead to flooding. Whether a heavy precipitation event actually leads to flooding depends on physical characteristics of the watershed and its land use properties. Steepness of the watershed, together with the ability of its reservoirs, soils and floodplains to absorb and hold water are factors that influence the speed of which precipitation moves into rivers. Faster transport, generally increase the likelihood of flooding. More formally, flood risk is defined as the probability of a flood event occurring, combined with its impact on people, the environment, cultural heritage and the economy, i.e. vulnerability to flooding is greater in an urban area and lower in a natural floodplain.

Today, floods remain one of the most costly natural disasters in Europe (Figure 2.6). Every year flood events in Europe, exceeds the capacity of existing systems to contain water, with damage to property and sometimes even loss of lives as a consequence (EEA, 2019a). Of the four most costly climate extremes in the EU, two are related to floods. The 2002 flood in Central Europe, which was also the most costly, exceeded EUR 20 billion and the 2000 flood in Italy and France had a cost of EUR 13 billion (2016 values).

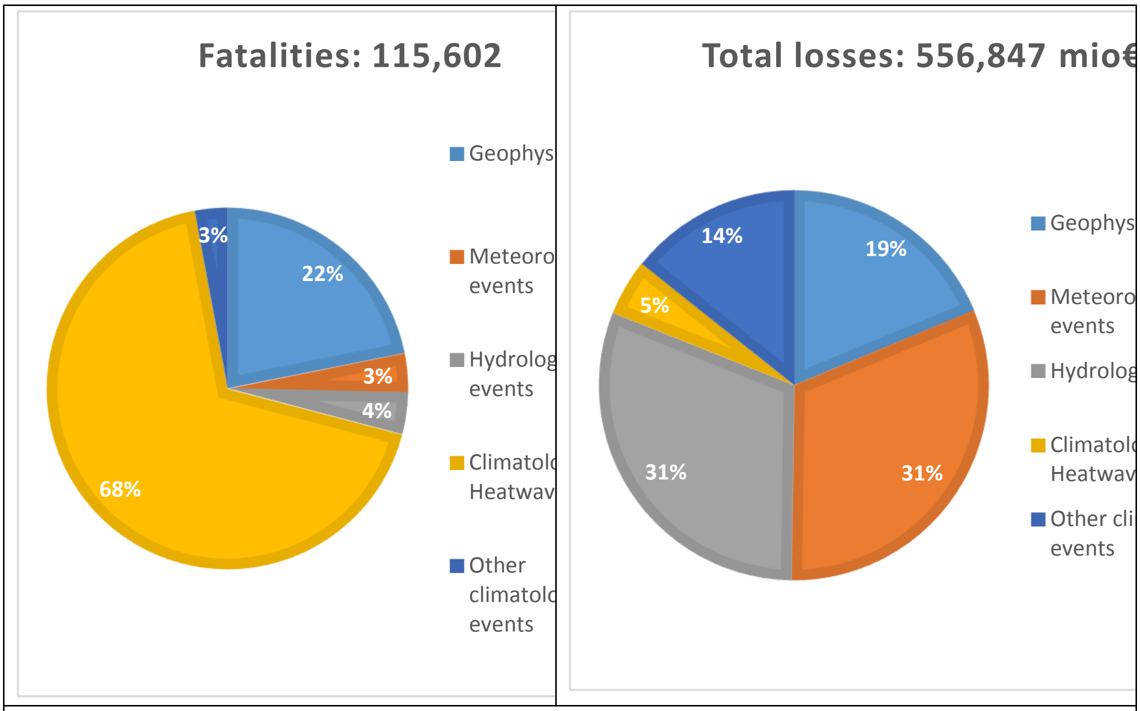


Figure 2.6. Fatalities and economic losses in EU-33 as a consequence of natural hazards (CLIM 039)

Note:
Geophysical events: earthquakes, tsunamis, volcanic eruptions
Meteorological events: storms
Hydrological events: floods, mass movements
Climatological events: cold waves, droughts, forest fires
Climatological events: heatwaves

For the period 1980-2017, total values for losses and insured losses in EUR million (in 2017 prices), based on the damage records from the NatCatSERVICE of Munich Re and the EUROSTAT structural indicators.

Data sources: NatCatSERVICE provided by Munich Re

2.4 Hydromorphological pressures and alterations

Within river basin districts, socio economic drivers generate a multitude of human activities that rely on the natural system. Important activities are agriculture and forestry, urbanization and transport, flood protection, hydropower production, navigation and recreation, that all, but in different ways, add pressure to the river-floodplain ecosystem. These changes are linked to the need to provide flood protection of people and property and to the historical desire to increase agricultural area, but also navigation and mining have added to pressures. Such pressures are broadly referred to as hydromorphological pressures – pressures to the natural system from changes to both hydrology (water flow) and morphology (physical characteristics) of rivers and floodplains.

Hydromorphological pressures covers a very wide range of changes, that all have different ways of influencing survival species, habitats and even ecosystems. The changes introduced by hydromorphological pressures impact the ecology of the natural system. They have a tendency to eliminate the lateral connectivity between the river and floodplain, reducing habitat quality, and influencing the species that can thrive. For example, barriers across rivers prevent fish from migrating upstream, reducing the ability of migratory fish to reach spawning areas. In Norway, following pressures from escaped farmed salmon and salmon lice, hydromorphological pressures are seen as the largest single factor influencing the wild salmon population (Forseth et al., 2017).

Under the Water Framework Directive, hydromorphological pressures are captured as one of the quality elements supporting the achievement of good ecological status. I.e. if benthic invertebrate fauna, fish or aquatic vegetation fail to achieve good ecological status, the possible impact of hydromorphological pressures needs to be assessed. The recent overview of the results in the second River Basin Management Plans under the Water Framework Directive show that hydromorphology is a significant pressure in 45% of Europe's rivers, with physical alterations to floodplains or the river channel accounting for 30% of those pressures, and dams, locks and weirs account for another 27% (EEA, 2018b, 2018c). The average value, however, masks large geographical variations, with some countries not reporting hydromorphological pressures and other reporting 85% of waterbodies impacted. Some examples of hydromorphological alterations linked to pressures are listed in Box 2, and the hydromorphological alterations of the Tisza river, Hungary is provided as an example of the large modifications Europes rivers have undergone (Box 3).

Box 2: Hydromporphological alterations

Large hydromorphological alterations linked to structural measures

Large hydromorphological alterations broadly falls into three categories: channel normalisation, construction of dikes, and dams.

Channel normalisation: Channel normalisation refers to the process of channel straightening, stabilisation with concrete lining, narrowing and deepening. As part of this process, islands and sand banks are removed and meanders are cut off. Such changes often leads to an increase in the discharge capacity of the main river channel which may cause higher flood risk due to increased discharge and water level. The modifications of the river channel also negatively alter natural river dynamics and morphological and sediment transport processes.

Dikes: Dikes are constructed for protection of land behind them and to confine river floodplains. This removes the water storage capacity of floodplains and increases discharge. Dikes encourages urban and industrial development in former floodplain areas, but if they are breached, flood damage is much greater. Dikes only provide protection up to a specific design capacity resulting in uncontrolled and unpredictable flooding events if capacity is exceeded.

Dams: Dams are used to regulate flow, create water storage reservoirs and to generate hydropower. In Europe, several thousand large dams (height >15 meters) have a large influence on regulating river flow dynamics and morphological and sediment transport processes both upstream and downstream of their location. In 1950, 1,210 large dams were distributed mainly in Spain, France, Italy, Austria and the United Kingdom. Nowadays, the dam density is much larger in all these countries and very high in Norway, Sweden, Balkan countries and Turkey. As examples, more than 130 dams regulate the flow of the Ebro river, and more than 60 dams regulate the flow of the Danube. Impacts on floodplains include much less flooding, i.e. stabilised channels and changed ecology. As sediment becomes stored in reservoirs behind dams, renewal does not occur, or becomes infrequent, which also influences the river connectivity. Dams hinder the natural movement of fish and other species. Although dams reduce flood risk, their potential failure can have catastrophic consequences. Article 4 of the Water Framework Directive may limit the construction of new large dams because they will most likely lead to deterioration of water status. However, in some countries the establishment of new dams has continued.

