EEA Report | No 24/2019

Floodplains: a natural system to preserve and restore

ISSN 1977-8449

25 1994-2019
European Environment Agency

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Cover design: EEA
Cover photo: Lindenborg River at Gravlev © Mads Christiansen
Layout: Rosendahls a/s

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Luxembourg: Publications Office of the European Union, 2020

ISBN 978-92-9480-211-8
ISSN 1977-8449
doi:10.2800/431107

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REG.NO. DK-000244

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Acknowledgements

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European Topic Centre on Inland, Coastal, and Marine waters (ETC/ICM) contributors: Lidija Globevnik, Luka Snoj, Mathias Scholtz, Christiane Schulz-Zunkel, Klaus Henle, Ursula Schmedtje, Eleftheria Kampa, Sebastian Birk, Jochem Kail, Kathrin Januschke, Jeanette Völker, Anne Lyche-Solheim.

The report team would also like to thank colleagues and stakeholders for their contributions: Ioannis Kavvadas and Frank Vassen, Directorate General for the Environment, European Commission.

EEA staff: Wouter Vanneuville, Peter Kristensen, Carlos Romao, Jan-Erik Petersen, Hans-Martin Füssel, Andrea Blatter, Rozle Kaucic, Caroline Whalley, Nihat Zal, Markus Erhardt, Gorm Dige, and Stéphane Isoard

EEA member countries in the National Reference Centre for freshwater under the European Information and Observation Network (Eionet), especially a very thorough review provided by Martina Bussettini.

Key messages

- Floodplains are an important part of Europe's natural capital, covering 7 % of the continent's area and up to 30 % of its terrestrial Natura 2000 site area. Statistics on the spatial extent and land use distribution of floodplains in Europe are available from the floodplain statistics viewer (https://www.eea.europa.eu/data-and-maps/data/data-viewers/floodplain-areas).

- Floodplains are found at the interface between rivers and their catchment. Studies have shown that 70-90 % of floodplains have been environmentally degraded as a result of structural flood protection, river straightening, disconnection of floodplain wetlands, agricultural land use and urbanisation over the past two centuries. The largest pressures on floodplains are linked to hydromorphological pressures, land use, and pollution.

- Important ecosystem services of a preserved or restored floodplains include natural water retention, carbon sequestration, water purification, habitats and biodiversity, and recreation. In degraded floodplains, the quality and quantity of these services is reduced.

- The ecosystem services provided by preserved or restored floodplains support achieving key objectives of the Water Framework Directive, the Habitats and Birds Directives, and Floods Directive. Presently, only 40 % of waterbodies achieve good ecological status and 17% of floodplain habitats achieve good conservation status.

- The most important pressures to tackle are linked to hydromorphological pressures, land use and pollution. Some land use practices increase flood risk potential and in part, hydromorphological pressures are linked to flood defence structures.

- Floods remain one of the most costly natural disasters and, in parts of Europe, climate change is anticipated to increase the flood risk. Developing strategies for managing flood risks that also provide benefits for other aspects of the environment is an important challenge. Nature based solutions have been shown as a viable and cost efficient alternative to structural measures.

- Preserved and restored floodplains have the potential to greatly increase the value and number of ecosystem services compared with ones solely optimised to deliver provisioning services. Exactly how much restoration is planned or needed to capitalise this potential is, however, not known at present.

- Ecosystem-based management could provide a unifying concept for developing a shared approach among the Water Framework, Floods, Habitats and Birds Directives and could be developed based on existing legislation that contains the most important elements. It could also support the development of a more coherent knowledge base.

- Ecosystem-based management and floodplain restoration requires the prioritisation of benefits, planning, public support, investment and time. EU and national funding instruments are available to support restoration. Although implementation is cumbersome and costly, there are many examples of successful restoration projects that are also greatly appreciated by the public because of their recreational qualities.

- Under the European Green Deal, climate change, biodiversity, eliminating pollution and the 'farm to fork' strategy are four policy areas that will support the achievement of its overarching objective. Floodplain restoration and ecosystem-based management, as described in this report, are important elements for achieving the objectives of the European Green Deal.

Executive summary

From 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 water bodies. In particular, this is because pressures from hydromorphology and diffuse pollution affect one third of water bodies in Europe. On average, approximately 40 % of Europe's surface water bodies achieve good ecological status or potential (EEA, 2018b). Similarly, an analysis of the conservation status of 37 floodplain habitats listed in the Habitats Directive shows that the vast majority have either inadequate or bad conservation status. Across Europe, only 17 % of floodplain habitats and species have good conservation status. These results are in line with global developments that show biodiversity decline that may eventually threaten human well-being (IPBES, 2019).

Although difficult to quantify, there is a link between the overall state 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 is only indirectly required under European environmental policies; however, floodplains that are maintained in their natural condition support the achievement of multiple European policy objectives, which are central, among others, to improving biodiversity and ecosystem services.

The flood risk is increasing in parts of Europe. Reconciling environmental objectives with flood risk management probably requires moving away from structural flood protection because it is a major source of floodplain degradation. Because of the multiple benefits provided by natural floodplains, EU policies encourage floodplain and river restoration based on nature based solutions, as well as conservation of existing natural floodplains, to be adopted in river basin or flood risk management plans, conservation plans and climate change adaptation plans. To this end, the link between the Water Framework and Floods Directives is essential. By recognising a shared objective, a clear incentive is provided to base flood risk management on nature based solutions.

Nature based solutions refer to initiatives in which 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 both cost effective and an integral part of ecosystem based management; they can include both morphological changes to the river and floodplain, and changes that involve managing land use within the floodplain. The EU promotes the increased use of nature based solutions as part of its green infrastructure initiative and has co-financed floodplain and river restoration projects through the LIFE+ programme and EU structural funds. Most countries also report the use of nature based solutions as measures in their flood risk management plans (EC, 2019c).

Recognition and prioritisation of the multitude of benefits provided by floodplain and river restoration could be ensured by using an approach rooted in ecosystem-based management when developing river basin and flood risk management plans. Such an approach would ensure that the multitude of benefits of potential restoration measures are considered, devising solutions suitable for meeting environmental objectives set across policies. In this context, this report is relevant for four priorities under the European Green Deal: climate change, biodiversity, eliminating pollution and the farm to fork strategy.

1 Introduction

1.1 Scope of the report: why care about floodplains?

Rivers are much wider than the channels we associate them with. River banks and the areas next to rivers, which are covered by water only during floods, are also part of the river system, and these areas act 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, store CO_2, ensure both natural flood protection and the healthy functioning of river ecosystems, and help sustain the high biological diversity present in these systems.

Today, floodplains are widely degraded and do not deliver the same level of services as natural floodplains. Estimates made based on the Danube, Ebro and Seine rivers and some German rivers suggest that, today, 70-90 % of Europe's floodplains are ecologically degraded (EEA, 2016a). These changes are of such magnitude that scientists talk of there having been a regime shift in the ecological functioning of many rivers since the introduction of anthropogenic pressures (Tockner and Stanford, 2002).

In 2018, the results of the second river basin management plans were published, among others, showing that currently only 40 % of Europe's rivers achieve good ecological status or potential (EEA, 2018c). Hydromorphological and diffuse pollution pressures are the two main pressures on water bodies and affect roughly one third of water bodies in Europe. Both of these pressures can be reduced through the improved management and restoration of floodplains and rivers, which could also benefit river and riparian ecosystems, habitats and species.

Rivers and floodplains have gradually degraded over recent centuries. Public safety from flooding and flood protection has developed and Europe's large rivers are important transport corridors, supporting trade over large distances. Improvements for 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 the security of the food supply.

Although these historical changes have supported both economic growth and flood protection, they have also had serious environmental consequences. The solutions that have been 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.

These changes have also made today's floods more damaging — flood waves today are higher and travel faster down the straightened rivers than in the past. They also carry larger amounts of fine sediments, creating larger deposits than would have been the case under more natural conditions. Further damage linked to fragmentation and reduced flooding 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.

Climate change projections suggest that challenges in managing floodplains will increase. In parts of Europe, high-intensity rainfall will increase, while in other areas drought could become more frequent. This may lead to altered flood risks, which could potentially increase the demand for structural flood protection in parts of Europe, while the demand for structural water storage will increase in other parts of Europe. The transition towards a green energy system will also increase the demand for hydroelectric energy, as it remains the only method for renewable energy storage.

Floodplains are an important part of Europe's natural capital, covering 7 % of the continent's area and up to 30 % of its terrestrial Natura 2000 site area. The new sediments brought to the floodplain during regular floods make floodplains naturally highly fertile areas. Combined with the use of rivers for transport, this has historically made floodplains ideal sites for human settlement and agriculture. Many of Europe's major cities are located on floodplains. While they are home to multiple protected species and habitats, they are also now home to 12 % of Europe's population;

in the Netherlands, this figure rises to more than 25 %. Agriculture is linked to an average of 55 % of land use activities, and the drive for increased urbanisation and economic growth continue to change Europe's river systems.

The ecosystem services provided by natural floodplains contribute considerably towards achieving environmental policy objectives. Because of their large degree of degradation, extensive river and floodplain restoration that improves the ecological integrity of these systems is needed to improve the current situation. The combined challenge of gaining recognition of the importance of such restoration, the need for altered land use practices, acquiring investments in restoration and gaining public acceptance makes floodplain restoration a major societal challenge that is further exacerbated by complex institutional barriers (Moss and Monstadt, 2008).

In Europe, the existing policy framework provides a unique opportunity to include floodplain assessments more systematically in future assessments and planning in the context of river basin and flood risk management plans. These plans can be further strengthened if the notion of ecosystem-based management is used to set priorities for altered land use management and restoration needs. Ecosystem-based management provides a system for the prioritisation of benefits across policies that enables reconciliation of multiple and sometimes conflicting land use objectives.

This report aims to provide an overview of the different aspects of floodplain management. In this first chapter we describe the global and European policy framework that covers floodplains. In Chapter 2, the basic characteristics of the floodplain-river system are provided and a description is given of how land use and populations in floodplains are distributed among the 33 EEA member countries and six cooperating countries ([1]) (EEA-39). In Chapter 3, some of the key ecosystem services provided by floodplains are described, together with approaches to river and floodplain restoration and examples of successful restoration projects. In Chapter 4, the conditions for successful implementation are discussed.

Overall, the analysis points to there currently being a fragmented management approach that would benefit from streamlining across Europe, to better prioritise land use practices and river restoration. Management could be improved through more stringent implementation of ecosystem-based management. In addition, it provides the context for a floodplain condition assessment, which is currently under development by the EEA and the European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM).

This report builds on other publications produced by the EEA, in particular (EEA, 2016a, 2016b, 2017b). In these reports, EEA examined the challenges linked to water management in cities, synergies between floodplain restoration and EU policies, and cost efficient flood risk reduction based on green infrastructure.

1.2 The catchment-floodplain-river system and EU policies

In their natural condition, rivers and floodplains are laterally connected, exchanging water, sediments, biota and nutrients in a shared natural system that also has a large capacity for CO_2 storage. Thus, floodplains act as a buffer between the catchment and the river; a floodplain's quality is closely linked to conditions in the river and within the catchment. Therefore, many of the human activities that lead to pressures on rivers and floodplains need to be managed at the catchment scale, while specific impacts are observed in the river and floodplain. Changes in river flow, sediment input, forest management, water transfers, agricultural activities and urbanisation all have the ability to change conditions in the river and 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, this will also lead to improvements in the floodplain (Januschke et al., 2011; Hering et al., 2015; Göthe et al., 2016). This interconnectedness underlines the importance of considering the catchment-floodplain-river ecosystem as a whole.

Environmental adjustments happen in a multitude of ways that depend on the conditions in the particular river basin in question and often continue over years, calling for increased focus on river basin management. The need for land use management and restoration of the catchment-river-floodplain system is, however, widely recognised in EU policies. The overview provided in Table 1.1 shows the many policies that either depend on restoration to achieve their objectives or encourage restoration through specific mechanisms such as green infrastructure. The Water Framework Directive, with its objective of reaching good ecological status or potential for biological quality elements linked to aquatic fauna

([1]) EEA cooperating countries are: Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia, and Kosovo*.
(*) Under United Nations Security Council Resolution 1244/99..

and flora, and its recognition of hydromorphological pressures that often underlie habitat degradation, is a very important driver for such improvements.

Defining the catchment-floodplain-river system provides a unifying concept for management across the policies listed in Table 1.1. It also demonstrates that there are benefits to including a broader perspective on the notion of rivers than is 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 overall ecosystem health, i.e. for the status of water in the river, flood protection and water retention, climate change mitigation and biodiversity.

The Water Framework Directive also operates with hydromorphology as a supporting quality element for the assessment of ecological status or potential of surface water bodies. If good status is not achieved, it is further assessed whether or not failure is due to significant hydromorphological pressures. When significant hydromorphological pressures are identified, hydromorphological monitoring and measures need to be implemented. Moreover, the Water Framework Directive includes important articles to ensure 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 contain provisions for preventing further degradation. Article 4(7) of the Water Framework Directive requires that only those new projects that do not risk altering the status of the water body are authorised, although some exemptions are possible. New projects that involve, for example, hydromorphological alterations or alterations of the groundwater level must be developed in a way that does not lower the status of the water body. Similarly, for new projects that could have an impact on protected sites (e.g. Natura 2000 sites, designated under the Habitats and Birds Directives), an appropriate assessment of the impacts has to be undertaken, according to Article 6(3) of the Habitats Directive. Generally only plans that will not adversely affect the site of concern can be approved. The Floods Directive requires all EU Member States to develop flood risk management plans that include an assessment of areas of potential flood risk and an evaluation of the assets that are at risk, with the specific objective of reducing adverse effects on human health, the environment, cultural heritage and economic activities.

As a cross-policy initiative, target 2 of the EU 2020 biodiversity strategy requires that at least 15 % of degraded ecosystems be restored by 2020, and, increasingly, implementing restoration approaches based on green infrastructure principles is seen as best practice. Such solutions enable multiple environmental policy goals to be achieved: 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. Therefore, 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 of Sustainable Development Goal 6.6.

While the policy overview shown in Table 1.1 is comprehensive, it is also fragmented. Many different approaches are taken to managing environmental concerns within the catchment-floodplain-river ecosystem and none are specific to floodplains. Presently, floodplains are recognised in the context of the Water Framework Directive, but they are not systematically assessed as part of river basin or other management plans, although the Water Framework Directive aims for an ecosystem-based management approach.