Smaller hydromorphological alterations

Of equally great importance to the very large hydromorphological alterations are the many small alterations that have also taken place especially to increase the area of suitable agricultural land, and to provide water for agriculture. It is in particular these smaller alterations that are addressed as a pressure under the Water Framework Directive, although countries approach those pressures very differently. One of the very effective ways of disconnecting floodplains from rivers is through drainage. A recent analysis showed that 52% of the agricultural area of Denmark was drained in the 20th century , primarily with the aim of increasing agricultural production (Møller et al., 2018). A similar development has occurred in other countries. Water abstraction for agriculture reduces groundwater levels, which if sufficiently large will dry out floodplain areas. A rough estimate suggests that there are 1-2 mio small barriers on rivers in Europe (P. Kristensen, pers com), and small and large reservoirs made with the aim of storing water for later irrigation and hydropower production are widespread.

Box 3: River Tisza, Hungary – A river with extensive hydromorphological alterations

Catchment size (km2)	Length (km)	Average Discharge (m3/sec)	Flood Discharge (m3/sec)	Population (mio)
157,186	965 Historical length: 1419	792	>4000	14

The Tisza river is an example of a river that historically has gone through extensive hydromorphological alterations which has effectively disconnected the river from its floodplain. Similar alterations have occurred on most major rivers in Europe, including the Rhine and Danube. Especially the demand for navigation and agricultural land have been strong drivers in this development. Controlling flooding was essential for establishing agricultural land. Flood and navigation works were initiated on the Tisza River in the 1800's. Prior to this, the plain would go through extensive flood and drought cycles, making it largely unsuited for agriculture. It supported flood tolerant land cover such as forests, meadows and fishponds. Deforestation together with mining and quarrying increased run-off and siltation and thus flood risk of the settlements in the valley (Lóczy et al., 2009). When completed in 1880, these works had changed the river length of 1491 km to 965 km, closing off 589 km (30%) of former channels, oxbov lakes and wetlands and establishing 136 km of new riverbed. As a result, around 80% of the wetland area has been lost. This is the most dramatic change of any river in Europe (Kolaković et al., 2016)

Today, large floods usually occur in later winter and early spring during combined events of rain and snow melt. Both groundwater and fluvial floods are common. In the basin headwaters in Slovakia and Ukraine, floods tend to be of shorter duration 2-20 days, whereas further downstream they can be of much longer duration due to the low slope – as much as 180 days occurred in 1970. Although the height of dikes and levees were designed to withhold a 50 year flood, they were breached several times in the last 130 years. The river has continued to adjust morphologically to the multitide of changes introduced, adjusting its cross-sectional area and bankfull width. The morphological response of the river was decreased flood conveyance (flood wave moved more slowly downstream) but increasing height of flood levels and thus increased flood risk (Amissah et al., 2018).

2.5 Pollution pressures

Although the Water Framework Directive and the Nitrates Directive in combination require reduction of nutrients and hazardous substances, those substances are still used. Floodplains commonly act as long term storage for water and sediments including those less desirable and hazardous substances. Nutrients and hazardous substances reaches floodplains from either the landside, from the river during floods, or from the atmosphere. Agricultural plant production uses nutrients and pesticides to promote plant growth. Often more nutrients are applied than taken up by plants, and unused nutrients are moved into streams either via groundwater (nitrates), or as attached to soil particles and moved with surface run-off (phosphorus). Those nutrients may cause eutrophication impacts on the floodplain but may also buffer against eutrophication impacts in the river. Active floodplains where vegetation is more prominent cycle nutrients into plants, and if soils are water logged, enable denitrification to take place. In the absence of an active floodplain, nutrients enters the river with less transformations and may cause eutrophication related impact on ecological status of rivers, lakes, transitional, and coastal waters.

During floods, sediments which may carry both nutrient and hazardous substance pollution are deposited on the floodplains, removing the polluting substances from the river, but in return polluting the floodplain. Especially in areas where mining and heavy industry were or still are important, heavy metal pollution of floodplains can be prominent, and may continue for decades after mining has been stopped (Ciszewski and Grygar, 2016). Examples of this can be found from most countries in Europe. Contaminated sediments are also of concern when performing river restoration as removing structural flood protection, weirs or dams. It has been found that contaminated sediments are often stored behind these structures, and may be released if structures are changed (Hahn et al., 2018). Atmospheric deposition of nutrients and mercury is a ubiquitous pressure, hence also occurs in floodplains (EEA, 2018b). Climate change induced increased temperatures is expected to alter the mobilization of chemicals in floodplains, but unfortunately, not much is known about environmental effects.

3 Improving ecosystem services and measures

3.1 Ecosystem services

The ecosystem services delivered by floodplains are linked to their dynamically changing, flooding and drying properties. The services provided are unique for specific locations due to dependencies on watershed properties and climate. In general and qualitative terms, more services are provided, the closer the floodplain is to its natural condition. The primary impact of the many hydromorphological pressures in floodplains has been to reduce both quantity and quality of ecosystem services delivered.

Ecosystem services are the many and varied benefits that humans gain freely from the natural environment. It is a concept for understanding that nature not only provide benefits and services for nature but also for people. Benefits include nutrition, access to clean water and air, health, safety, and well-being (MEA, 2005; EC, 2013). In the context of the EU 2020 Biodiversity Strategy (EC, 2011), the EU has undertaken the challenge to operationalise the concept of ecosystem services. Services are outputs from ecosystems that have values to humans, either because of their explicit market or cultural values, or because of their role in mitigating environmental pressures.

Services are categorised as provisioning, regulating & maintaining, or cultural. Provisioning services are material and outputs from ecosystems that can be exchanged, traded, or consumed. Provisioning services includes food and drinking water, as well as materials used in any kind of manufacturing. Regulating & maintaining services are natural processes that support achieving a healthy environment, and if intact, they save management investments and efforts contributing to achieving environmental policy objectives at low or no cost at all. Cultural services are linked to the benefits for human well-being by ecosystems whether of spiritual of recreational nature.

The relationship between the natural functions of the ecosystem and the elements of human well-being have been described as series of steps in the cascade model which captures the key connections from biophysical structures (such as the floodplain) and their functions through services to benefits and values for human well-being in the social system (Potschin and Haines-Young, 2011).

Benefits, however, generate pressures to the biophysical system. A negative feedback loop may be established where increased pressures reduce the benefits gained, but this may in return be modified by policy regulation or altered management practices.

The model enables assessing the over-all value of multiple services, contrasting the value of a single service and its pressures against the value and pressures of others. Often a trade-off exists between provisioning and regulating & maintaining services. For example, Pressures stemming from provisioning services may undermine the delivery of the regulating services.

Table 2 provides an overview of services provided by floodplains and explains how they could support EU policies. Improving many of the regulating & maintenance services will support achieving EU policy objectives. In this report our aim is to provide examples of the services that are important for the healthy functioning of the flood area. However, it is not attempted to quantify those services, either in terms of volume or economic value. Such quantification requires considerable local knowledge not available at the European level.

Table 2: Qualitative overview of provisioning, regulating & maintenance, and cultural services provided by undisturbed floodplains. This Table is further detailed in Annex 3 and it is linked to Table 3.