Table 1.1 Overview of policy objectives and targets of policies that would either benefit from or support the improvement of floodplain conditions

Policy objectives and targets	Sources	Target year	Agreement type
Policy objectives that benefit from or support the improvement of floodplain conditions			
Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Sustainable Development Goal 6.6 (UN, 2016)	2030	Non-binding global commitment
Prevent nitrates from agricultural sources from polluting surface and groundwaters by promoting the use of good farming practices	**EU Nitrates Directive (EU, 1991)**		**Legally binding EU commitment**
Conservation and protection of habitats and species listed in Annexes I and II	**EU Habitats Directive (EU, 1992) and Birds Directive (EEC, 1979)**		**Legally binding EU commitment**
Achieve good ecological and chemical status of all surface water bodies and good chemical and quantitative status of groundwater bodies in Europe	**Water Framework Directive (EU, 2000)**	**2015**	**Legally binding EU commitment**
Assess and manage flood risks, aiming to reduce the adverse consequences for human health, the environment and cultural heritage	**Floods Directive (EU, 2007)**	**2015**	**Legally binding EU commitment**
Protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean	**Drinking Water Directive (EU, 1998)**	**2004**	**Legally binding EU commitment**
Maintain and enhance ecosystems and their services by establishing green infrastructure and restoring at least 15 % of degraded ecosystems	EU 2020 biodiversity strategy, target 2 (EC, 2011)	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 (EC, 2012)		Non-binding EU commitment
Establishment of green infrastructure	Green infrastructure — enhancing Europe's natural capital (EC, 2013b)		Non-binding EU commitment
Measures such as the reconnection of the floodplain to the river, remeandering and the restoration of wetlands to 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 (EC, 2015a)		Non-binding EU commitment
Adaptation of flood risk management to climate change	EU climate change adaptation strategy and disaster risk reduction (EC, 2013a) and rescEU on strengthening EU Disaster Management (EC, 2017)		Non-binding EU commitment

Note: Text in bold refers to legally binding commitments within the European Union. Further explanation of some objectives is provided in Annex 1.

2 Floodplains: a natural system 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. For the largest rivers in Europe (i.e. rivers of Strahler level 3 to 8), Copernicus provides a potential riparian zone definition and a high-resolution geographical database of ecosystems for the riparian zone in Europe (Box 2.1). It was, however, found that not all flood-prone areas were captured by the potential riparian zone provided by Copernicus. Instead, the extent of the potential floodplain has been calculated as a combination of the Copernicus layer and a 100-year return period flood-hazard map provided by the Joint Research Centre (JRC). Thus, the potential floodplain captures the area that could be flooded during an event with a return period of once every 100 years, as well as the river area (Box 2.1).

The extent of the potential floodplain has been used to calculate key statistics for the 33 EEA member countries and six cooperating countries (EEA-39). It should be noted that limiting the characterisation to rivers of Strahler level 3 or above leads to a significant underestimation of the river network and floodplain area. In countries with a large majority of smaller drainage basins such as Cyprus or Denmark, the country statistics for the potential floodplain extent are considerably underestimated. Similarly, Malta does not have rivers and is not included. This analysis also does not cover exposure to coastal floods.

The data provided by the potential floodplain extent and the Copernicus land monitoring service enable the calculation of some basic statistics for floodplains that also highlight the challenges of their management. These statistics show, in broad terms, three of the multiple uses of floodplains — urban centres, agriculture and nature protection — and how they differ among countries. Further details of the statistics shown here are available in a floodplain statistics data viewer (EEA, 2019b).

The potential floodplain area has been calculated for the EEA-39 countries. Because of the difference in size of these countries, the floodplain area also differs; therefore, the relative share of the country area has been calculated to show these differences (Figure 2.1). On average, approximately 7 % of the EEA-39 area is located in the potential floodplain. Approximately 12 % of the population lives in this area, as many of Europe's urban centres are also located here, underlining the importance of flood protection for a large share of the population in Europe. In Austria, Bosnia and Herzegovina, Liechtenstein, the Netherlands and Slovakia, more than 25 % of the population lives in the potential floodplain (Figure 2.2).

As a result of land use activities and flood protection, most ecosystems in the potential floodplain are not made up of natural riparian vegetation. Across the EEA-39, the main Mapping and Assessment of Ecosystems and their Services (MAES) ecosystem classes found in the floodplain are croplands (35 %), grasslands (15 %), rivers and lakes (23 %), urban areas (6 %) and woodlands (16 %) (Figure 2.3). The remaining 5 % are distributed among heathlands, sparsely vegetated land and wetlands. However, out of the 39 countries, 27 have an area of combined cropland and grassland ecosystems that exceeds 50 % of their floodplain area. Croplands and grasslands are associated with agricultural activities that often contribute to environmental pressures in the floodplain. In contrast, Finland, Iceland, Norway and Sweden, where agriculture is much less prominent, have less than 10 % of their floodplain area covered by these ecosystem types. In these countries, a large majority of the ecosystems are rivers and lakes, and woodlands. Iceland is an outlier, as it is the only country with a high proportion of heathlands and sparsely vegetated area in the floodplain (Figure 2.3).

Because of the ecological importance of the floodplain, EU countries have on average designated 25 % of their floodplain area as Natura 2000 sites (Figure 2.4). In Bulgaria, Croatia, Estonia and Poland, close to 40 % of the floodplain area has been designated. Natura 2000 sites are designated for the protection of species and

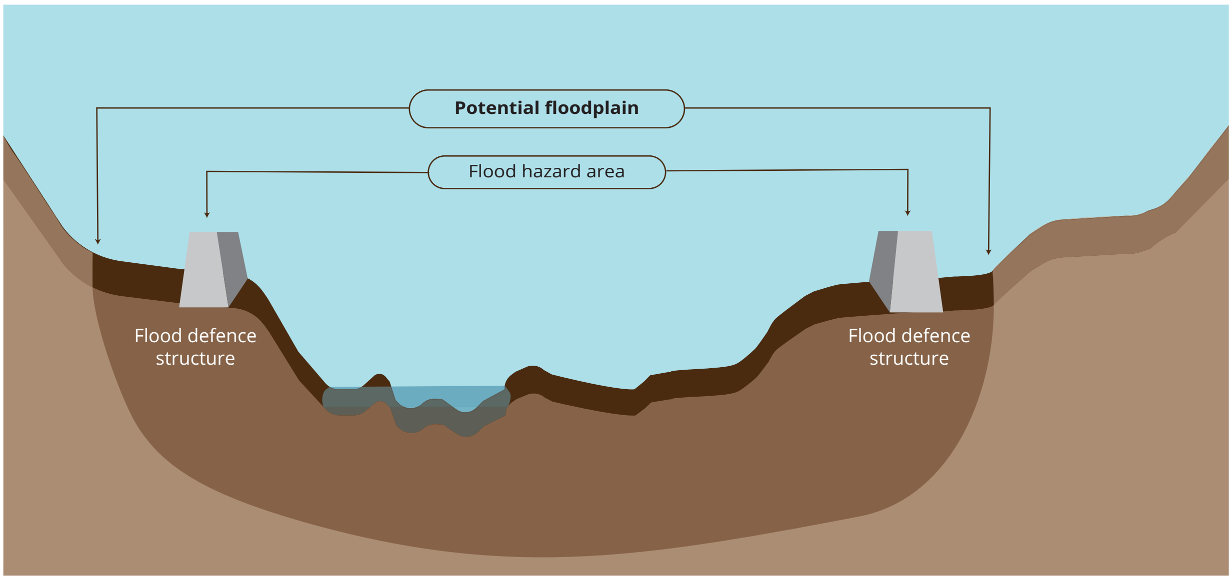
Box 2.1 Copernicus — the riparian zone product and the floodplain statistics viewer

Copernicus is a European system for monitoring the Earth using Earth observation satellites and *in situ* sensors (Copernicus, 2019). The riparian zone product provides a detailed land cover data set of ecosystem types in the EEA-39 countries (33 EEA member countries and six cooperating countries) and a delineation of riparian zones (Copernicus, 2019). Approximately 525 000 km^2 is mapped, covering rivers of Strahler levels 3 to 8, with a 100-m grid size (GAF, 2015). The floodplain system is classified using seven Mapping and Assessment of Ecosystems and their Services (MAES) ecosystem types (EC, 2014), which are a mixture of land use types and ecosystems. The ecosystems have been analysed at four progressively increasing levels of detail. At level 1, used in this report, the seven ecosystem types captured are croplands, grassland, heathland and shrub, rivers and lakes, sparsely vegetated land, woodland and forest, and urban areas.

The schematic drawing below shows the conceptual definition of the potential floodplain. The potential floodplain captures the area that could be flooded during a flood event with a return period of once every 100 years, as well as the river area. If flood defence structures are present, the floodplain is reduced to the flood hazard area inside those structures. For the purpose of this report, the flood hazard area is not accounted for, as data are not available. The potential floodplain area was derived by adding two spatial layers:

- the Joint Research Centre's flood hazard map for Europe for a 100-year return period (JRC, 2016), based on Lisflood model results (Burek et al., 2013);
- the Copernicus potential riparian zone layer from the data set, namely a delineation of the riparian zone.

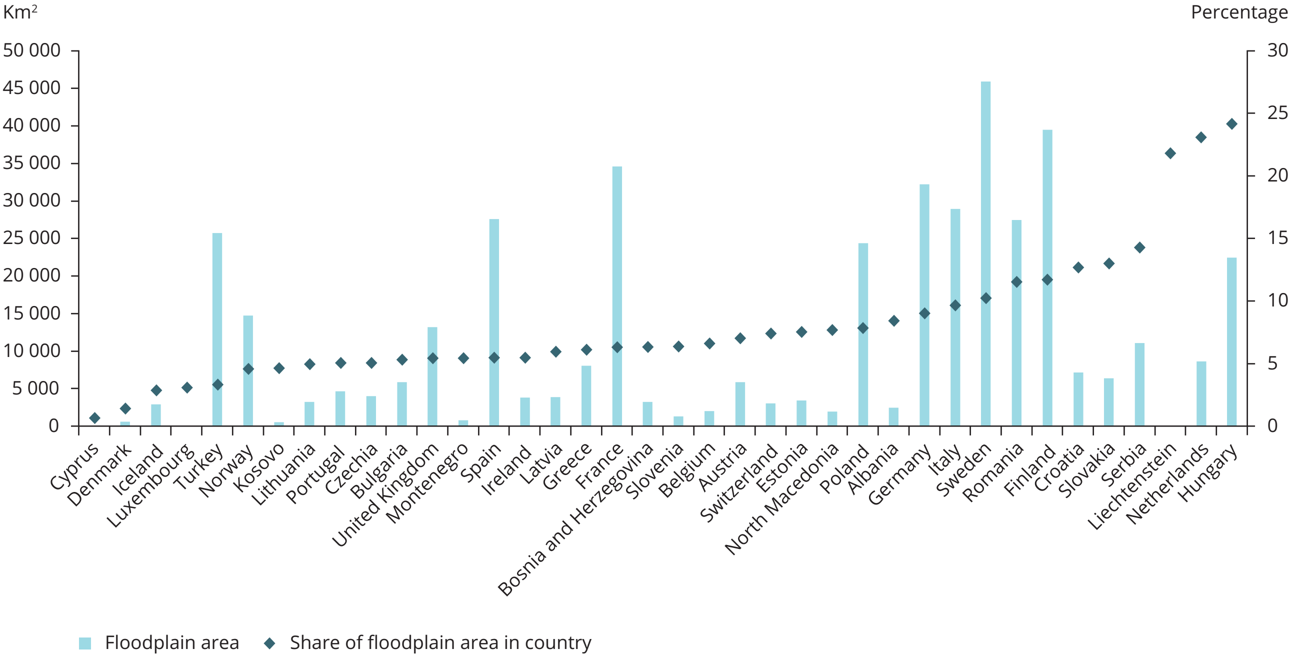
The metadata and data for the potential floodplain data set are available in the EEA Spatial Data Infrastructure. See ETC/ICM, 2020 for link.



The Copernicus riparian zone data set has been combined with the potential floodplain and used to develop a floodplain statistics data viewer (https://www.eea.europa.eu/data-and-maps/data/data-viewers/floodplain-areas). The viewer provides statistics on the spatial extent and land use distribution in floodplain areas of Europe.

habitats listed under the Habitats and Birds Directives. Countries have elected to place their Natura 2000 sites around the wetlands in the floodplain. Although the total wetland area is a small share of the floodplain in most countries, many countries have included more than 70 % of the wetland area into their Natura 2000 sites designated in the floodplain (Figure 2.5). A large share of rivers and lakes are also included in floodplain Natura 2000 sites (EEA, 2019b).

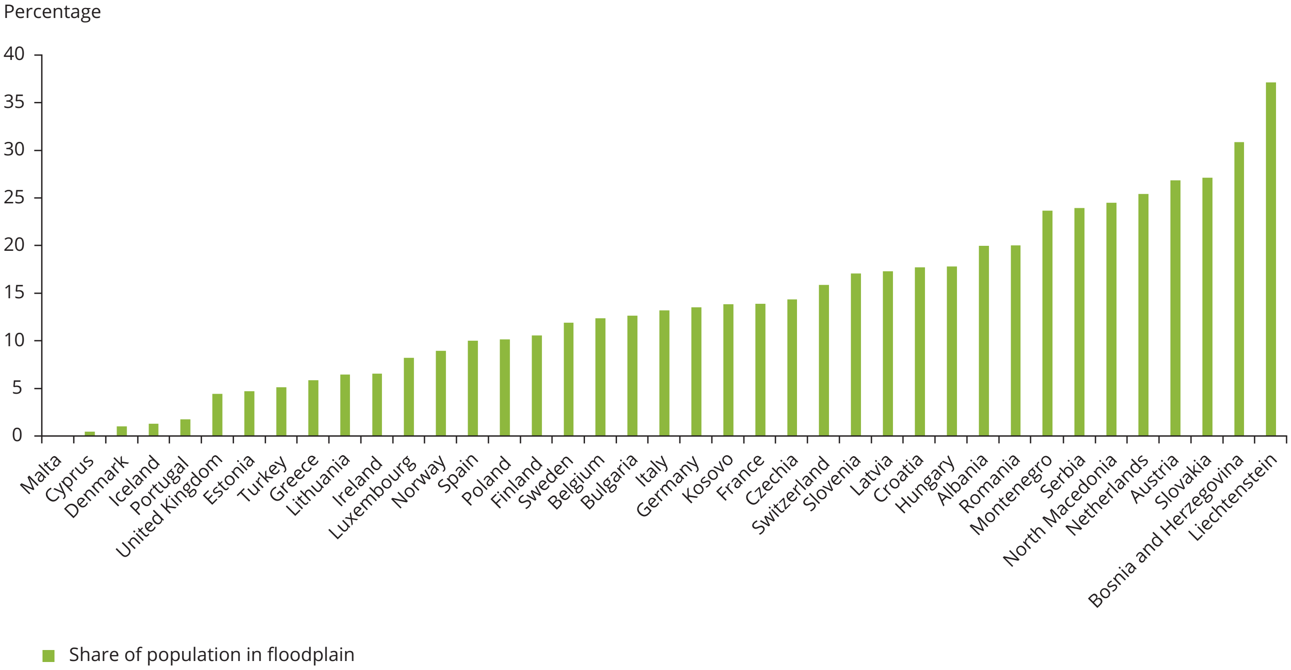
Figure 2.1 Floodplain area



Notes: The country coverage is the EEA-39. In the EEA-39, 7 % of the area is in the floodplain of rivers of Strahler level 3 and above.

Source: EEA (2019b).