Main Sections	Ecosystem service / CICES class	Environmental Policy relevance
Provisioning	**Geological resources**	
	Clean water / surface and groundwater for drinking	
	Food production: fish	
	Food production: **agricultural plant production** / cultivated plant production	
	Food production: **Agricultural animal production** / animals reared to provide nutrition	
Regulation & Maintenance	**Flood control**	FD: reduction of flood risk Climate change adaptation
	Hydrological cycle and water flow regulation: **Groundwater recharge and water storage**.	Climate change adaptation WFD: good groundwater quantitative status
	Erosion control and prevention	WFD: Hydromorpho-logical condition
	Bio-remediation by micro-organisms, algae,plants, and animals: **Water purification**	WFD: good ecological status WFD: good chemical status
	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals: **Carbon sequestration**	Climate change mitigation
	Soil conservation, formation & composition: decomposition and fixing processes and their effect on soil quality	HD: Relevant for species richness
	Seed dispersal	WFD: good ecological status HD: Species conservation and richness
	Conservation of biodiversity: maintaining nursery populations and habitats (Including gene pool protection)	HD: Species and habitat conservation
Cultural	**Recreation**	Positive experiences by the public generates acceptance of objectives of other policies.

Notes: Services highlighted in bold are repeated in Table 3.

Source: (Haines-Young and Potschin, 2017)

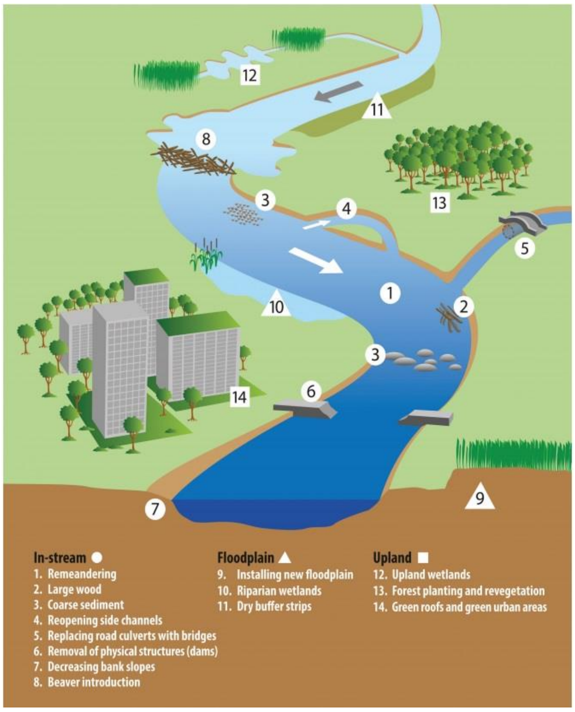
3.2 Measures

Restoration efforts based on the principles of nature based solutions attempts to restore the natural connections between the river and floodplains, in this way improving the delivery of regulating & maintaining ecosystem services. Most of nature-based solutions directly affect hydromorphological features of the river-floodplain system, improving hydromorphological quality.

Across Europe there are many examples of successful restoration projects. In an analysis of 119 river restoration projects, carried out between 1989-2016, Szałkiewicz et al., 2018 show that river restoration in Europe increasingly builds on more holistic solutions including actions in the river channel, floodplain and catchment. Many examples can be found in the overview provided by Natural water retention measures project (NWRM, 2019), the EEA website Climate Adapt (EEA, 2018a), or on the website of the EU funded project RESTORE (ECRR, 2019). The latter provides a database that up to now, holds 1162 river restoration case studies from 31 countries. Examples of more in depth analyses are provided through the EU funded FP7 project REFORM (Reform, 2015). Since 1995 the Life+ programme of the European Union has funded more than 100 floodplain restoration projects. Together these projects support a comprehensive knowledgebase on the environmental benefits of river restoration that is presently finding its way into European policy.

Today the benefits of multifunctional management of floodplains is much more broadly accepted than when the EU Floods Directive entered into force in 2007.Both the REFORM and NWRM projects have provide systematic classifications of specific restoration measures that have been implemented across Europe. NWRM focused on natural water retention measures in a broad sense, whereas the REFORM project focused specifically on river restoration. An overview of the most important restoration measures to improve the natural hydromorphological properties of river-floodplain systems is provided in Figure 3.1.

Figure 3.1. Examples of natural water retention measures. Measures are further detailed in 0.

<table>
<tr><th>Measures</th><th rowspan="2">
</th></tr>
<tr><td>Wetland restoration
Reconnection of oxbow lakes
Meadows and pastures
Buffer strips and hedges
Forest riparian buffers
Embankment or dike relocation
Removal or lowering of dikes
Re-meandering
Stream bed renaturalisation
Riverbed material renaturalization
Natural bank stabilisation
Elimination of riverbank protection
Renaturalisation of polder areas
Coarse woody debris
Restoration and reconnection of seasonal streams
Removal of dams and other longitudinal barriers</td></tr>
</table>

Source: NWRM, 2019 and Reform, 2015

The specific ecosystem services provided depend on the measure, but all measures listed, support multiple provisioning and regulating & maintaining services.

Table 3: Qualitative effect of measures on ecosystem services. (Linked to Table 2)

Legend: Positive | Negative | Low-None

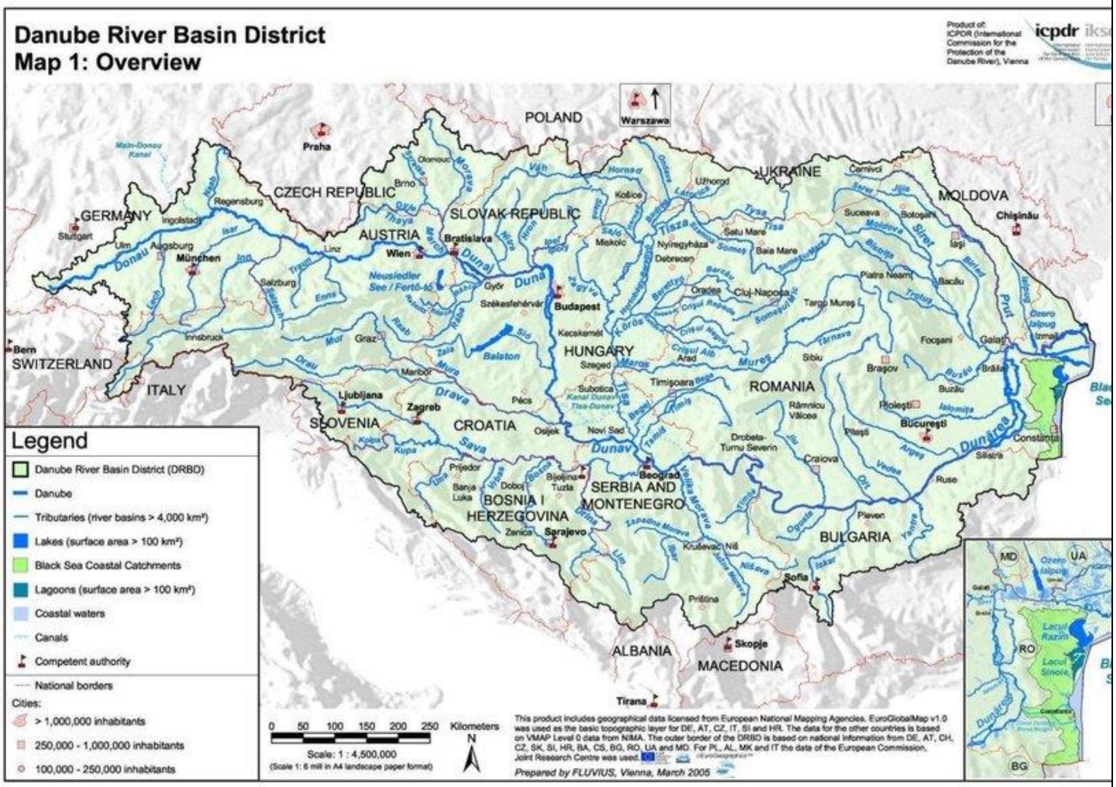
Measures	Ecosystem Services												
	Provisioning					Regulating & Maintaining							
	Geological resources	Clean water	Food production: Fish	Food production: Agricultural plant production	Food production: Agricultural animal production	Flood risk reduction	Carbon sequestration	Groundwater recharge and water storage.	Erosion control and prevention	Water purification	Seed dispersal	Soil conservation, formation & composition	Conservation of biodiversity
Wetland restoration		Positive	Positive	Negative	Negative	Positive	Positive	Positive		Positive	Positive	Positive	Positive
Reconnection of oxbow lakes			Positive			Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Meadows and pastures		Positive		Negative	Positive	Positive	Positive	Positive	Positive	Positive		Positive	
Buffer strips and hedges		Positive		Negative		Positive			Positive	Positive	Positive		
Forested riparian buffers			Positive	Negative		Positive	Positive		Positive	Positive	Positive	Positive	Positive
Dike relocation		Positive	Positive	Negative	Negative	Positive		Positive	Positive	Positive	Positive	Positive	Positive
Removal or lowering of dikes		Positive	Positive	Negative	Negative	Positive		Positive	Positive	Positive	Positive	Positive	Positive
Re-meandering		Positive	Positive	Negative		Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Stream bed renaturalisation	Positive		Positive			Positive		Positive	Positive				Positive
Riverbed material renaturalization		Positive	Positive			Positive			Positive				Positive
Natural bank stabilisation		Positive	Positive			Positive			Positive	Positive		Positive	Positive
Removal of bank protection	Positive		Positive	Negative		Positive			Negative		Positive	Positive	Positive
Renaturalisation of polder areas			Positive	Negative		Positive		Positive	Positive		Positive	Positive	Positive
Coarse woody debris	Positive		Positive			Positive			Positive				Positive
Restoration and reconnection of seasonal streams	Positive	Positive	Positive			Positive		Positive	Positive		Positive	Positive	Positive
Removal of dams and longitudinal barriers	Positive		Positive			Positive			Positive		Positive	Positive	Positive