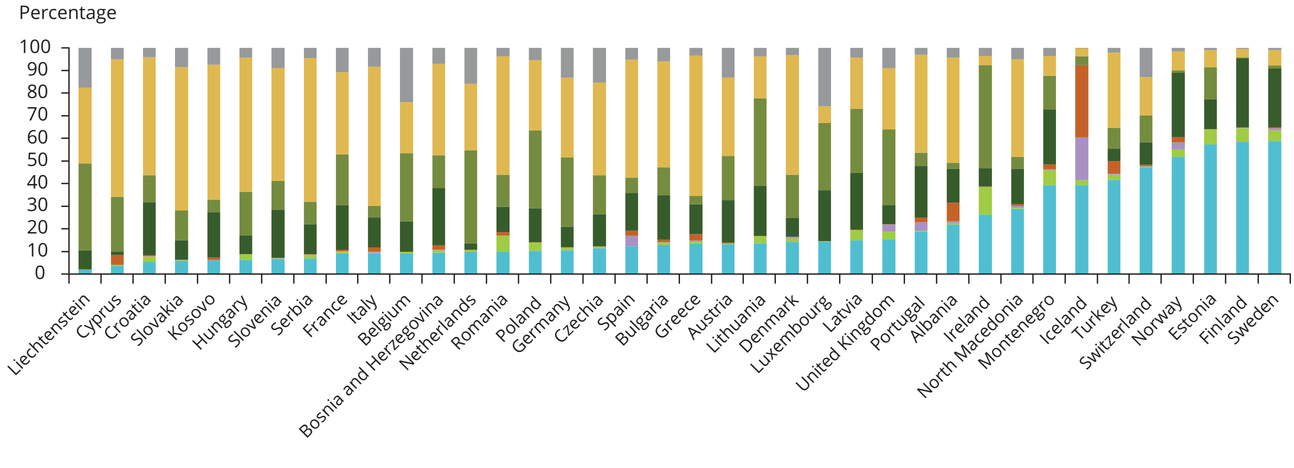
Figure 2.2 Share of the population living in floodplains



Notes: The country coverage is the EEA-39. In the EEA-39, 12 % of the population lives in floodplains. Liechtenstein has a very high value because it is a small country with a high proportion of floodplains.

Source: EEA (2019b).

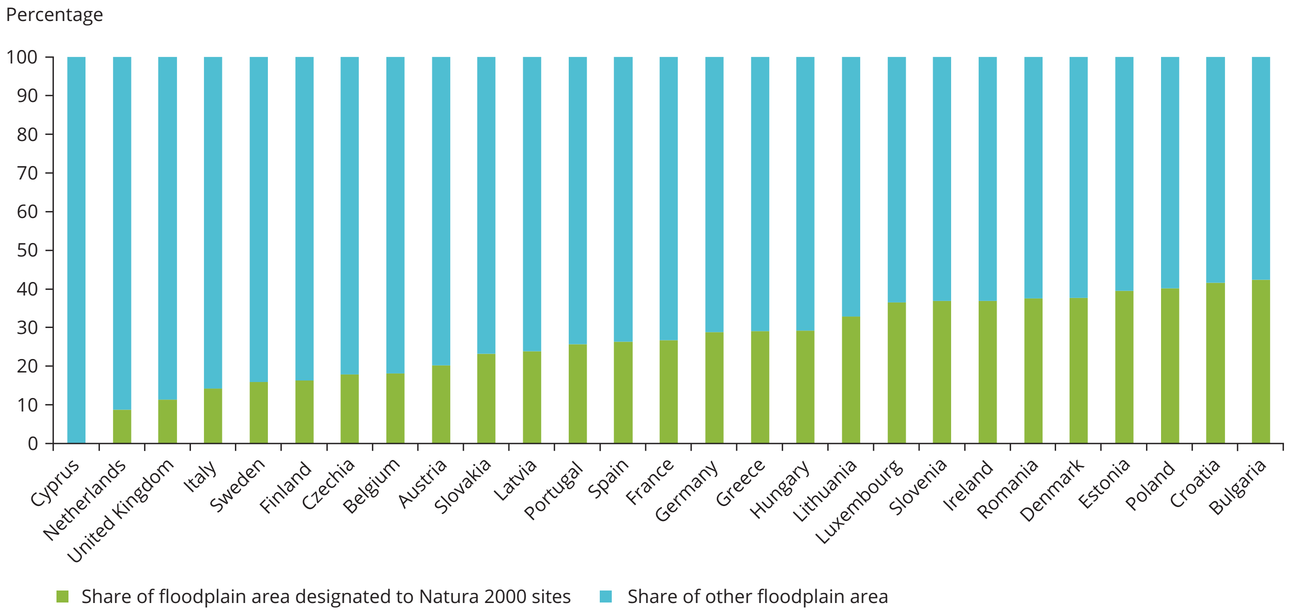
Figure 2.3 Ecosystem distribution in floodplains



Notes: The country coverage is the EEA-39. In the EEA-39, 55 % of the floodplain area is made up of croplands, grasslands and urban areas. The extent of coastal floods is not considered.

Sources: EEA (2019b); Copernicus (2019).

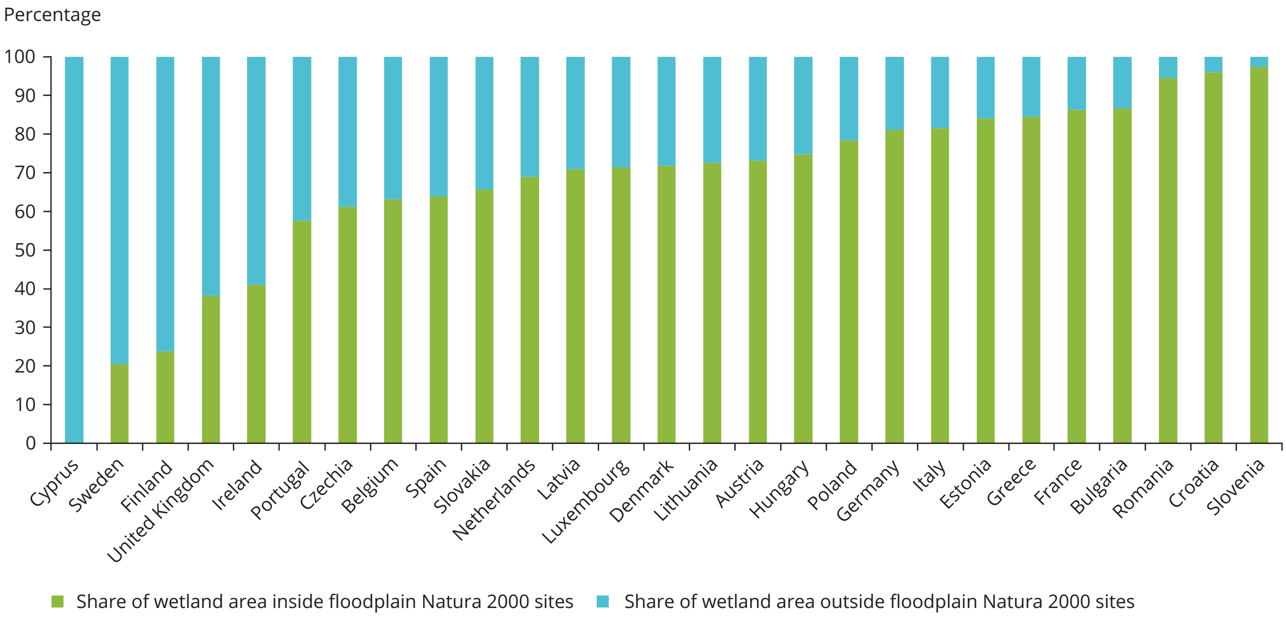
Figure 2.4 Share of the Natura 2000 network area in floodplains



Notes: The country coverage is the 28 EU Member States. In the EU, 25 % of the floodplain area has been designated as Natura 2000 sites.

Source: EEA (2019b).

Figure 2.5 **Share of the wetland area in floodplain Natura 2000 sites**



Note: The country coverage is the 28 EU Member States.

Source: EEA (2019b).

2.2 Current floodplain status in Europe

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 waterlogging are important properties of a natural wetland. Both water and substrate properties are highly dynamic, creating a multitude of ecological niches that are in permanent exchange with the river and its catchment area, and these act to form ecological resilience over time (Fuller et al., 2019). Floodplain soils often comprise peat with high organic matter content. When waterlogged, peat has a very large capacity to store carbon, but when drained or ploughed, greenhouse gasses (CO_2, N_2O and CH_4) are released because organic matter decomposition is initiated (Gyldenkærne and Greve, 2015).

The loss of floodplains in Europe has been extensively studied and the effects in terms of disconnection, incision and loss of habitats have been evaluated. Those studies show that such changes in floodplains are substantial. An overview of floodplain loss in Europe was presented in EEA (2016). Depending on the river, 70-100 % of the floodplain had been lost over past centuries. 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. Today, changes continue to occur in the floodplain, but at low rates. On the negative side, land take calculations show that between 2000 and 2018 a transformation to artificial surfaces occurred in the floodplain, primarily from croplands, but this change corresponded to < 1 % of the floodplain area. In fact, the primary land cover flow between 2000 and 2018 was linked to the creation and management of forest, accounting for 2 % of the total floodplain area (EEA, 2019b). These changes are of course small compared with the historical changes.

This loss is reflected in assessments of conservation status carried out under the Habitats Directive (EU, 1992). An analysis of the conservation status of 37 floodplain habitats for the period 2013-2018 shows that the vast majority have either inadequate or bad conservation status (Figure 2.6). Across Europe, only 17 % of floodplain habitats and species have good conservation status, reflecting the high degree of disturbance to floodplain systems. One of the habitats assessed is riparian forests (Box 2.2). One of the natural characteristics of this habitat is inundation for a large number of days within a year. Disturbances stem from, in particular, urbanisation and agriculture, which have both had a very large impact on drainage.

Box 2.2 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 rivers, where inundation can be up to 180 days per year. Hardwood forest is found further away from rivers, where groundwater levels are lower and inundation occurs on 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 have a favourable conservation status and many have disappeared altogether. Unfortunately, riparian forests cannot be distinguished from other deciduous forest types in the Copernicus riparian zone product. Therefore, an independent estimate of their extent in the floodplain is not available.

2.3 Climate change and altered flood risk

In Europe, global warming is projected to lead to both a 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 that are 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 further increase flood 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, 2017c, 2019d).

Floods are 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 types of event may lead to flooding. The extent of a flood event depends on geological and physical characteristics of the watershed and its land use properties. The steepness of the watershed together with the ability of its reservoirs, soils and floodplains to absorb and retain water are factors that influence the speed of run-off. Faster transport generally increases the likelihood of flooding. For example, an analysis of the changed flood regime of the River Trotus in Romania showed that the combination of uncontrolled deforestation and changed agricultural land use led to the increased flood risk (Avram et al., 2018). More recently, awareness has increased regarding increased flooding following forest fires. Severe forest fires alter the soil's water retention capacity and, in large rainfall events following a fire, water moves more rapidly and stronger erosion occurs, eventually also affecting floodplains (Stoof et al., 2012; Coschignano et al., 2019). The burnt area in the Mediterranean region has shown a slightly decreasing trend since 1980, but with high interannual variability; the meteorological fire hazard has increased over the same period. These opposite trends suggest that efforts to improve fire management have generally been successful (EEA, 2019c).

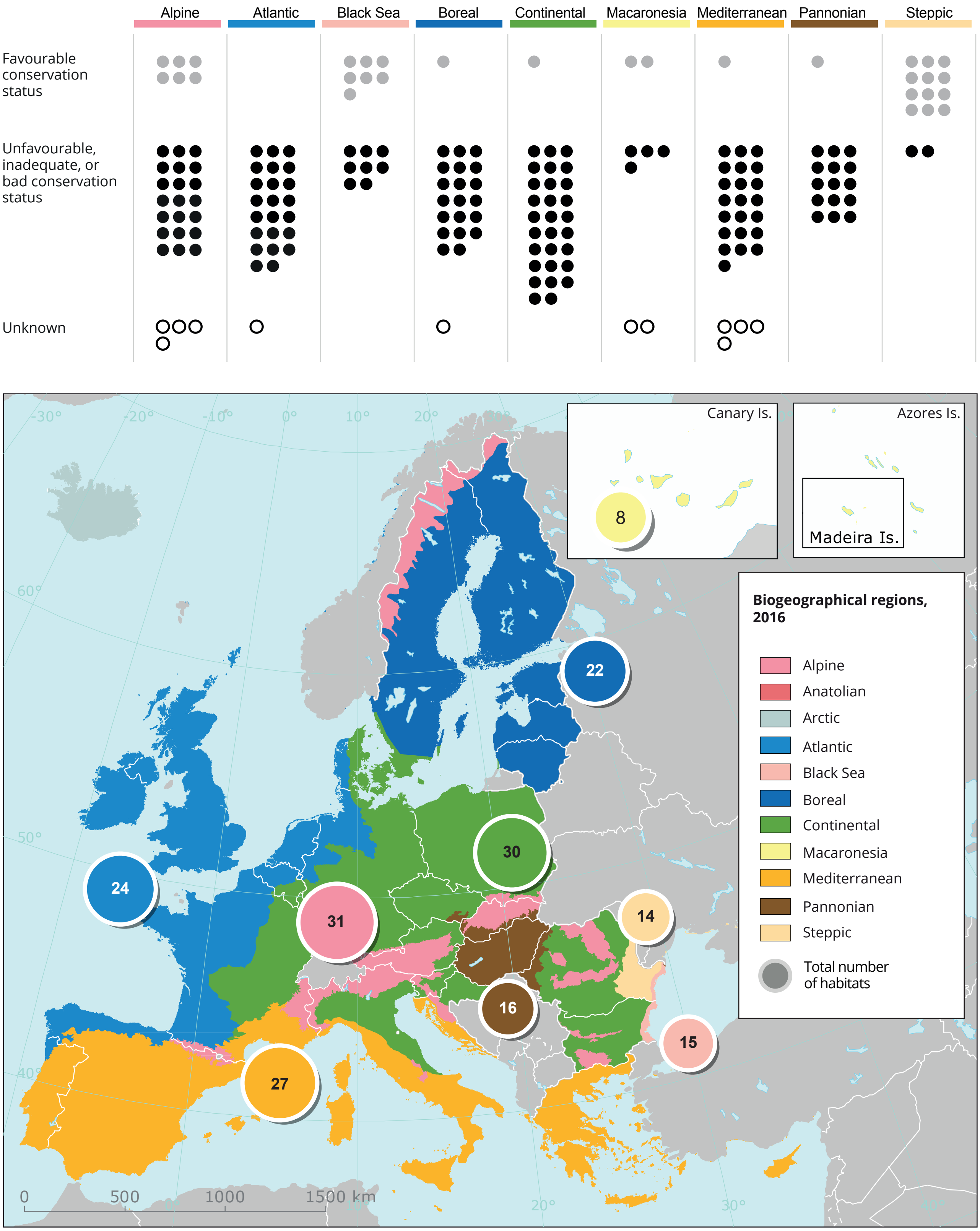
Floods are defined in terms of their return period: the larger the event, the longer the return period. Usually, flood protection is designed to protect against floods that return once every 100 years and to protect both urban centres and agricultural land. Model calculations analysing the impacts of a changed climate suggest that the 100-year return period is likely to change across Europe. These calculations are based on changes in climate and do not consider changes in land use, which could also influence flood magnitude.

Today, floods remain one of the most costly natural disasters in Europe (Figure 2.7). Every year, some flood events in Europe exceed the capacity of existing systems to contain water, resulting in damage to property and sometimes even loss of lives (EEA, 2019a). Of the four most costly climate events in history in the EU, two were related to floods. The 2002 flood in central Europe, which was also the most costly, exceeded a cost of EUR 20 billion and the 2000 flood in Italy and France had a cost of EUR 13 billion (2016 values).

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. the vulnerability to flooding is greater in an urban area and lower in a natural floodplain). Model studies of the socio-economic impacts of river floods suggest that future climate change will increase the flood risk in almost all countries in Europe. A worst case climate change scenario could increase the socio-economic impact of floods in Europe more than three-fold by the end of the 21st century (Koks et al., 2019).

Figure 2.6 Conservation status of Europe's floodplains across biogeographical regions

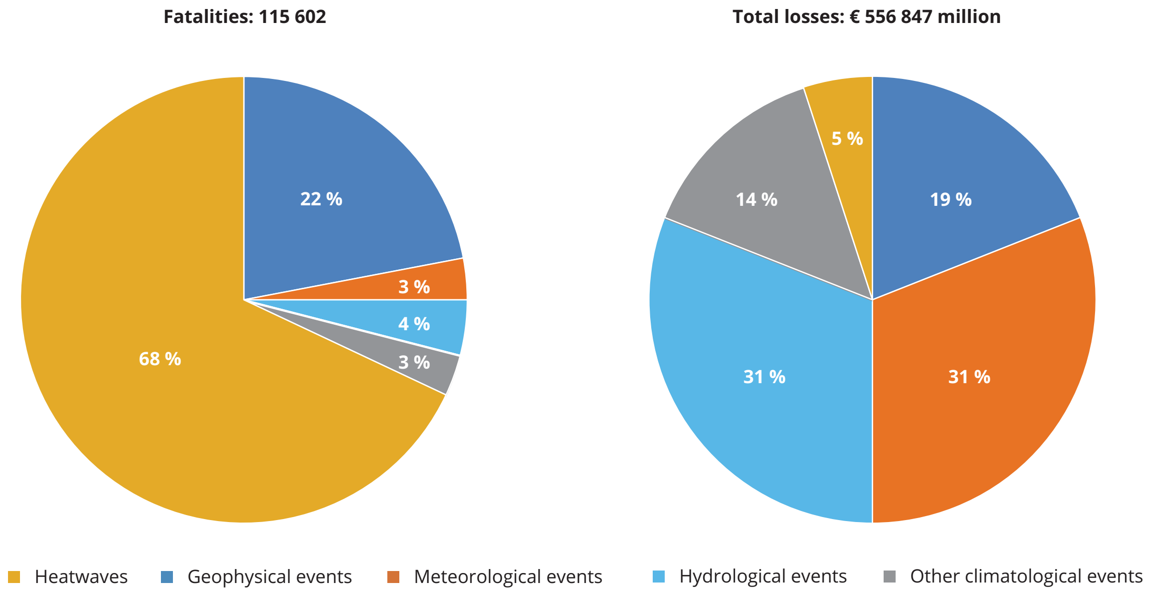
Number of floodplain habitats per biogeographic region (2013-2018)



Note: Each dot represents an assessment outcome on the biogeographical scale. The analysis encompasses nine floodplain forest habitats, nine floodplain grassland habitats and 19 aquatic floodplain habitats.

Source: Data from 2013-2018 Art 17 reporting (EEA, 2020a).

Figure 2.7 Fatalities and economic losses in the EEA-33 as a consequence of natural hazards (EEA, 2019a)



Notes: Meteorological events refer to storms, hydrological events to floods and mass movements, and climatological events to cold waves, droughts, forest fires and heatwaves. For the period 1980-2017, total values for losses and insured losses are in million euros (in 2017 prices), based on the damage records from the NatCatSERVICE of Munich Re and the Eurostat structural indicators. Country coverage is EEA-33, 33 EEA member countries.

Source: NatCatSERVICE provided by Munich Re.

Flood protection in the most vulnerable areas is already prominent today, and an increased focus on flood risk management can be anticipated as a result of the changing climate. As a consequence, flood defence systems will increasingly need to be based on both existing structural flood protection and the natural water retention capacity of floodplains. In addition, the implication of the Floods Directive is that the flood hazard area is increasingly considered in spatial planning (Thieken et al., 2016). People living in floodplains will also need a much greater awareness of the flood risk implications and will need to know how to respond in the case of a flood.

2.4 Hydromorphological pressures and alterations

Within river basin districts, a multitude of human activities depend on the river's natural resources. Important activities are agriculture and forestry, urbanisation and transport, flood protection, hydropower production, navigation and recreation; all of these activities add pressure on the river-floodplain system but in different ways. These pressures are linked to activities that support the need to provide flood protection for people and property and to the historical desire to increase agricultural areas and navigation. These pressures occur because both rivers and their floodplains are subject to a multitude of human uses that have altered their hydrology, morphology and connectivity, as well as catchment land use, over centuries. These uses are diverse, and changes to the river and its floodplains include increasing efforts to straighten rivers to make them navigable, drainage to gain agricultural land, urban development and the need for ports, flood protection, water storage, hydropower and cooling water. In general, hydromorphological pressures influence habitats, the survival of species and interactions between them and thus can affect entire ecosystems.

Hydromorphological pressures ([2]) cover changes to both the hydrology (water retention and flow) and the morphology (physical characteristics) of rivers and floodplains (Box 2.3). The changes introduced by hydromorphological pressures affect the ecology of the natural system. They have a tendency to eliminate the

([2]) Hydromorphology refers to the geomorphological and hydrological characteristics of a water body, which are also conditions for its ecosystem. Hydromorphological pressures are changes to the natural water body as a result of human needs to control river flow, erosion and floods, as well as drainage, river straightening, or harbour construction.

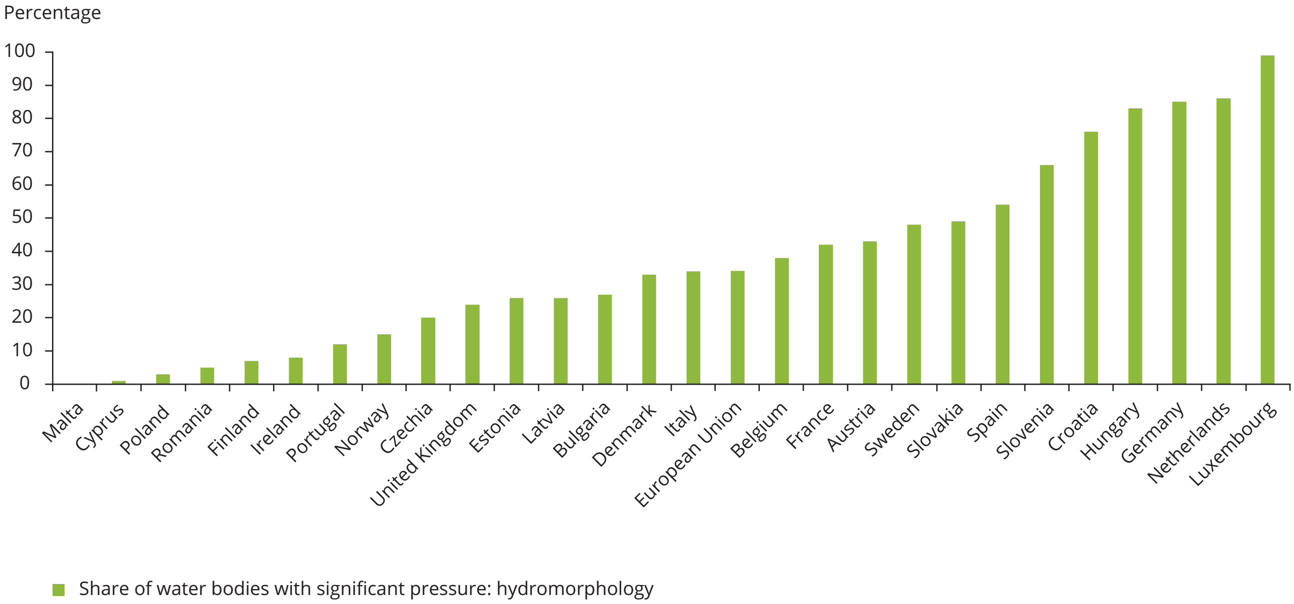
lateral connectivity between a river and its floodplain, reducing habitat quality and influencing the species that can thrive. For example, barriers across rivers prevent fish from migrating upstream, reducing the ability of migratory fish to reach spawning areas. In Norway, following pressures from escaped farmed salmon and salmon lice, hydromorphological pressures are seen as the largest single factor influencing the wild salmon population (Forseth et al., 2017).

Hydromorphological pressures were assessed in the second river basin management plans reported under the Water Framework Directive (EEA, 2018c). Hydromorphological pressures are one of the main reasons that surface water bodies fail to achieve good ecological status; such pressures are listed as significant for 34 % of surface water bodies (Figure 2.8). Most of these pressures stem from the physical alteration of river channels or the riparian zone or shore, or from dams, locks and other barriers. The average value, however, masks large geographical variations, with some countries reporting that less than 10 % of their water bodies are under significant hydromorphological pressures and Luxembourg reporting that 99 % of its water bodies are affected by such pressures. An assessment of free-flowing rivers in Europe shows that a very large share of Europe's large rivers are, in fact, no longer free flowing (Figure 2.9), highlighting the widespread implications of hydromorphological pressures. Some examples of hydromorphological pressures are listed in Box 2.3, and the hydromorphological alterations of the Tisza river in Hungary are given as an example of the large modifications that Europe's rivers have undergone (Box 2.4).

Transversal structures (e.g. dams, weirs and locks), in particular, act as barriers for movement of sediment and biota. They hamper the passage of fish, which is particularly significant for the life cycle of eels, sturgeons and salmon because migration is part of the reproductive cycle of these species. Fish are one of the biological quality elements assessed in rivers under the Water Framework Directive. Recent research in the United Kingdom identified that 97 % of the river network is fragmented and that less than 1 % of catchments are free of artificial barriers (Jones et al., 2019). Lateral connectivity between rivers and floodplains is also of critical importance, as this enables floodplains to retain water for natural flood protection. Recent assessments of protected freshwater fish (including migratory) species under the Habitats Directive show continued decline. Hydroelectric dams and weirs are often cited as the main pressure (EEA, 2020b).

It is difficult to assess the trends in hydromorphological pressures based on information reported under the Water Framework Directive because the categorisation of those pressures changed between the reporting of

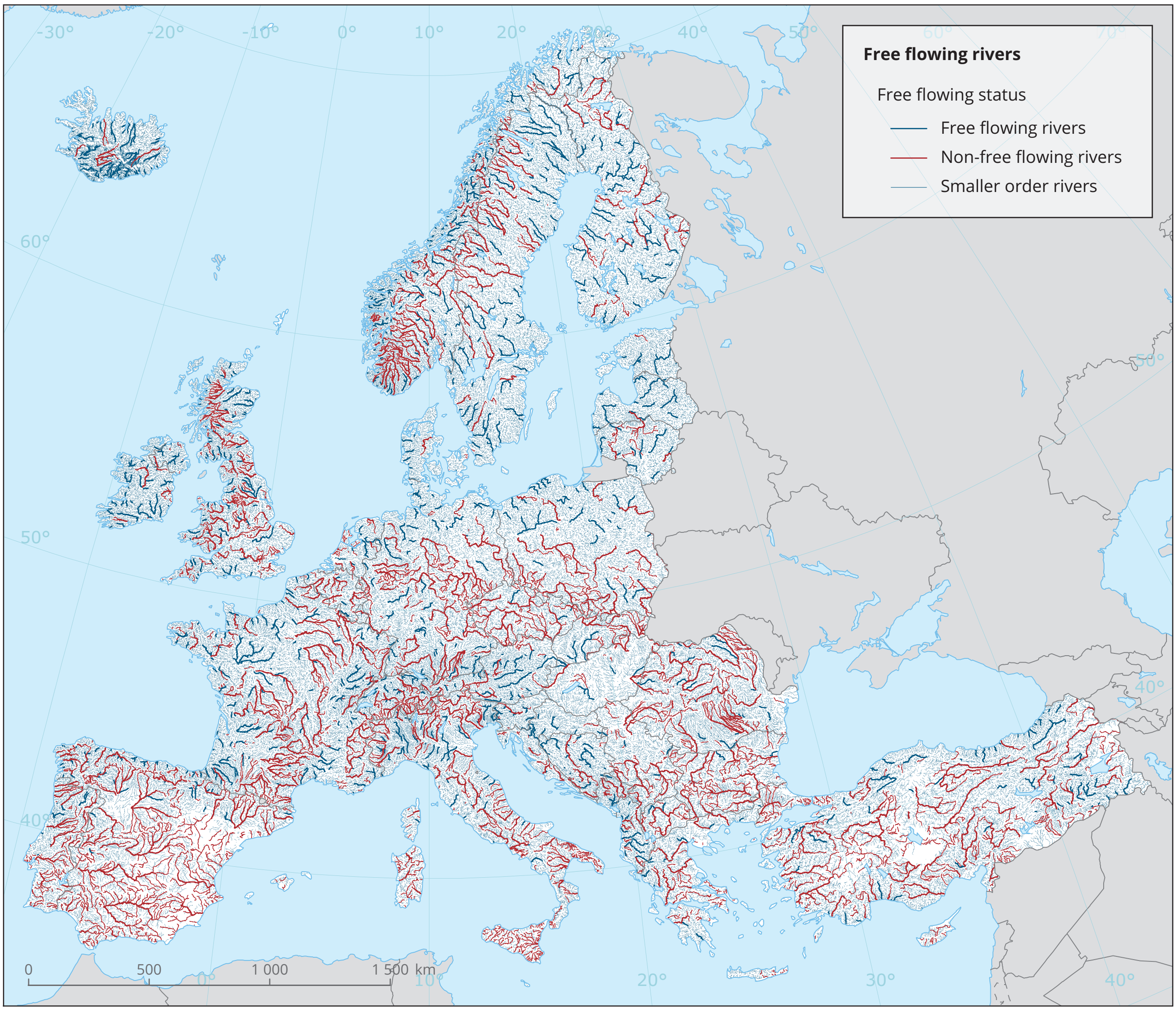
Figure 2.8 Share of water bodies with hydromorphological pressures by country



Note: Greece and Lithuania did not provide reports.

Source: EEA (2018c, sheet: SWB presssures).