Sources: Inspired by NWRM, 2019 and Reform, 2015, and based on expert judgement.

3.3 Examples of river and floodplain restoration

With increasing awareness, examples of river-floodplain systems restoration measures or works aiming to improve river-floodplain systems function are getting rising. In this sense, here we presented two examples aiming to improve river-floodplain systems conditions. One of them is work from the Danube river basin, which examines river-floodplain restoration potentials and showing broad sense collaboration perspective in the international river basin. The other is the Skjern River Restoration, which is one of the successful examples of river-floodplain restoration measures.

Box 4: Restoration activities on the Danube River: the need for international planning.



Danube river basin covers more than 800,000 square kilometres, 10% of continental Europe. It is the most international river basin in the world, which is shared by 19 countries, of which 11 are EU member states and 4 are candidate countries. More than 80 million people live in the Danube river basin and accordingly, a huge variety of human activities affects this area (ICPDR, 2015).

The Danube has highly valuable ecological diversity with its plants and animal species, and critical habitats. This biodiversity and habitats are under pressures which source from several drivers including hydropower, flood defence, navigation, agriculture, water supply, etc. Changes in the natural hydrological regimes and geomorphological process threat the Danube's river biodiversity, and disconnection of floodplains and wetlands represents one significant hydromorphological alteration in the Danube River Basin (ICPDR, 2015). Compared to the floodplain area of the 19th Century, only less than 19% of the former floodplain area (7,845 km2 out of a once 41,605 km2) remain in the basin (ICPDR, 2009). Along the Hungarian Danube south of Budapest and along the entire Romanian-Bulgarian stretch, most of the floodplains are disconnected by narrow flood protection dikes (ICPDR, 2008).

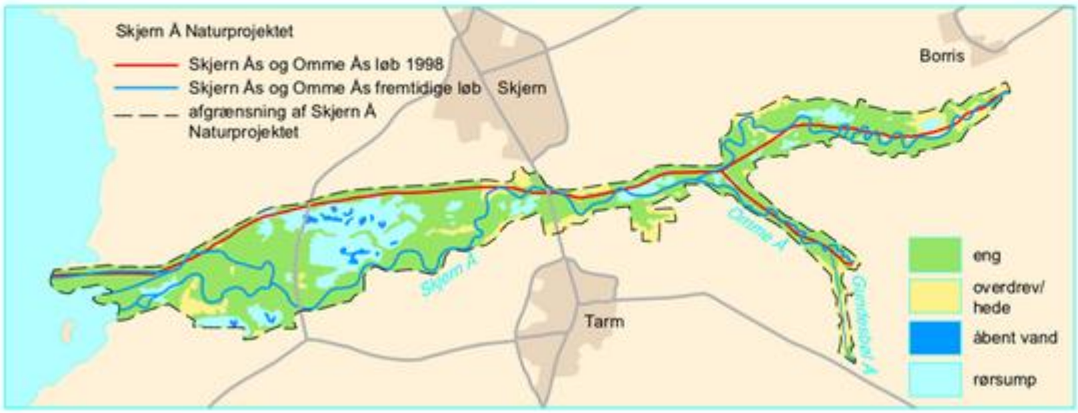
In the Danube basin, a total of 193,475 Ha of wetlands and floodplains have been identified to have a reconnection potential. Out of these and as part of the JPM implementation 2009-2015, 5,715 Ha are fully and 40,920 Ha are partly reconnected to the river. Where measures were already completed they have positive effects on water status and flood mitigation. In the future WFD cycles there are plans to reconnect additional 146,840 Ha of wetlands and floodplains to the Danube River or its tributaries (ICPDR, 2015).

Estimated effect of measures on the basin-wide scale

In the period between 2009 and 2015 more than 50,000 ha of wetlands and floodplains have been partly or totally reconnected, and their hydrological regime improved respectively. Measures for a further 15,000 ha are planned to be taken until 2021. Beneficial effects are expected to be manifold, including improvements in the functioning of the aquatic ecosystem like the provision of fish habitats for spawning, nursery and feeding. Next to being biodiversity hotspots helping to improve and secure water status, wetlands and floodplains play a significant role for flood retention.

Detailed analysis on the potential for reconnection, the establishment of an inventory, prioritisation and investigations on the different implications, what is planned to be accomplished until 2021 in coordination with the implementation of the EU Floods Directive, will help to gain further clarity on the estimated effects on the basin-wide scale.

Box 5: River Skjern, Denmark



This case study is an example of floodplain habitat change following first drainage and straightening and later restoration of a river in Western Denmark.

Catchment size (km2)	Length (km)	Average Discharge (m3/sec)	Flood Discharge (m3/sec)	Average Slope (%)
2100	94	36	200	0.07

Historically, the lower river Skjern (Denmark) ran through large areas with wetlands, many backwaters, islands and oxbow lakes and it contained a large variation in habitats. Also, natural sediment accretion at the river mouth formed a delta with extensive flooding as a consequence, leading to flood control attempts already in the 1800. In 1968, channelization and extensive wetland drainage was completed (red line, drawing above) with the aim of agricultural land reclamation. The channelization, however, led to major environmental degradation and in 2001–2002 a combined Danish and EU project transformed 19 km of channelized river into 26 km meandering river (blue line, drawing above), converting 2200 hectares of land back into lakes, shallow wetlands, meadows and meandering watercourses.

An evaluation based on 10 years of monitoring following the restoration, showed that the restoration indeed had reconnected the river with its floodplain and that riparian areas are today periodically flooded. Since the restoration, it has become a rest area for migrating birds, and populations of otter, amphibians, salmon and insects are increasing or improving. However, flooding is controlled and tamed due to the restoration design and the restoration has failed to re-create the natural habitats formerly present (Kristensen et al., 2014). Even if the river does not flood naturally, biodiversity has improved following restoration and the recreational value has increased. The area now supports a large tourism industry rooted in salmon fishing. Although value cannot readily be attached, the agricultural land would today have been of marginal value in comparison.