Figure 2.9 Free-flowing rivers in Europe



Note: The majority of large rivers in Europe are not free flowing. The assessment of free flowing is based on a connectivity index, calculated from indicators of fragmentation, flow regulation, infrastructure development, water abstraction and sediment-trapping capacity. Free-flowing rivers were identified as those with an index above 95 % (Grill et al., 2019).

Source: Reproduced from Grill et al., 2019 with permission from the authors.

the first and second river basin management plans, and no alternative method exists. However, EU Member States, Norway, Switzerland and Turkey are developing assessment methods for hydromorphological status (Kampa and Bussettini, 2018). At present, 55 different assessment methods are being used across Europe that aim to evaluate the impacts of hydromorphological pressures on the status of water bodies. Relevant measures needed to achieve good ecological status or potential are also considered as part of this work.

2.5 Pollution pressures

The Water Framework Directive, the Urban Waste Water Treatment Directive and the Nitrates Directive in combination require a reduction in nutrients and hazardous substances, but those substances are still used on fields and in industrial production, and reach floodplains from both point and diffuse sources. Nutrients and hazardous substances reach floodplains from the catchment, from the river during floods

Box 2.3 Examples of hydromorphological pressures

Channel straightening: this refers to the process of channel straightening, bank stabilisation with concrete lining, narrowing and deepening of rivers. In this process, islands and sand banks are removed and meanders are cut off. The purpose of these changes is to more rapidly drain the river catchment, but in return the increased discharge may cause a higher flood risk downstream. If the upstream sediment load is unaltered, this in turn leads to erosion in the straightened reach and sediment deposition downstream of it, leading to costly maintenance (Bettes, 2008) (see also Box 2.4 for a description of the channel straightening of the Tisza river, Hungary).

Dikes: dikes are constructed to protect the land behind them and to confine river floodplains. This removes the water storage capacity of floodplains and increases discharge. Dikes encourage agricultural, urban and industrial development behind them, namely in former floodplain areas. If they are breached, the flood damage behind them can be considerable. Dikes provide protection only up to a specific design capacity, resulting in uncontrolled and unpredictable flooding events if this capacity is exceeded.

Dams: in Europe, several thousand large dams (height > 15 m) and an estimated 1-2 million small barriers on rivers store water for irrigation, generate hydropower and regulate flow. These structures have a large influence on regulating river flow dynamics and morphological and sediment transport processes both upstream and downstream of their location. Downstream of dams, sediment shortage can lead to the scouring and deepening of the riverbed, floodplain cut-off and the lowering of the groundwater level.

In 1950, there were 1 210 large dams in Europe, located mainly in Austria, France, Italy, Spain and the United Kingdom. Nowadays, the dam density is much larger in all of these countries and is also very high in the Balkan countries, Norway, Sweden 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.

The impacts of dams on floodplains include reduced flooding (i.e. stabilised channels and changed ecology). As sediment becomes stored in reservoirs behind dams, sediment renewal in floodplains becomes infrequent, potentially influencing the river connectivity. Dams hinder the natural movement of fish and other species. Although dams reduce the flood risk, their failure can have catastrophic consequences.

Drainage: one of the very effective ways of disconnecting floodplains from rivers is through drainage. Drainage reduces the water retention capacity of floodplain soils, which benefits agricultural yields but at the detriment of wetland habitats and water retention. Drainage is widespread across northern Europe. 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).

Water abstraction: is a major pressure on floodplains. Water abstraction reduces groundwater levels, which, if sufficiently large, will dry out floodplain areas.

or from the atmosphere. They can be transported either dissolved in water or attached to sediments. Floodplains commonly act as long-term storage for water and sediments, including for less desirable and hazardous substances.

Pollution from mining, heavy industry, power plant cooling water and waste water may contain hazardous substances that are emitted into rivers. Farmers use nutrients and pesticides to promote plant growth. Often, more nutrients are applied than are taken up by plants, and unused nutrients or hazardous substances are moved into streams either via groundwater or attached to soil particles and are moved with surface run-off. The dissolved nutrients may cause eutrophication impacts on the floodplain but may also buffer against eutrophication impacts in the river. An undisturbed floodplain where vegetation is more prominent cycles nutrients into plants and, if soils are waterlogged, allows denitrification to take place. In the absence of an undisturbed floodplain, nutrients enter the river with fewer transformations and may cause eutrophication-related impacts on the ecological status of rivers, lakes, and transitional and coastal waters. For this reason, unploughed buffer zones between agricultural lands and rivers are encouraged to reduce diffuse nutrient pollution from fields to rivers.

During floods, sediments that may carry both nutrient and hazardous substance pollution are deposited on floodplains, removing the polluting substances from the river, but in return polluting the floodplain. Particularly 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,

Box 2.4 River Tisza, Hungary — a river with extensive hydromorphological pressures

Catchment size (km^2)	Length (km)	Average discharge (m^3/second)	Flood discharge (m^3/second)	Population (millions)
157 186	Historical: 1 419 Today: 965	792	> 4 000	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. The demand for navigation and agricultural land have, in particular, been strong drivers of this change. Controlling flooding was essential for establishing agricultural land. Flood and navigation works were initiated on the Tisza river in the 1800s. Before these works, the plain would have gone through extensive flood and drought cycles, making it largely unsuited for agriculture. It supported flood-tolerant land cover such as forests, meadows and fish ponds. Deforestation together with mining and quarrying increased run-off and siltation and thus increased the flood risk of the settlements in the valley (Lóczy et al., 2009). When completed in 1880, these works had changed the river length from 1 491 km to 965 km, closing off 589 km (30 %) of former channels, oxbow 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 late 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 short in duration (2-20 days), whereas further downstream they can be of a much longer duration because of the low slope — flooding for as much as 180 days occurred in 1970. Although the height of dikes and levees was chosen to withhold a 50-year flood, they have been breached several times in the last 130 years. The river has continued to adjust morphologically to the multitude of changes introduced, adjusting its cross-sectional area and width. The morphological response of the river was decreased flood conveyance (the flood wave moved more slowly downstream) but an increasing height of flood levels and thus an increased flood risk (Amissah et al., 2018). The lowland section of the Tisza river today experiences higher water levels for a given discharge than in the past because sedimentation has reduced the lowland channel volume over the past 170 years.

2016). During large floods, the risk of pollution of rivers and floodplains is increased because of storm water overflows, oil leaks or flooding of industrial areas, waste sites or mining areas. In Wales, United Kingdom, it was found that sediments deposited during a flood in 2012 were contaminated by up to 82 times the guideline levels, which caused contamination of cattle feed and subsequent cattle mortality (Foulds et al., 2014). Contaminants are also spread to rivers and floodplains following accidents. A particularly catastrophic event occurred in 2000 when a large-volume storage facility burst and water contaminated with cyanide and heavy metals from mining activities was released into the Someş river, Romania, eventually spreading to the Danube. Remnants of these pollutants and from former industrial and waste disposal sites continue to spread during floods (Marshall et al., 2017). In areas where climate change is expected to increase the frequency or magnitude of floods, the risk of contamination of floodplain soils following resuspension of contaminated sediments may also be increased. This risk is especially linked to former mining areas (UK Environment Agency, 2009).

Contaminated sediments are also of concern when performing river restorations, such 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), providing additional complications to potential restoration projects. Contaminated sediments may have to be disposed of safely as hazardous waste in landfills.

The atmospheric deposition of nutrients and mercury is a ubiquitous pressure and hence also occurs in floodplains (EEA, 2018b). Increased temperatures as a result of climate change are expected to alter the mobilisation of chemicals in floodplains, but, unfortunately, not much is known about the environmental effects.

3 Ecosystem services and the measures supporting them

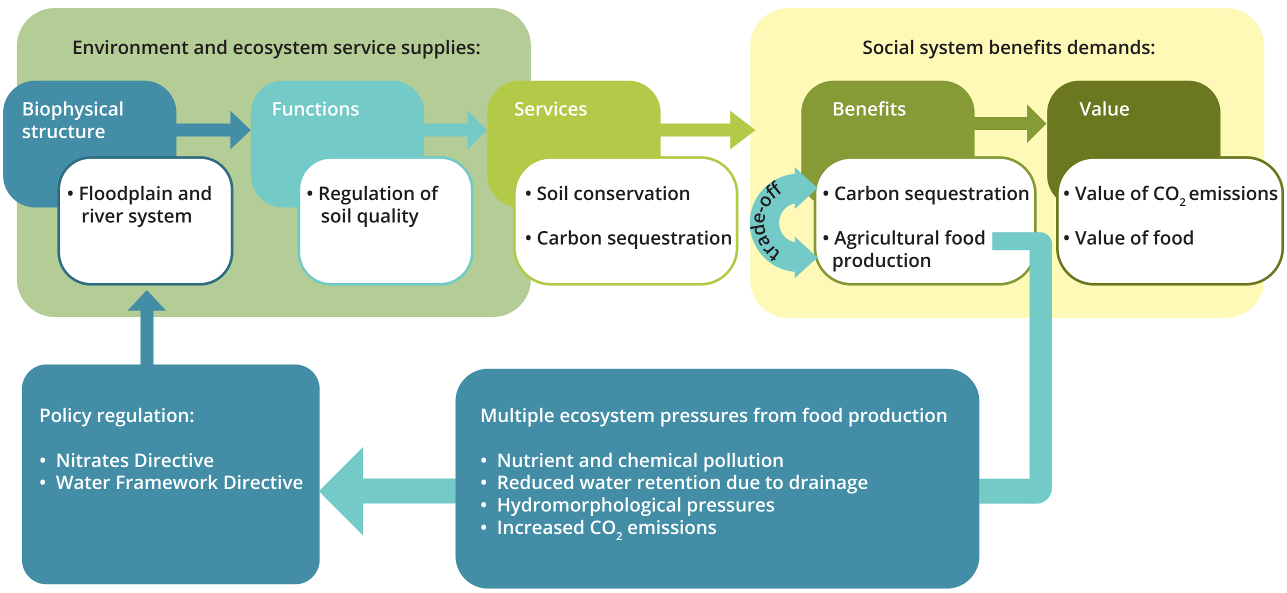
3.1 The ecosystem services concept

Ecosystem services are the many and varied benefits that humans gain freely from the natural environment. It is a concept for understanding that the natural environment provides benefits and services not only for nature, but also for people. Benefits include nutrition, access to clean water and air, health, safety and well-being (MEA, 2005; EC, 2013c). 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 value to humans, either because of their explicit market or cultural values or because of their role in mitigating environmental pressures. Explicit analysis of the value of all services relevant to a particular ecosystem is viewed as important for achieving a better balance between activities. Today, services such as water retention capacity and pollination are widely recognised for their overall value to society; it is also recognised that there are benefits of regulating the activities that could otherwise harm those 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 as a result of dependencies on watershed properties and climate. In general and qualitative terms, the closer the floodplain is to its natural condition, the higher the quality and the quantity of the services it provides. The primary impact of the many pressures on floodplains has been to reduce both the quantity and the quality.

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

Figure 3.1 A simplified ecosystem cascade model



Source: Reproduced from Potschin and Haines-Young (2011) with permission of Sage Publications Ltd. © 2011 Sage Publications Ltd.

well-being provided by ecosystems, whether these are of a spiritual or a recreational nature.

The relationship between the natural functions of the ecosystem and the elements of human well-being have been described as a series of steps in a cascade model that captures the key connections in river systems, 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 on the biophysical system. A negative feedback loop may be established in which increased pressures reduce the benefits gained, but this may in turn be modified by policy regulation or altered management practices (Figure 3.1).

The ecosystem cascade model enables the overall value of multiple services to be assessed, contrasting the value of a single service and its pressures with the value and pressures of other services. Often a trade-off exists between provisioning services and regulating and maintaining services. For example, pressures stemming from a high level of provisioning services may undermine the delivery of regulating services. In this way, a more holistic and nuanced perspective on the benefits of nature can be obtained than would be possible if only human activities were considered. A greater appreciation of the value of nature is viewed as critical for establishing more sustainable land management practices.

Table 3.1 provides an overview of services provided by floodplains and explains how they could support EU policies. Improving many of the regulating and maintaining services will support the achievement of EU policy objectives. In this report, our aim is to provide examples of the services that are important for the healthy functioning of floodplains. However, quantifying those services has not been attempted, in terms of either volume or economic value. Such quantification requires considerable local knowledge, which is not presently available at the European level. Floodplains are diverse, and specific services and their quality are spatially distributed, depending on floodplain and river features, hydrology, ecosystem characteristics and biological patterns. Developing models for understanding the ecosystem service delivery of rivers on a large scale is an area that still needs to be researched. Nonetheless, the promise of establishing a method that better allows different planning scenarios to be balanced is viewed as a positive development by environmental managers. The approach creates a shared basis for communication and knowledge exchange among stakeholders, facilitating the development of integrated management options, and sheds more light on potential conflicts of interest.

The significance of ecosystem services is also that they provide an overview of the many possible benefits that can be obtained, namely through restoration, more natural hydrology or altered land management practice. The specific ecosystem services provided depend on specific measures. Table 2.2 provides an overview of these relationships and gives the direction of impact in relation to overall service delivery, as not all services benefit the floodplain environment. All of the measures listed support multiple provisioning services and regulating and maintaining services. The effectiveness of the measures has not been assessed.

3.2 Ecosystem-based restoration

Restoration efforts based on improving ecosystem functioning attempt to restore the natural connections between the river and floodplains and, in this way, improve the delivery of regulating and maintaining ecosystem services. Many such nature-based solutions directly affect hydromorphological features of the river-floodplain system, improving hydromorphological quality, but also have elements of flow regulation and land use in them.

Both the Restoring Rivers for Effective Catchment Management (Reform) and the Natural Water Retention Measures (NWRM) projects provide systematic classifications of specific hydromorphological restoration measures that have been implemented across Europe (Reform, 2015b; NWRM, 2019). The NWRM project focuses on natural water retention measures in a broad sense, whereas the Reform project focuses specifically on river restoration. An overview of the most important restoration measures for improving the natural hydromorphological properties of river-floodplain systems is provided in Figure 3.2. Measures that improve riverbeds and banks are important for floodplains because sediment, water and biodiversity interact with the floodplain during floods. In this way, they also support the services of seed dispersal and biodiversity conservation. It should be noted though, that seed dispersal is not only a positive service, as less desirable, invasive species are also spread through this mechanism.

Water abstraction and impoundment in reservoirs has altered the natural flow in many of Europe's rivers. However, the quantity, timing and quality of river flows are critical ecosystem services, shaping both aquatic and floodplain ecosystems. Measures linked to regulating and maintaining those factors more in line with natural conditions are often referred to as ecological flows. In the context of the Water Framework Directive, such ecological flows are considered as 'a hydrological regime consistent with the achievement

Table 3.1 Qualitative overview of provisioning, regulating and maintenance, and cultural services provided by undisturbed floodplains

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 water and groundwater for drinking	Provision of water	Drinking Water Directive
	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 because of their 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 and 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 onto the floodplain. The storage capacity of floodplains minimises extreme groundwater fluctuations	Climate change adaptation WFD: good groundwater quantitative status
	Regulation of baseline flows and extreme events	**Erosion control and prevention**	Vegetated floodplains stabilise river banks and control soil erosion	WFD: hydromorphological condition
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bioremediation by microorganisms, 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

Table 3.1 Qualitative overview of provisioning, regulating and maintenance, and cultural services provided by undisturbed floodplains (cont.)

Main sections	CICES group	Ecosystem service/ CICES class	Specific examples for floodplains	Environmental policy relevance
Regulation and maintenance	Regulation of soil quality	Filtration/ sequestration/ storage/accumulation by microorganisms, algae, plants and animals: **carbon sequestration**	Organic carbon from either river sediments or floodplain vegetation accumulates in floodplain soils. In a waterlogged state, greenhouse gasses (CO_2 and N_2O) are retained in the soil, whereas when ploughed and drained, they are released	Climate change mitigation
	Regulation of soil quality	**Soil conservation, formation and composition:** decomposition and fixing processes and their effect on soil quality – carbon sequestration	During floods, nutrient-rich sediments are removed from the river and deposited on floodplains, which reduces the nutrient concentration in the river. This creates new fertile sediment deposits and often changes the substrate structure and composition. However, in the case of upstream pollution, this mechanism can have long-lasting negative impacts	HD: relevant for species richness Climate change mitigation
	Life cycle 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
	Life cycle 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	Experiences and interactions with natural environment	**Recreation**	Floodplains are used for a multitude of recreational activities	Positive experiences for the public generates acceptance of objectives of other policies

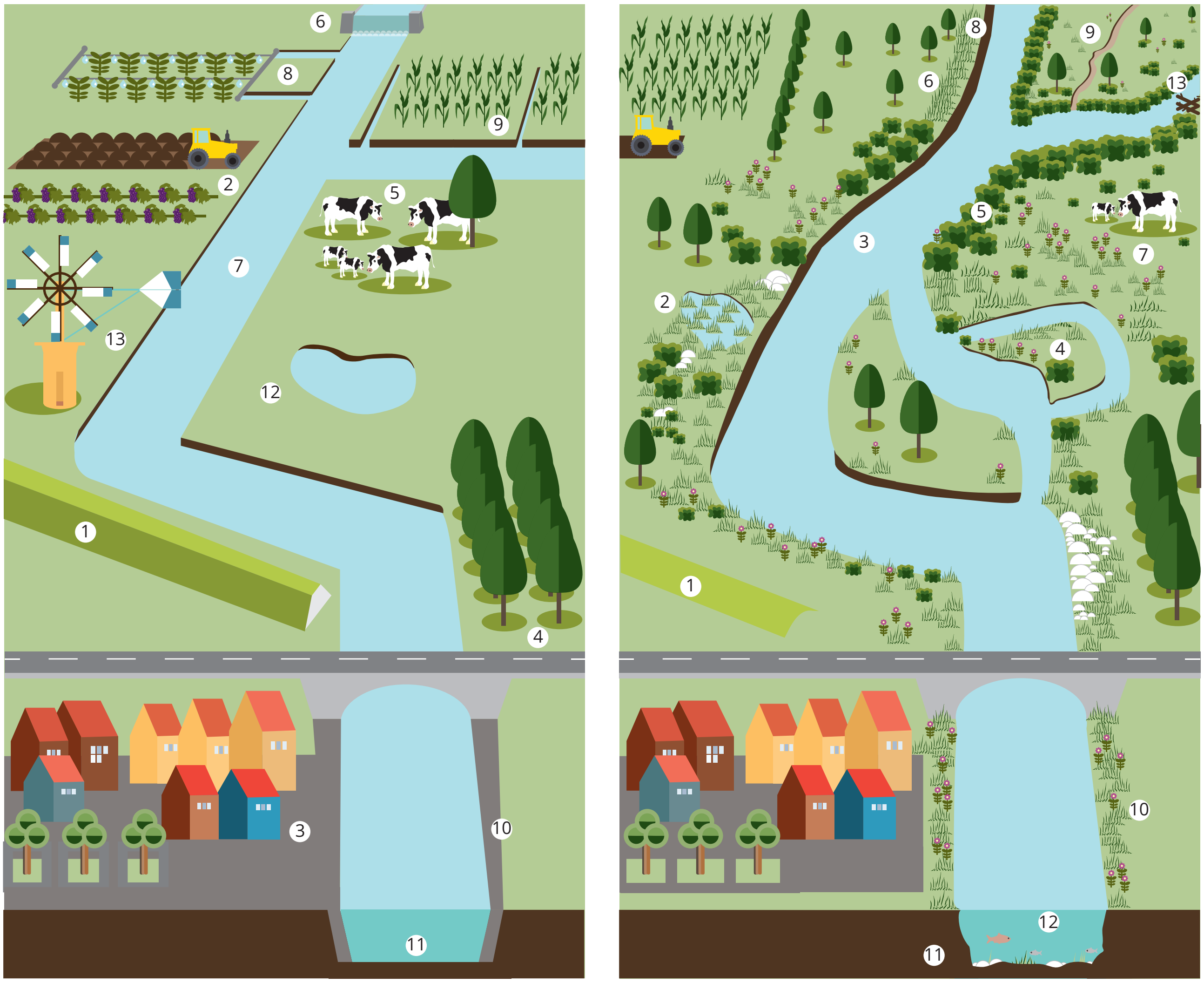
Notes: The services highlighted in bold are repeated in Table 2.2. CICES, Common International Classification of Ecosystem Services; FD, Floods Directive; WFD, Water Framework Directive; HD, Habitats Directive.

Source: Haines-Young and Potschin (2018).

of the environmental objectives' of the Water Framework Directive in natural surface water bodies, and they are to be considered part of river basin management plans (EC, 2015b). As many floodplain habitats do rely on flooding, these measures are important for ensuring the integrity of riparian habitats and seed dispersal. Measures include increasing the water use efficiency of cooling water, hydropower turbines, irrigation and water supply systems (Hornung et al., 2019).

In addition, land use both in floodplains and in the catchment is an important factor to regulate when improving service delivery. Major land uses include agriculture, woodlands, and urban areas (71 % of the total floodplain area (Figure 2.3)). The provisioning service of agricultural production tends to take place at the expense of regulating and maintaining services that support water retention and biodiversity. Adopting good agricultural practices (e.g. no or minimum tillage, crop rotation, catch covers, integrated crop/livestock systems and balanced fertiliser and pesticides use) may improve services linked to groundwater recharge and water storage, erosion control, water purification and carbon sequestration. Farm-level measures need to be complemented by catchment-scale measures such as requirements for buffer strips and reducing drained areas. Reducing the drainage of peat soils (carbon content greater than 12 %) is particularly beneficial for reducing greenhouse gas emissions,

Figure 3.2 Examples of hydromorphological restoration measures that improve the natural water retention capacity and habitats in floodplains



Alteration of the natural structure, hydrology, sediment processes, and habitats

1. Dikes
2. Cultivated fields
3. Urbanisation
4. Forestry
5. Grazing cattle
6. Dams, weirs, or barriers
7. Changing river planform
8. Drainage channels
9. Irrigation channels
10. Channelisation and river bank re-enforcement
11. Degraded river bed habitas
12. Disconnection of oxbow lakes and similar features
13. Water abstraction

Floodplain habitats and lateral connectivity restoration measures

1. Dike relocation, removal or lowering of dikes
2. Wetland restoration
3. Re-meandering of rivers
4. Reconnection of oxbow lakes
5. Forested riparian buffers
6. Buffer strips and hedges
7. Meadows and pastures

Hydrology and sediment management restoration measures

8. Removal of dams, weirs, or barriers
9. Restoration and reconnection of seasonal streams

In-channel habitat restoration measures

10. Elimination of river bank protection
11. Natural bank stabilisation
12. River bed renaturalisation
13. Coarse woody debris

Note: Measures are further detailed in Annex 3.

Sources: NWRM (2019); Reform (2015b).

as the decomposition rate is reduced when soils are waterlogged, reducing emissions of N_2O and CO_2. In Denmark, this reduction has been calculated to be 6 % of the national greenhouse gas emissions or around 25-30 % of total agricultural greenhouse gas emissions (Gyldenkærne and Greve, 2015). Waterlogged soils also increase denitrification, thus reducing nitrogen emissions to water, but they reduce agricultural yields. Floodplains are significant habitats for important herbs and other useful plant species that can be harvested (e.g. reed, cattail, mint and nettle), but these are usually not cultivated.

Riparian forests provide important floodplain habitats, but few remain in Europe. Re-establishing riparian forests is an important part of floodplain restoration.

Urban areas and roads contribute to the soil sealing of floodplains, reducing their water retention capacity. Because of climate change projections, the awareness of natural water retention measures in cities is increasing. Natural water retention includes diverse measures ranging from green roofs and rain gardens to water retention basins and, to a much greater extent, planning for room for water in emergency

Table 3.2 Qualitative effects of hydromorphological measures on ecosystem services (linked to Table 3.1)

Direction of impact: Positive / Negative / Low-none

Hydromorphological measure	Ecosystem services: Provisioning					Regulating and 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 and composition	Conservation of biodiversity
Floodplain habitats and lateral connectivity restoration measures													
Dike relocation, removal or lowering of dikes		Positive	Positive	Negative	Negative	Positive		Positive	Positive	Positive	Positive	Positive	Positive
Wetland restoration		Positive	Positive	Negative	Negative	Positive	Positive	Positive		Positive	Positive	Positive	Positive
Re-meandering of rivers		Positive	Positive	Negative		Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Reconnection of oxbow lakes			Positive			Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Forest riparian buffers			Positive	Negative		Positive	Positive		Positive	Positive	Positive	Positive	Positive
Buffer strips and hedges		Positive		Negative		Positive			Positive	Positive	Positive		
Meadows and pastures		Positive		Negative	Positive	Positive	Positive	Positive	Positive	Positive		Positive	
Hydrology and sediment management restoration measure													
Removal of dams and barriers	Positive		Positive			Positive			Positive		Positive	Positive	Positive
Restoration and reconnection of seasonal streams	Positive	Positive	Positive			Positive		Positive	Positive		Positive	Positive	Positive
In-channel habitats restoration measures													
Elimination of river bank protection	Positive		Positive	Negative		Positive			Negative	■	Positive	Positive	Positive
Natural bank stabilisation		Positive	Positive			Positive			Positive	Positive		Positive	Positive
Riverbed renaturalisation		Positive	Positive			Positive			Positive				Positive
Coarse woody debris	Positive		Positive			Positive			Positive				Positive

Sources: Table re-drafted from NWRM, 2019 and Reform, 2015; assessments depend on expert judgments.

situations (NWRM, 2019). However, the extreme costs of flood damages (Figure 2.7 Fatalities and economic losses in the EEA-33 as a consequence of natural hazards (EEA, 2019a)), demonstrate that not enough has been done and also that more can be done in urban areas to promote the services that support biodiversity conservation. The EU's Seventh Framework Programme (FP7) project Demonstrating Ecosystem Services Enabling Innovation in the Water Sector (Dessin) developed a standardised methodology that allowed a monetary value to be assigned to scenarios for water management measures.

Across Europe, there are many examples of successful restoration projects. In an analysis of 119 river restoration projects carried out between 1989 and 2016, it is shown that river restoration in Europe increasingly builds on more holistic solutions including actions in the river channel, floodplain and catchment (Szałkiewicz et al., 2018). Projects often build on the implementation of multiple measures, encompassing a mixture of structural restoration and altered flow management and land use, thus improving multiple ecosystem services. Many examples can be found in the overview provided by NWRM (2019), on the EEA Climate-Adapt website (EEA, 2018a) and on the website of the EU-funded Restore project (European Center for River Restoration, 2019). The Restore website provides a database that holds 1 162 river restoration case studies from 31 countries. Examples of more in-depth analyses are provided through the EU-funded FP7 Reform project (2015b). Since 1995, the Life+ programme of the EU has funded more than 100 floodplain restoration projects. Together, these projects support a comprehensive knowledge base on the environmental benefits of river restoration that is presently finding its way into European policy.

With increasing awareness, the numbers of examples of restoration measures or works aiming to improve river-floodplain systems' functioning are rising. In this regard, here we present three examples aiming to improve river-floodplain systems' conditions. One of them is a project from the Danube river basin, which shows potential ways of restoring floodplain-river systems and demonstrates the broad collaboration in this international river basin (Box 3.1). The second is a restoration project of the Skjern river, which is one of the most successful examples of river-floodplain restoration measures (Box 3.2), and the third is restoration of a Natura 2000 site on the Ebro river with the aim of improving the conservation status of four protected species, such as the European mink (*Mustela lutreola*), the otter (*Lutra lutra*), the European pond turtle (*Emys orbicularis*) and the black-crowned night heron (*Nycticorax nycticorax*) (Box 3.3).


Lindenborg River © Mads Christiansen

Box 3.1 Restoration activities on the Danube river — the need for international planning

The Danube river basin is the largest basin in Europe and covers more than 800 000 km^2 or 10 % of continental Europe. Shared by 19 countries, it is the most international river basin in the world. Of these 19 countries, 11 are EU Member States. More than 80 million people live in the Danube river basin and, accordingly, a huge variety of human activities affect this river and its tributaries (ICPDR, 2015).

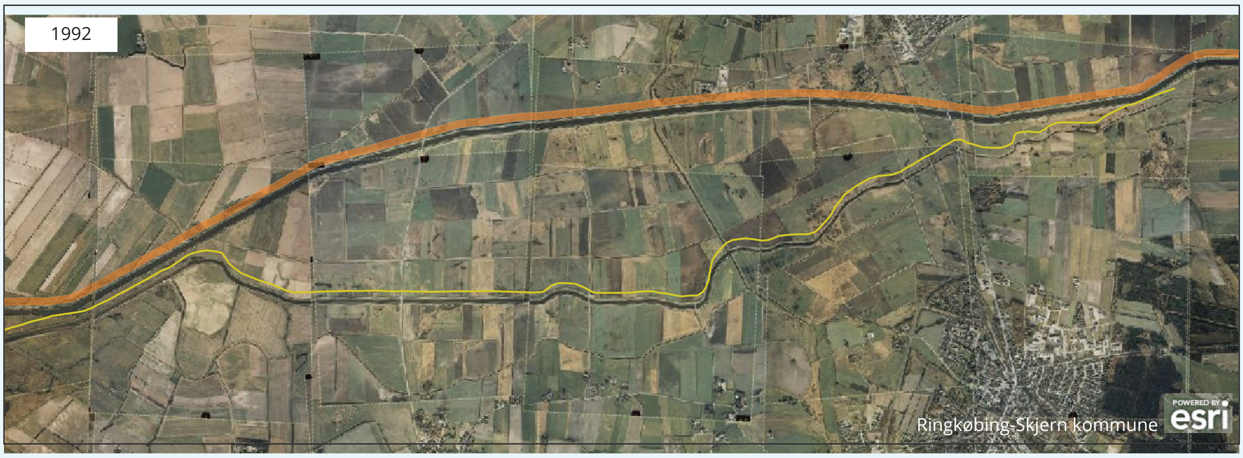
The Danube has very high biodiversity. However, it is threatened by hydropower, flood defence, navigation, agriculture, and water abstraction. These activities have changed natural hydrological regimes, disconnected floodplains and wetlands, and changed geomorphological processes, fundamentally altering habitats (ICPDR, 2015). Around 19 % of the 41 605 km^2 historical floodplain area remains (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).