Box 6: Natura 2000 site restoration on the Ebro River, Spain

This case study demonstrates the need for integrated management across a large catchment.

Catchment size (km2)	Length (km)	Present Average Discharge 1985 – 2004 (m3/sec)	Former Average Discharge 1950 – 1985 (m3/sec)	Population
85000	930	310	410	2.7 mio

The Ebro River, Spain is an example of a river that has undergone large structural changes in the 20th century in response to increasing agricultural production and urbanization. The natural climate in the Mediterranean region is one with strongly seasonal precipitation patterns: high precipitation in the autumn and spring, and drought in the summer. With the aim of providing downstream flood control and storing water for later agricultural use, extensive dam and reservoir development has been undertaken in the 20th century. Today more than 130 dams and reservoirs are found in the watershed, and estimates suggest that 99% of its former sediment load never reaches the sea. The dams have stabilized water flow in the river and eliminated most floods, which in turn has stabilized the river channel. Unfortunately, however, the stable flows have also greatly impoverished ecosystems of the river and floodplain. The natural floodplain vegetation is characterised by pioneering species (provide examples: grasses, shrubs) due to frequent disturbances, but the stabilised hydrological regime has enabled forrests to develop in the floodplain; the natural rejuvenation processes no longer take place (Ollero, 2010; Díaz-Redondo et al., 2018)

Due to these disturbances, restoration of the Ebro river is a subject of active debate. Bank protection and dike structures were removed as part of the European LIFE+ 09 NAT/ES/000531 Project Mink Territory project between 2010 and 2015. The project aim was improving the conservation status of protected species, such as the European mink (*Mustela lutreola*), the otter (*Lutra lutra*), the European pond turtle (*Emys orbicularis*) and the Blackcrowned night heron (*Nycticorax nycticorax*). The conservation status of these species depends on the quality of the floodplain, especially that the hydraulic connections between river and floodplain are intact (Territoriovision, 2015).

Climate change scenarios for the Mediterranean underscore the importance of adapting river morphology to a setting where river dynamics and and floodplain connections are more intact because they allow the system to increase its water retention capacity, thus providing a buffer to both floods and drought. Past investments have shown that more traditional measures have not paid off, all though they have come at a large environmental cost (Díaz-Redondo et al., 2018).

However, improved management of the river will also require the collaboration among a large number of public autorities in regards to achieving the best possible plan for future management, and it is clear that the River Basin and Flood Risk management plans required as part of the Water Framework and the Floods Directives are key to achieving a long term strategy for more sustainable development of the Ebro watershed.

Photo: The European Mink (*Mustela lutreola*); Credit: Petr Mückstein (www.bio-foto.com)

4 Managing from an ecosystem perspective

Optimal management of floodplains requires strategies that aim at reducing economic losses and threats to human lives due to floods, while at the same time protecting the natural resources and functioning of floodplains.

The practical implementation of the Water Framework, Floods, Habitats and Birds Directives takes place through implementation of management plans. Whereas River Basin and Flood Risk Management Plans operate on the scale of river basin districts (180 river basin districts have been designated across Europe), the Habitat and Birds Directives operate with management plans for each Natura2000 site (more than 27 000 sites, covering 18% of Europe's territory (EEA, 2019c)).

Closing the implementation gap

In EU Member States, there are increased incentives in considering nature based solutions. Most countries report on using nature based solutions as measures in their Flood Risk Management plans (EC, 2019), and EU Member States are improving river hydromorphology as part of the River Basin Management Plans. Measures aimed at improving longitudinal continuity, river restoration, improvements of riparian areas, removal of hard embankments, improvements of flow regime or nature based solutions are reported. Moreover such solutions have been found to be a cost-efficient means of reducing flood risk while at the same time supporting other ecosystem oriented objectives (EEA, 2017b).

There are, however, also gaps in implementation. The analysis of the first Flood Risk Management Plans showed that almost all countries consider some aspect of climate change, but only 10 EU Member States had serious reflections of climate change impacts (EC, 2019). Many Member States could not factor in the impact of climate change on the magnitude, frequency and location of floods. Generally, historical data were used. They carry the risk of not reflecting future weather conditions or potential changes in the frequency and severity of floods (ECA, 2018). Improving these assessments will be a key effort in the next round of Flood Risk Management Plans. The outlook of altered flood risk due to climate change, further emphasises the importance of establishing Flood Risk Management Plans that consider possible changes to flooding in coming years together with the need for increased water retention. Investments in restoration projects made through programmes like LIFE + is likely to act as an EU level driver for more river and floodplain restoration building on methods that enable natural water retention.

The need for more holistic planning recognised by the Strategic Environmental Assessment Directive (EC/42/2001), which requires that plans such as the flood risk, river basin, or protected sites management plans are assessed in regards to their ability to promote over all sustainable development. It is used as a tool to assess cross boarder coherence of river basin management plans in international river basin districts and to secure that planned development indeed is sustainable from the point of view of cross-policy environmental objectives. Often considerations under this Directive lead to altering plans towards more sustainable solutions (EC, 2015).

The more forward looking question of what is actually needed to meet targets across directives, within a catchment and on a decadal timescale, however, remains unanswered. Possibly, this gap could be filled by an ecosystem based management approach where the impact of multiple land use activities is reconciled against environmental objectives. Although the need for river and floodplain restoration is widely acknowledged through the Water Framework, Floods, Habitats and Birds Directives, it is usually not assessed from a holistic river basin management perspective, nor are restoration needs considered at the scale of a catchment or river basin. Restoration measures are in competition with many other uses of the river-floodplain system, and a more holistic analysis could support balancing management priorities. Large river restoration project are costly and time demanding undertakings. Hence it is natural and probably also desirable that they are carried out one project at the time. However, a perspective on restoration needs within a river basin, from a holistic and cross-policy perspective could be very helpful for informing the management and planning process.

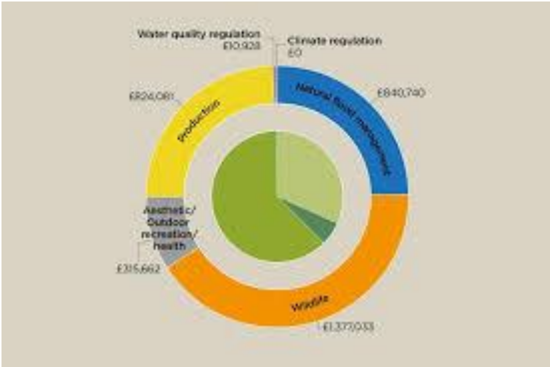
Improved coherence

Many decisions related to water management also have profound impact on habitats and species that depend on water. While river basin and flood risk management plans attempt to coordinate measures, this is less the case with Natura 2000 management plans. An assessment of the Natura 2000 network concluded that the network had not been implemented to its full potential, in part due to incomplete management plans and follow-up (ECA, 2017). Coordination across the Water Framework, Floods, Habitats and Birds Directives may also be hampered by the large difference in scale between the planning areas. However, as shown in this analysis, many of the services provided by the floodplain also benefit biodiversity, and the measures that achieve improved ecological and conservation status are often the same.

Managing from the perspective of ecosystem services enable a system where the relationship between services and trade-offs between competing service provision can be evaluated. This is not straightforward to accomplish, but compelling examples such as the restoration of Chimney Meadows, UK that demonstrate an almost 6 fold increase in value of a restored area through consideration of multi-functional aspects of the area (Box 7), suggest that there is a lot to be gained using such approaches. Once a holistic assessment of watershed or river basin priorities are available, it becomes more straightforward to inform the planning process on management trade-offs needed to establish a more sustainable use scenario.