The International Commission for the Protection of the Danube River (ICPDR) has performed a catchment-level analysis of the floodplain reconnection potential of the Danube and its tributaries and has identified management objectives and associated restoration measures that have a reconnection potential. As part of the implementation of the Joint Programme of Measures 2009-2015, 3 % of the wetland and floodplain area was fully reconnected and 21 % was partly reconnected to the river. For the future Water Framework Directive cycles, there are plans to reconnect the remaining area of wetlands and floodplains to the Danube river or its tributaries (ICPDR, 2015). Anticipated benefits include improvements in the functioning of the aquatic ecosystem such as the provision of fish habitats for spawning, nursery and feeding. In addition to being biodiversity hotspots that help to improve and secure water status, wetlands and floodplains play a significant role in flood water retention and thus also support the improvement of flood risk management.

Catchment-level assessment has identified priority areas for river restoration in the river based on multi-functionality related to biodiversity and ecosystem services, the availability of remaining semi-natural areas and the reversibility of human activities (Funk et al., 2019). The catchment scale is critical for achieving policy objectives.

Box 3.2 River Skjern, Denmark

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



Restoration of river Skjern, Denmark

- River Skjern, 1992
- Irrigation ditch, 1992
- River Skjern, 2018

0 1 2 3 4 5 km

Catchment size (km²)	Length (km)	Average discharge (m³/second)	Flood discharge (m³/second)	Average slope (%)
2 100	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 variety of habitats. In addition, natural sediment accretion at the river mouth formed a delta with extensive flooding as a consequence, leading to flood control attempts already in the 1800s. In 1968, channelisation and extensive wetland drainage was completed with the aim being to reclaim agricultural land. The channelisation, however, led to major environmental degradation and, in 2001-2002, a combined Danish and EU project transformed 19 km of channelised river into 26 km of meandering river, converting 2 200 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 otters, amphibians, salmon and insects are increasing or improving. However, flooding has been controlled and tamed as a result of 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 since the restoration and the recreational value of the area 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 3.3 Natura 2000 site restoration on the Ebro river, Spain

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

Catchment size (km^2)	Length (km)	Average discharge 1985-2004 (m^3/second)	Average discharge 1950-1985 (m^3/second)	Population (millions)
85 000	930	310	410	2.7

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 urbanisation. The natural climate in the Mediterranean region is associated 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 was undertaken in the 20th century. Today, more than 130 dams and reservoirs are found in the watershed, and estimates suggest that 99 % of the Ebro's former sediment load never reaches the sea. The dams have stabilised water flow in the river and eliminated most floods, which in turn has stabilised 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 (e.g. grasses and shrubs) as a result of frequent disturbances, but the stabilised hydrological regime has enabled forests to develop in the floodplain; the natural rejuvenation processes no longer take place (Ollero, 2010; Díaz-Redondo et al., 2018).

Because of 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+ Mink Territory project between 2010 and 2015. The project's aim was to improve 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 black-crowned night heron (*Nycticorax nycticorax*). The conservation status of these species depends on the quality of the floodplain, in particular on the hydraulic connections between the river and the floodplain being intact (Territoriovision, 2015).

Climate change scenarios for the Mediterranean highlight the importance of adapting river morphology to ensure that river dynamics and floodplain connections are more intact than at present, because these elements allow the system to increase its water retention capacity, thus providing a buffer to both floods and drought. Past investments have shown that structural or engineering measures have not paid off, although they have come at a large environmental cost (Díaz-Redondo et al., 2018).

However, improved management of the river will also require collaboration among a large number of public authorities in regard 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 Floods Directives are key to achieving a long-term strategy for more sustainable development of the Ebro watershed.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Ebro river in Zaragoza, an example of floodplain urbanisation.

4 Managing floodplains from an ecosystem perspective

The improved management of floodplains requires strategies that aim to reduce economic losses and threats to human lives due to floods, while at the same time reducing pressures, thus protecting the natural resources and functioning of floodplains, which are so important for achieving environmental policy objectives. Improved management is likely to require consideration of the optimal delivery of ecosystem services and the most suitable restoration scheme for achieving them.

Here we discuss improved management from the perspective of closing the implementation gap, improved coherence and improved collaboration. The 'implementation gap' refers to how existing policy could be better mobilised towards achieving objectives. 'Coherence' refers to the extent to which policies work in the same direction or if some objectives are conflicting. Finally, 'collaboration' refers to the interaction among the many stakeholders that participate in this process. These are also the three dimensions that need to be strengthened to improve management from an environmental perspective.

4.1 Closing the implementation gap

The many examples of floodplain restoration projects collected, for example, by the Natural Water Retention Measures project (NWRM, 2019), through the EEA Climate-Adapt website (EEA, 2018a) and through the website of the EU-funded project Restore (European Center for River Restoration, 2019), as well as the multitude of projects funded through LIFE+, demonstrate that there is an increased awareness of the many benefits that can be achieved through floodplain restoration and of the fact that realising those benefits is necessary for making progress towards the objectives of the Water Framework, Floods, Habitats and Birds Directives. The practical implementation of those directives takes place through the 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 Habitats and Birds Directives operate with measures for each Natura 2000 site (more than 27 000 sites, covering 18 % of Europe's territory (EEA, 2019e)), set in the context of prioritised action frameworks. Prioritised action frameworks are national multiannual planning tools that give financial prioritisation to the overall measures for Natura 2000 sites.

It is not, however, easy to get an overview of all of the relevant management measures or their effectiveness, on either the river basin or the European scale. Most countries report on using nature-based solutions as measures in their flood risk management plans (EC, 2019c) and EU Member States are improving river hydromorphology as part of their river basin management plans. Measures aimed at improving longitudinal continuity, river restoration, making improvements to riparian areas, removing hard embankments, improving flow regime or implementing nature-based solutions are reported. While reporting on programmes of measures certainly indicates activity, the wealth of approaches to assessments and the wide variety of actual information reported mean that an overview is difficult. Activities under the common implementation strategy of the Water Framework Directive aim to further streamline hydromorphological assessments in particular (Kampa and Bussettini, 2018; EC, forthcoming). Such improvements are likely to lead to a much greater understanding of hydromorphological restoration needs. There is not much evidence of the need for altered land management practices or water abstraction in these plans, although some countries set targets for reductions in their emissions.

The analysis of the first flood risk management plans showed that almost all countries consider some aspects of climate change, but only 10 EU Member States gave serious consideration to climate change impacts (EC, 2019c). 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. However, historical data 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 as a result of 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 such as LIFE+ are 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 is also recognised by the Strategic Environmental Assessment Directive (EC, 2001), which requires that plans such as flood risk, river basin or protected site management plans are assessed in regard to their ability to promote overall sustainable development. This directive is used as a tool to assess cross-border coherence of river basin management plans in international river basin districts and to ensure that planned development is sustainable from the point of view of cross-policy environmental objectives. Often, considerations under this directive lead to plans being altered to include more sustainable solutions (EC, 2019c).

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. This gap could possibly be filled by an ecosystem-based management approach in which the impact of multiple land use activities is reconciled against multiple environmental objectives. Although the need for river and floodplain restoration is widely acknowledged through the Water Framework, Floods, Habitats and Birds Directives, their objectives are usually not assessed from a holistic river basin management perspective, nor are restoration needs considered on 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 the balancing of management priorities. Large river restoration projects are costly and time-demanding undertakings. Therefore, they are often carried out one project at a time. However, a consideration of restoration needs within a river basin from a holistic and cross-policy perspective could be very helpful for informing the management and planning processes (Hillman and Brierley, 2005).

4.2 Improved coherence

As part of closing the implementation gap, consideration also needs to be given to the coherence between environmental policies. Many decisions related to water management also have a 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 in Natura 2000 management plans. As Natura 2000 site management focuses primarily on measures, coordination is possible, but the approach differs between countries, making an overview challenging. An assessment of the Natura 2000 network concluded that the network had not been implemented to its full potential, in part because of incomplete management plans and follow-up (ECA, 2017). However, as shown in this analysis, many of the services provided by the floodplain also benefit biodiversity, and the measures needed to achieve improved ecological and conservation status are often the same.

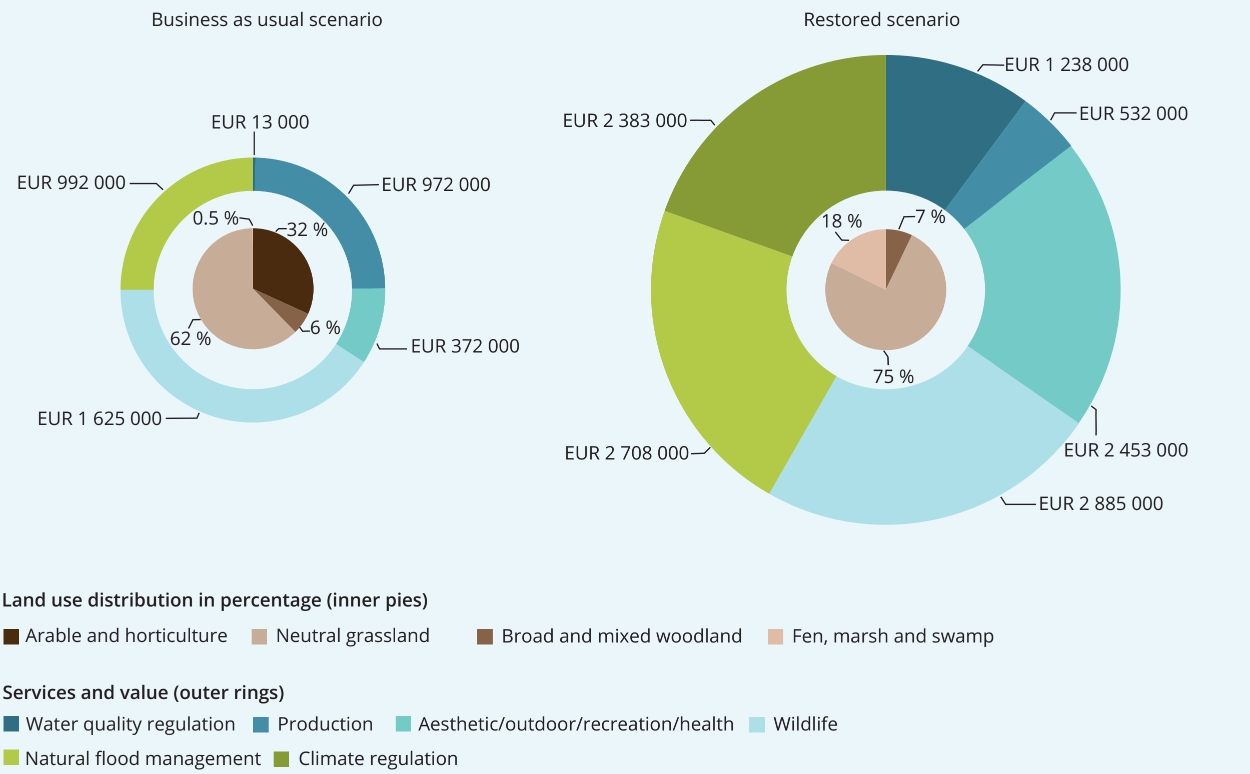
Ecosystem-based management refers to a system for managing multiple human activities and their pressures that aims to ensure that the ecosystem is healthy and resilient while at the same time delivering multiple ecosystem services that people both want and need (McLeod and Leslie, 2009). Rather than optimising management strategies towards single outputs (e.g. agricultural yield), ecosystem-based management aims to optimise the delivery of ecosystem services, thus enabling a greater range of ecosystem functions.

Managing from the perspective of ecosystem services enables a system to be developed in which 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, United Kingdom, suggest that there is a lot to be gained from using such approaches. The Chimney Meadows study demonstrated that an almost six-fold increase in the value of a restored area could be achieved by considering multi-functional aspects of the area (Box 4.1). Once a holistic assessment of watershed or river basin priorities is available, it becomes more straightforward to inform the planning process on managing the trade-offs needed to establish a more sustainable use scenario.

The example of Chimney Meadows suggests that improved floodplain management can be achieved through the optimisation of socio-economic targets, addressing specific restoration measures and the delivery of related ecosystem services by implementing specific restoration measures. This is, however, a complex undertaking and achieving positive results requires a combination of political prioritisation, planning of relevant measures, cooperation among multiple governing institutions and an active stakeholder process, often spanning years. Although such processes are often challenging and difficult, there are many examples of very positive outcomes.

Box 4.1 Chimney Meadows — an approach based on ecosystem services assessment

Chimney Meadows, a nature reserve in the United Kingdom, provides an example of how to approach an ecosystem assessment. Chimney Meadows is a 260-hectare farm that was purchased with the aim of converting its land used for intensive agricultural production into a species-rich floodplain meadow and wetland habitat for wading birds (Hölzinger and Haysom, 2017). Two scenarios that considered the difference in value over a 30-year period were compared. The first was a business-as-usual scenario where the intensive agricultural production was maintained. The second scenario considered restoration through conversion of arable land into a combination of grassland, fen, marsh and swamp areas. Although the value of the agricultural production decreased in the restoration scenario, the area provided a three times greater value because the value of other services increased. New, more valuable water- and climate-regulating services were established and the value of flood protection, wildlife and recreational services also increased. In the business-as-usual scenario, services included agricultural production, natural flood management, wildlife habitat and outdoor recreation.



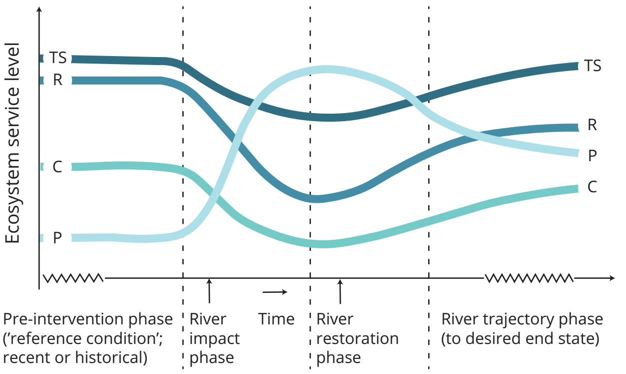
Source: Reproduced from Lawson et al., 2018 with permission of the authors.

As shown in the example of Chimney Meadows, the delivery of provisioning services tends to take place at the expense of regulating and maintaining services 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 gained from this more holistic approach. Through restoration, it may be possible to initiate a development trajectory over time through which 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.

Applying ecosystem-based management more systematically to the catchment-floodplain-river ecosystem allows us to be explicit about its functions for sustaining life, human well-being and long-term

Figure 4.1 Trade-offs between ecosystem services



Note: TS, total services provided; R, regulating and maintaining services; P, provisioning services; C, cultural and recreational services.