Box 7: Chimney Meadows: An approach based on ecosystem services assessment

An example of how to approach an ecosystem assessment has been shown for the nature reserve Chimney Meadows in the UK. Chimney meadows is a 260 ha farm which was purchased with the aim of converting its intensive agricultural production into a species rich floodplain meadow and wetland habitat for wading birds. The arable land was converted into a combination of grassland, fens, marsh and swamp area. Although the value of the agricultural production decreased, the area provided almost 6 times greater value following the restoration because the value of other services increased, and new services of climate regulation and water regulation were added. Prior to restoration, services encompassed agricultural production, natural flood management, wildlife habitat and outdoor recreation. Following restoration, which mainly comprised of converting arable land into marsh and swamp area, the value of agricultural production decreased but new, more valuable water and climate regulating services were established, and the value of flood protection, wild life and recreational services also increased.

	
Ecosystem services and their value prior to restoration	Ecosystem services and their value following restoration.

Source: Lawson et al., 2018

The example for Chimney Meadows suggests, improved floodplain management can be achieved through optimisation of the ecosystem services delivered by implementation of specific restoration measures. This is, however, a complex undertaking, and achieving positive results requires a combination of political prioritisation, planning of relevant measures, corporation among multiple governing institutions, as well as an active stakeholder process, often spanning across years. Although such processes are often challenging and difficult, there are many examples of very positive outcomes.

As shown in the example of Chimney Meadows, the delivery of provisioning services tend to take place at the expense of regulating & maintaining and cultural services, and in this example, reducing the intensity of provisioning services, gave rise to increased value of other services. Realising this potential often requires restoration and changed land use practices.

Recently, it has, however, become increasingly apparent that there are considerable benefits to be realised from this more holistic approach. Through restoration, it may be possible to initiate a development trajectory over time where the overall value of ecosystem services is increased (Figure 4.1). Historically, rivers have undergone an impact phase, with high priority given to provisioning services. In a river restoration phase, the increased value of regulating and cultural services is prioritised, although possibly at the expense of provisioning services. However, the result of the restoration could be a higher overall value of the services delivered. The overall aim of holistic planning should be to establish the needs of this development trajectory.

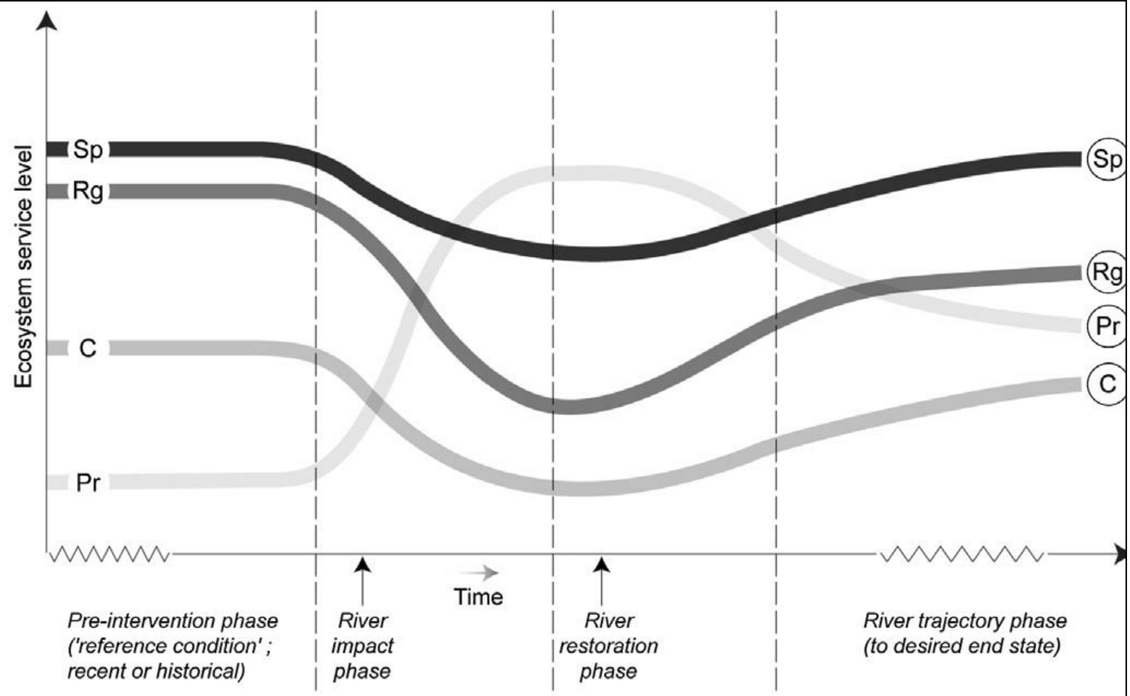


Figure 4.1: Trade-offs between ecosystem services. Source: Gilvear et al., 2013

Sp= Total services provided, Rg= Regulating and maintaining services, Pr= Provisioning Services, C= Cultural and recreational services

Improved cooperation

It is important that all stakeholders are involved in the prioritisation process. The quality of their cooperation whether institutions, authorities or the public, influences the outcome of implementation (Sander, 2018). Water management authorities typically work at river basin and catchment scales, while land use planners typically work at the scale of administrative areas, such as municipalities. As a result, their planning units often do not match up, creating barriers in terms of integration (EC, 2014).

Floodplain restoration projects will face large opposition if they do not make sense to the local community or to landowners affected by the restoration. Hence, in the planning phase there is a need to be transparent in communicating the project aims and to be open to changes. Overall, public support has been found to be essential for the success and acceptance of floodplain restoration measures. It has also been found that once completed, a large majority of the local population greatly value the restored area. An analysis of public acceptance towards river restoration in Germany found that even in full awareness of the costs of restoration projects (approximately 400,000 Euros per river km), 70% of the interviewees regard further restoration projects as useful and only 6% as not useful (Deffner and Haase, 2018). An example of citizen engagement is provided in Box 8,

Box 8: Engaging citizens in the development of restoration and Flood Risk Management Plans in the Orbigo River Basin (Spain)

The Orbigo River in Spain has been severely modified. Originally a braided river, embankments were stabilized and the river channelized to protect the agricultural land, settlements and other infrastructure. This had strong impacts on the aquatic ecosystem and the species and habitats that today are also part of a Natura 2000 site.

The restoration project aimed at recovering the longitudinal and lateral connectivity of the river through removal and set back of levees and adapting weirs and other transversal barriers. By restoring river connectivity with the floodplains, the hydraulic storage capacity of the river during floods was increased, and multiple natural processes were restored, incl. the recovery of the natural floodplain, an increase in species and habitat diversity and the recharge of the alluvial aquifer. The project is a good example of multiple benefits of one restoration measure on the Floods, Water Framework, Habitats and Birds Directives, by reducing the negative effects of floods, improving the ecological status of the water bodies and enhancing the diversity of species and habitats.

Due to the concerns of the citizens living near the river, a large public participation process was initiated. The public was informed from the beginning of the initial design to the implementation of the measures. About 50 meetings were held. Citizens were actively involved in the decision-making process. This was an innovative approach since up to then, public participation was merely an administrative formality. Public participation provides communication and transparency, in order to get social consensus and shared decision making, given that social acceptance is also essential for the success of a project that is using solutions of green infrastructure for the first time after so many years of grey solutions carried out in the latest 50 years (Global Water Partnership, 2015) .

5 Conclusions and Outlook

Floodplain conservation and restoration is necessary for achieving good ecological status of the Water Framework Directive and good conservation status of species and habitats that depend on water of the Habitats and Birds Directives. Floodplains are widely recognised as an important part of the river system, and environmental improvements in floodplain are likely necessary to improve the ecological status of rivers and conservation status of species and habitats found in the unique floodplain environment.

The path to improving the environmental condition of floodplains has been established through European policies. Specifically, the link between the Floods and Water Framework Directives is essential because it establishes the need to consider other ways of providing flood protection than traditional structural measures. Strengthening the link between River Basin, Flood Risk and Natura 2000 management plans could support achieving good conservation status for species and habitats that depend on water. Often the same measures could fulfil achieving objectives for all directives.

Exactly how much restoration is planned or needed is not clear at present partly because this cannot be extracted from River Basin or Flood Risk Management plans, and planning across the three directives does not take place. Ecosystem based management could provide a unifying concept for developing a shared approach among the Water Framework, Floods, Habitats and Birds Directives. Such an approach would also support development of a more coherent knowledgebase.

At the same time it is clear that implementation of restoration projects is complex, and balancing the many trade-offs are likely to be needed. It may be helpful to support the flood risk, river basin and protected sites management plan process with a more holistic ecosystem based analysis to support the development of long term strategies towards achieving environmental objectives.

Today, the knowledgebase linked to understanding both the floodplain conditions and improvements achieved over time is still very limited; more is needed to develop a European overview. An actual assessment of floodplain condition that also enables tracking changes over time is still needed in order to approach assessment towards the 15% restoration target. Also more knowledge is needed on the link between restoring floodplains and achieving policy objectives. Today, the knowledge base is very fragmented. While the Water Framework Directive has been instrumental in establishing the importance of hydromorphological status for achieving good ecological status in rivers, many different methods and assessment approaches are in use, challenging a consistent European overview.

List of abbreviations

Abbreviation	Name	Reference
EEA	Eureopean Environment Agency	www.eea.europa.eu

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Annex 1 European and Global Policy Context

Achieving the objectives of policies in Table 1, requires that policy commitments are considered across policies. Below it is summarised how achieving objectives of one policy may support achieving those of another.

Global Sustainable Development Goal 6.6 - By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes: Recognises that ecosystem health of floodplains as part of wetland and river ecosystems are an essential element for achieving a sustainable future in a global context, hence also in Europe.

EU Water Framework Directive (2000/60/EC): The overarching objective of the EU Water Framework Directive is to provide a framework for the inland surface waters which prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems (WFD, Art 1(a)). Achieving the WFD objective of good ecological status is supported by an increased area of natural, active floodplains due to their enhanced water and nutrient retention capacity. Achieving good ecological status in rivers, among others, requires minimizing hydromorphological and pollution pressures. Diffuse nutrient pollution is reduced where floodplains are more natural. Hydromorphology in rivers is defined by hydrological regime, river continuity, and morphological conditions. These parameters are impacted by structural flood control measures that also disconnect floodplains from their river. The main management tool of the WFD is the development of River Basin Management Plans for River Basin Districts and it is in this context that diffuse pollution and hydromorphological pressures should be addressed (EEA, 2016; EEA, 2018).

EU Biodiversity Strategy, target 2 (COM/2011/244): It is required that ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems by 2020. Increasing the area of natural floodplain will explicitly support achieving this target.

EU Floods Directive (2007/60/EC): The key objective of the Floods Directive is to reduce flood risk across Europe, also in the light of climate change. Through emphasis on natural water retention measures, flood risk reduction can support achieving water management and conservation objectives. The main management tool of the Floods Directive is the development of Flood Risk Management Plans for the same River Basin Districts as defined by the Water Framework Directive (EEA, 2016).

EU Habitats and Birds Directives (1992/43/EEC & 2009/147/EC): Floodplains are highly valuable habitats and form an important part of the Natura 2000 Network. Analyses from DE and NL suggest that a considerable share (around 50-60 %) of nationally designated Natura 2000 sites are active floodplains. Several habitats and species listed in the Habitats Directive (Annex I habitat types and Annex II species) are found on active floodplains, as are birds encompassed by the Birds Directive. Increased area of active floodplains is likely to improve conservation status assessments of listed habitats and species (EEA, 2015; EEA, 2016).

EU climate change adaptation strategy and disaster risk reduction (COM/2013/0216): Climate change may increase the risk and vulnerability to floods in disaster prone areas (areas of potential significant flood risk). Floods may cost lives and are the cause of billions of euros of damage and insurance costs each year in the EU. Floodplain restoration is one approach to mitigate extreme flood events. A better understanding of the role of floodplain management can help develop measures to mitigate the effects of climate change and extreme weather events (EEA, 2016; EEA, 2017a).

Green Infrastructure (GI) — Enhancing Europe's Natural Capital (COM/2013/0249): Green infrastructure is identified as an important step towards protecting natural capital. Natural water retention measures are part of green infrastructure (EEA, 2017b). Consequently, floodplains provide key contributions to Green Infrastructure.

Common Agricultural Policy and the Nitrates Directive

Floodplain restoration can be partially funded as part of the subsidies provided under the Common agricultural Policy for Rural Development Plans, but are not widely used. The Rural Development Plans provide funding of several measures related to floodplain restoration. In the current Rural Development Plans, Member States have used six different measures to subsidize floodplain restoration: M4.4 (non-productive investments, M5 (Prevention or Restoration after a weather event), Measure 7 (basic services) Measure 8.4 and 8.5 (floodplains linked to forests) and M10. In addition Rural Development Plans could finance flood prevention efforts. An analysis of 52 final, approved Rural Development Plans (all national and a selection of regional RDPs) found that to tackle morphological pressures, wetland restoration (33% of RDPs), floodplain management (29% of RDPs), re-meandering (19% of RDPs), and the removal of embankments and dykes (19% of RDPs) were cited most frequently (Rouillard and Berglund, 2017).

Under the Article 3(2) of the Nitrates Directive, EU MS establish buffer strips along water courses that must respect requirements for land application of fertiliser near water courses. Buffer strips are usually found in floodplains or on riverbanks, but there is no requirement for them to resemble a natural system, although they are established to reduce nutrient inflows to the river. Buffer strips are one of the most widely adopted measures in Europe.

Annex 2 Definitions

The terms natural water retention measures, green infrastructure, and nature based solutions are used interchangeably, but do have different meanings

Green infrastructure is a strategically planned network of natural and semi-natural areas with environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities and enhances biodiversity. The Natura 2000 network constitutes the backbone of the EU green infrastructure. The European Commission has developed a Green Infrastructure Strategy (COM/2013/0249). This strategy aims to ensure that the protection, restoration, creation and enhancement of green infrastructure become an integral part of spatial planning and territorial development whenever it offers a better alternative, or is complementary, to less sustainable choices (commonly referred to as grey infrastructure).

Natural water retention measures target restoration or maintenance of aquatic ecosystems through developing, restoring, or maintaining the environmental capacity to store water based on natural processes. Natural water retention measures can stand alone or support a green infrastructure network, if one is present.

Nature based solutions refer to the sustainable management and use of nature for tackling societal challenges such as climate change, water security, food security, human health, and disaster risk management. The term is not used widely in EU policy, but is used in the environmental management community and has a broader meaning that natural water retention measures.

Ecosystem-based management refers to managing multiple human activities and their pressures with the aim of ensuring healthy and resilient ecosystems while at the same time delivering the services that people want and need (McLeod and Leslie, 2009). Ecosystem-based management is a concept derived within the scientific community. It has not been adopted as such in EU environmental policies, although many of its elements (eg having ecosystem health as a key objective) are embedded in them. The notion of the need to reconcile many different priorities while maintaining a healthy ecosystem for the same area is key to all environmental management decisions, and in this context an ecosystem based approach can be a helpful tool.

Annex 3 Ecosystem service overview

Figure/Map/ Table/Box A1.1 Caption

Main Sections	CICES Group	Ecosystem service / CICES class	Specific examples for floodplains	Environmental Policy relevance
Provisioning		**Geological resources**	Gravel mining	
	Surface or groundwater used for nutrition, materials or energy	**Clean water /** surface and groundwater for drinking	Provision of water	
	Reared and wild aquatic animals for nutrition, materials or energy	**Food production: fish**	Nursery areas for wild species and sites for aquaculture	
	Cultivated terrestrial plants for nutrition, materials or energy	Food production: **agricultural plant production** / cultivated plant production	Floodplains are used extensively for agricultural plant production due to extraordinarily fertile soils	
	Reared animals for nutrition, materials or energy	Food production: **Agricultural animal production** / animals reared to provide nutrition	Grazing on floodplain areas	
Regulation & Maintenance	Regulation of baseline flows and extreme events	**Flood control**	Floodplains potentially have a large water retention capacity which buffers against floods and droughts. If water is allowed space to spread horizontally during floods, the overall magnitude of the flood is reduced. Vegetated floodplains trap water during floods. This can create a blockage to water passage, thus increasing flood height, but it also decreases the speed of downstream water movement, reducing flood height. Trees and other vegetation remove large quantities of water through evapotranspiration.	FD: reduction of flood risk Climate change adaptation
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation: **Groundwater recharge and water storage**.	During floods, groundwater reservoirs will be recharged with water flooding from the river on to the floodplain. The storage capacity of floodplains minimises extreme groundwater fluctuations	Climate change adaptation WFD: good groundwater quantitative status
	Regulation of baseline	**Erosion control and prevention**	Vegetated floodplains stabilise river banks and controls soil erosion	WFD: Hydromorpho-logical condition

Main Sections	CICES Group	Ecosystem service / CICES class	Specific examples for floodplains	Environmental Policy relevance
	flows and extreme events			
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae,plants, and animals: **Water purification**	Microorganisms in floodplains remove nitrogen through denitrification during flood events and subsequent high groundwater levels.	WFD: good ecological status WFD: good chemical status
	Regulation of soil quality	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals: **Carbon sequestration**	Organic carbon from either river sediments or floodplain vegetation accumulates in floodplain soils.	Climate change mitigation
	Regulation of soil quality	**Soil conservation, formation & composition**: decomposition and fixing processes and their effect on soil quality	During floods, nutrient rich sediments are removed from the river and deposited on flood plain, hence reducing nutrient concentration in the river. This creates new fertile sediment deposits, and often changes the substrate structure and composition. However, in case of upstream pollution, this mechanism can generate long lasting negative impact.	HD: Relevant for species richness
	Lifecycle maintenance, habitat and gene pool protection	**Seed dispersal**	During regular floods seeds are dispersed throughout floodplains securing species resilience.	WFD: good ecological status HD: Species conservation and richness
	Lifecycle maintenance, habitat and gene pool protection	**Conservation of biodiversity**: maintaining nursery populations and habitats (Including gene pool protection)	Regular flooding creates a multitude of ecological niches, making floodplains hotspots of biodiversity.	HD: Species and habitat conservation
Cultural	Physical and experiential interactions with natural environment	**Recreation**	Floodplains are used for a multitude of recreational activities.	Positive experiences by the public generates acceptance of objectives of other policies.

Annex 4 Measures that improve services

Figure/Map/ Table/Box A1.1 Caption

Selected Measures	Qualitative description of the measure
Wetland restoration and management	- Contributes to flood attenuation via water retention, provides water quality improvement, and habitat and landscape enhancement. - Encompasses both spatially large-scale and small-scale measures, such as; clearing trees, cutback of dikes to enable flooding, changes in land-use, and agricultural measures like adapting cultivation practices in wetland areas.
Reconnection of oxbow lakes and similar features	- Favours the overall functioning of the river by restoring lateral connectivity, diversify flows and improve water retention during floods. - Consists of several measures, such as removing terrestrial lands between both water bodies and cleaning the river section of the present oxbows.
Meadows and pastures	- Offers the potential for temporary flood storage, increases water retention and runoff attenuation via reducing the surface flow of water and allowing greater infiltration to the soil. Also protects water quality by trapping sediments. - Soil cover is maintained at all times with meadows and pastures which are rooted vegetation.
Buffer strips and hedges	- Improves water filtration, slows surface flow, and thereby promotes the natural retention of water. It can also improve water quality by reducing the amount of nitrates, phosphates and suspended solids originating from agricultural run-off. - Encompasses maintaining or re-establishment of natural vegetation cover (grass, bushes or trees) at the margin of fields, arable land, transport infrastructures, and watercourses. Although forest riparian buffer measure is one of the buffer strip measures, it is considered as a separate measure because it generally has a different design, implementation, and management criteria.
Forest riparian buffers	- Serves a number of functions related to water quality and flow moderation. Excess nutrients can efficiently be taken up by the trees in riparian areas. Riparian buffers also slow water and increase infiltration and this improves water retention and can decrease sediment inputs to surface waters. - Tree covered buffer strips alongside the stream and the other waterbodies are maintained and re-established. This measure also mostly associated with set-asides following forest harvest, but it is also important for urban, agricultural and wetland areas.
Setting-back of embankments and dikes / dike relocation	- Enlarges the storage capacity of a floodplain and leads to enlargement and restoration prospects for a floodplain. It also provides an adequate area to enhance hydrological and geomorphic processes, improves the potential to restore some elements of the riparian ecosystem, and promotes instream habitat heterogeneity (Rohde et al., 2005). - Remove embankments on both side of rivers and relocate them further from the river. Maintaining the bank protection, groins or anchored tree fascines can be installed after widening (Set back embankments, levees or dikes - REFORM wiki, forthcoming).
Removal/lowering of minor embankments	- Enlarges the effective river floodplain. Increases physical, hydrological and other natural processes (Roni et al., 2005). Supports habitats. - Encompasses lowering the embankments to allow floodwaters to reach the floodplain and removing embankments entirely.

Re-meandering	- Increases the storage capacity of a river channel, decrease a river's slope and water velocity. Improves lateral interactions, sedimentation process, and biodiversity. Provides habitat for a wide range of aquatic and land species. - Consists in creating a new meandering course or reconnecting cut-off meanders.
Stream bed renaturalisation	- Improves the erosion process, supports habitat richness, and increases travel time of water. - Consists in removing concrete or inert constructions in the riverbed and on riverbanks and replacing them with other natural structures like vegetation.
Riverbed material renaturalization	- Increases habitat types, improves the natural process and lateral connectivity of rivers, support sediment controls. - Consists in recovering the nature-like structure and composition of the bed load and setting the equilibrium between coarse and fine sediment.
Natural bank stabilisation	- Decreases degradation and erosion, and increases rivers' natural movement and habitat richness. It also increases pollutant and sediment filtration process. - Consist in recovering ecological components of riverbanks via application of bioengineering.
Elimination of riverbank protection	- Enhances lateral connections of the river, diversify flows (depth, substrate, and speed) and habitats, caps floods in the mainstream. It is a prerequisite for many other measures like re-meandering or widening, as well as initiating later channel migration and dynamics. - Consists in removing some parts of the bank protections.
Renaturalisation of polder areas	- Increases the storage capacity of a floodplain, reduces flood risk, supports erosion and sediment control, and increase habitat richness. - Consists in enhancing polders with sub-natural characteristics, allowing better water storage in watercourses inside the polder.
Coarse woody debris	- Slows water flow velocity and can reduce the peak of flood hydrographs. Retains food and provide additional habitat for aquatic life, such as refuges and spawning sites. Woody debris can also increase sediment storage in the stream and aggrade streambeds. - Consist in installing logjams (woody debris) using local timber materials.
Restoration and reconnection of seasonal streams	- Provides essential ecosystem services to society, including flood control and irrigation. Favours the overall functioning of the river by restoring lateral connectivity, diversifying flows and ensuring the proper functioning of these seasonal streams for better water retention during floods. - Consist in maintaining and protection of the river system, its natural dynamics, and its environment; in particular, removing terrestrial lands between the river and the seasonal streams, preservation of buffer space, limitation of abstraction or pumping
Removal of dams and other longitudinal barriers	-Restores the slope and the longitudinal profile of the river, therefore allowing re-establishment of fluvial dynamics, as well as sedimentary and ecological continuity. -Consist in removing of longitudinal obstacles, especially inert ones.