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sustainability. Attaching value in particular to regulating ecosystem services that, under current conditions, are undersupplied enables greater transparency as regards environmental trade-offs as a consequence of current management practices.

Some of these principles have already transpired in European legislation. The management units of the Water Framework and Floods Directives are river basin districts that, to a very large extent, overlap with catchment boundaries. However, biodiversity management takes a different approach, operating on the geographical scale of biogeographical regions. Many habitat types and species, however, also depend on water and wetland availability, which is often associated with rivers and 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.

4.3 Financing restoration

To date, river and floodplain restoration projects have been fully or partially funded by the EU through European structural funds and LIFE+ projects. Between 2000 and 2017, the EU invested EUR 516 million in different projects to improve biodiversity or ecosystem service delivery in rivers and floodplains under the LIFE+ programme (EC, personal communication, 2019). This investment was matched by a similar level of investment in the EU Member States.

To a certain extent, the need for the more balanced prioritisation described earlier is captured by the cross-compliance required under the common agricultural policy. Cross-compliance is a mechanism that links direct payments to farmers' compliance with basic standards for the environment and maintaining land in good agricultural and environmental condition. In this way, the requirements of the environmental policies discussed in this report are integrated into the common agricultural policy. Therefore, common agricultural policy investments support the establishment of measures such as buffer strips and organic farming and the implementation of best practice methodologies. However, inconsistencies arise and, although these investments are very large, the environmental gains are not as large as they could be (EC, forthcoming).

The EU has recognised that the scale of investments needed is beyond the capacity of the public sector and so proposed a sustainable finance regulation in 2018 to enable the financial sector to play a key role by re-orienting investments towards more sustainable technologies and businesses and financing sustainable growth over the long term (EC, 2019b). Emphasis has been placed on developing a taxonomy that lists economic activities that can make a substantial contribution to climate change mitigation and criteria that do no significant harm to other environmental objectives. It also presents a framework for evaluating substantial contributions to climate change adaptation. Nature based solutions as discussed here, could become part of this taxonomy.

4.4 Improved cooperation

To make ecosystem-based management work, collaboration is needed 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, 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.

The solutions for achieving the multiple policy objectives listed in Table 1.1 can often be the same, and often need to be established in floodplains. If they are well planned, they can lead to an overall improvement of ecosystem health in rivers, floodplains and, eventually, the entire catchment. Measures, however, often aim to address specific human activities, but to achieve

Box 4.2 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 stabilised and the river was channelised to protect 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 to recover the longitudinal and lateral connectivity of the river through the removal and set back of levees and adapting weirs and other transversal barriers. By restoring the river's connectivity with the floodplains, the hydraulic storage capacity of the river during floods was increased and multiple natural processes were restored, including the recovery of the natural floodplain, an increase in species and habitat diversity and the recharging of the alluvial aquifer. The project is a good example of the multiple benefits that can be gained from one restoration measure based 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.

Because of the concerns of the citizens living near the river, a large public participation process was initiated. The public was informed throughout, from 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 because, until then, public participation was merely an administrative formality. Public participation enables communication and transparency, allowing social consensus and shared decision-making to be achieved. Social acceptance is essential for the success of a project such as this, namely one that was using green infrastructure solutions for the first time after 'grey' solutions had been carried out for the previous 50 years (Global Water Partnership, 2015).

societal buy-in to implementation, the overall link to socio-economic demands also needs to be addressed.

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 on river basin and catchment scales, while land use planners typically work on 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, 2019c).

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, transparency is needed in communicating the project aims, stakeholders must be open to changes, and this process must take into account local communities and the time needed for negotiations. 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 values 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 EUR 400 000 per kilometre of river), 70 % of the interviewees considered further restoration projects useful and only 6 % considered them not useful (Deffner and Haase, 2018). An example of citizen engagement is provided in Box 4.2.

4.5 What we do at the EEA

Today, knowledge on both the floodplain conditions and the improvements achieved over time is still very limited; a better understanding is needed to develop a European overview. An actual assessment of floodplain conditions is still needed to work towards the current 15 % restoration target. In addition, more knowledge is needed on the link between restoring floodplains and achieving policy objectives.

The existing 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, making it challenging to create a consistent European overview.

In response to the importance of the floodplain, the EEA and the European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM) are currently developing a European assessment of human impacts on the floodplain. The methodology behind the assessment is based on principles known from the Water Framework Directive. Floodplains in Europe are grouped according to their type. Assessment indicators are used to quantify human impacts by quantifying the deviation from a reference condition on morphological and ecological conditions of floodplains. Both typology and assessment indicators are based on data sets available on the European scale. The typology is meant to provide an overall grouping of floodplains based on physical characteristics of river basins and flows. In contrast, assessment indicators are meant to highlight deviations from the natural state, especially in relation to hydromorphology and land use.

Once the assessment has been developed, it will help support further discussions on restoration needs from the perspective of managing flood risks, improving the status of water and the conservation status of some of Europe's habitats and species. It is anticipated that restoration objectives will appear in the upcoming biodiversity strategy, and this work could potentially support the monitoring of that strategy. In addition, this work could support the provision of recommendations for the development of river basin and flood risk management plans in the future (e.g. through the enhanced uptake of ecosystem-based management).

Lindenborg River © Svend Birkelund Andersen

5 Conclusions and outlook

Across Europe, floodplain restoration projects have been undertaken throughout the past three decades. These projects have been undertaken because it has been increasingly recognised that a natural preserved floodplain is more valuable than a disturbed one, and that it is worthwhile for society to increase the benefits provided by floodplains through restoration. A natural preserved floodplain delivers multiple ecosystem services and, through restoration, the environmental condition of degraded floodplains can be improved to deliver a much higher level of ecosystem services across Europe.

However, studies also show that the implementation of restoration projects is complex and that balancing the many trade-offs is likely to be needed. It may be helpful to support the flood risk, river basin and protected site management plan process with a more holistic ecosystem-based analysis to support the development of long-term strategies towards achieving environmental objectives.

On the one hand, the path to improving the environmental condition of floodplains through altered land use management and restoration has been established through European policies. On the other hand, the results achieved to date suggest that much more work is needed. On average, only approximately 40 % of Europe's surface water bodies achieve a good ecological status or potential (EEA, 2018c). Hydromorphological pressures are one of the two most commonly listed pressures on around one third of water bodies. Only 17 % of floodplain habitats and species have a good conservation status. In this report, it is argued that there is a significant gap in implementation, namely there is insufficient consideration of the multiple objectives across directives, which could be accommodated by serious consideration of an ecosystem-based approach to management across directives. Such an approach offers a much more nuanced view on the value of the natural system and the most relevant management measures needed to achieve specific services.

The tools needed for an ecosystem-based approach are largely available within the Water Framework, Floods, Habitats and Birds Directives. All those directives require plans and programmes of measures to achieve their stated objectives. Strengthening the link between river basin, flood risk and Natura 2000 management plans could support the achievement of a good conservation status for species and habitats that depend on water. If carefully planned, the same measures could fulfil objectives across those policies, while at the same time maximising the benefits provided from a particular site, supporting a knowledge-to-action approach. In particular, the link between the Floods and Water Framework Directives is essential because it establishes the need to consider ways of providing flood protection other than traditional structural measures and it places emphasis on the need to reduce hydromorphological pressures.

The European Green Deal launched in December 2019 is about improving the well-being of people (EC, 2019a). Its overarching objective is to make Europe climate-neutral and to protect our natural habitat because it will be good for people, the planet and the economy. Under the European Green Deal, climate change, biodiversity, eliminating pollution and the farm to fork strategy are four policy areas that support the achievement of its overarching objective, and the achievement of these objectives could be supported by floodplain restoration as described in this work. The need to conserve and restore biodiversity and reduce chemical and nutrient pollution in rivers, lakes and wetlands (and hence also in floodplains) is reinforced between the three policy areas. As a consequence, it is anticipated that much greater awareness of the preservation and restoration needs of floodplains will develop. Furthermore, the reinforced links between policy areas are indeed the links needed to build a more ecosystem-based approach to management. As part of the farm to fork strategy, 40 % of the funding under the common agricultural policy will be spent on climate-related initiatives and could provide some of the funding needed to alter land use practices in floodplains, moving towards more sustainable approaches.

Certainly, the need to prioritise the preservation and restoration of floodplains is necessary to gain the many benefits associated with flood risk mitigation and adaptation and climate change mitigation, to achieve a good ecological status within the Water Framework Directive and to achieve a good conservation status among species and habitats that depend on water within the Habitats and Birds Directives. Prioritising environmentally friendly land use and nature-based restoration, rather than structural solutions, will lead to benefits for more of the ecosystem services that are necessary for improving the ecological status of rivers and the conservation status of species and habitats found in the unique floodplain environment.

Exactly how much restoration is planned or needed in Europe is not clear at present. In spite of its obvious importance for the policies discussed, floodplain restoration has not been systematically included in river basin or flood risk management plans. For developing more strategic approaches to restoration in the future, it will be important to develop a more coherent knowledge base. It could include more systematic and consistent approaches to ecosystem-based management used to draw conclusions on restoration needs across directives. A more coherent approach would also support a more targeted approach towards financing restoration, perhaps moving out of the project domain and into planning towards more holistic objectives. Certainly, the approach taken by the European Green Deal suggests that integrating across policy domains is broadly seen as key to achieving the deal's ambitious targets.

The work in progress by the EEA and the European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM) to develop a floodplain assessment method could support the development of a more coherent knowledge base. A consistent method across Europe would not only quantify the condition of floodplains, but also help to establish a framework for a structured discussion of knowledge and information gaps, as well as of restoration needs on the European scale, which will be needed as part of the upcoming biodiversity policies and pollution elimination policies under the European Green Deal.

Straightened section of Lindenborg river © Trine Christiansen

Abbreviations

CICES	Common International Classification of Ecosystem Services
Dessin	Demonstrating Ecosystem Services Enabling Innovation in the Water Sector
EEA	European Environment Agency
EEA-33	33 EEA member countries
EEA-39	33 EEA member countries and six cooperating countries
ETC/ICM	European Topic Centre on Inland, Coastal and Marine Waters
EU	European Union
FD	Floods Directive
FP7	Seventh Framework Programme
HD	Habitats Directive
ICPDR	International Commission for the Protection of the Danube River
JPM	Joint Programme of Measures
JRC	Joint Research Centre
MAES	Mapping and Assessment of Ecosystems and their Services
NWRM	Natural Water Retention Measures
Reform	Restoring Rivers for Effective Catchment Management
WFD	Water Framework Directive

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Annex 1 European and global policy context

Achieving the objectives of the policies listed in Table 1.1 requires that the policy commitments of different policies be considered. This annex summarises how achieving the 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: this goal recognises that the ecosystem health of floodplains (as part of wetland and river ecosystems) is essential for achieving a sustainable future in the global context and 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 inland surface waters that 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 (Article 1(a) of the Water Framework Directive). Achieving the objective of good ecological status will be supported by increasing the area of natural, active floodplains because of their enhanced water and nutrient retention capacity. Achieving good ecological status in rivers, among others, requires minimising hydromorphological and pollution pressures. Diffuse nutrient pollution is reduced when floodplains are more natural. Hydromorphology in rivers is defined by the hydrological regime, river continuity and morphological conditions. These parameters are affected by structural flood control measures that also disconnect floodplains from their river. The main management tool of the Water Framework Directive 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, 2016a, 2018b).

EU biodiversity strategy, target 2 (COM/2011/244): this strategy requires 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 floodplains will explicitly support the achievement of this target.

EU Floods Directive (2007/60/EC): the key objective of the Floods Directive is to reduce the flood risk across Europe, also in the light of climate change. Through emphasis on natural water retention measures, flood risk reduction can support the achievement of 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 district as defined by the Water Framework Directive (EEA, 2016a).

EU Habitats and Birds Directives (92/43/EEC and 2009/147/EC): floodplains are highly valuable habitats and form an important part of the Natura 2000 network. Analyses from Germany and the Netherlands 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 listed within the Birds Directive. An increased area of active floodplains is likely to improve the conservation status assessments of listed habitats and species (EEA, 2016a, 2020a).

EU climate change adaptation strategy and disaster risk reduction (COM/2013/0216): climate change may increase the risk of 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, 2016a, 2017a).

Green infrastructure — 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. 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 for several measures related to floodplain restoration. In the current rural development plans, Member States have used six different measures to subsidise floodplain restoration: measure 4.4 (non-productive investments), measure 5 (prevention or restoration after a weather event), measure 7 (basic services), measures 8.4 and 8.5 (floodplains linked to forests) and measure 10 (agri-environmental climate measures). 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 rural development plans) found that to tackle morphological pressures, wetland restoration (33 % of rural development plans), floodplain management (29 % of rural development plans), re-meandering (19 % of rural development plans) and the removal of embankments and dykes (19 % of rural development plans) were cited most frequently (Berglund et al., 2017).

Under Article 3(2) of the Nitrates Directive, EU Member States must establish buffer strips along watercourses that respect the requirements for the land application of fertiliser near watercourses. 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 change 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 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 green infrastructure offers a better alternative, or is complementary, to less sustainable choices (commonly referred to as grey infrastructure).

Natural water retention measures target the restoration or maintenance of aquatic ecosystems through developing, restoring or maintaining their 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 are solutions to societal challenges that are inspired and supported by nature, which are cost-effective, provide simultaneous environmental, social and economic benefits, and help build resilience. Such solutions bring more (and more diverse) nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions (EC, 2016), and thus they simultaneously provide benefits for biodiversity and human well-being (Cohen-Shacham et al., 2016).

Ecosystem-based management refers to managing multiple human activities and their pressures with the aim of ensuring that ecosystems remain healthy and resilient 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 (e.g. 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 Measures that improve services

Selected restoration measures	Qualitative description of the measure
Floodplain habitats and lateral connectivity restoration measures	
Dike relocation, removal, or lowering of dikes	Dike relocation/setting back embankments and dikes • 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) • Removes dikes and embankments on both sides of rivers and relocates them further from the river. To maintain bank protection, groins or anchored tree fascines can be installed after widening.
	Removal or lowering of dikes • Enlarges the effective river floodplain. Increases physical, hydrological and other natural processes (Roni, 2005). • Covers the lowering or removal of dikes entirely to allow floodwaters to reach the floodplain
Wetland restoration	• Contributes to flood attenuation via water retention; provides water quality improvement and habitat and landscape enhancement • Covers spatially large- and small-scale measures, such as clearing trees, the cutback of dikes to enable flooding, changes in land use and agricultural measures such as adapting cultivation practices in wetland areas
Re-meandering of rivers	• Increases the storage capacity of a river channel and decreases a river's slope and water velocity. Improves lateral interactions, the sedimentation process and biodiversity. Provides habitats for a wide range of aquatic and land species • Consists of creating a new meandering course or reconnecting cut-off meanders
Reconnection of oxbow lakes	• Favours the overall functioning of the river by restoring lateral connectivity, diversifying flows and improving 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 oxbow lakes
Forested 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. A forested riparian buffer measure is considered a separate measure from other buffer strip types because it has different design, implementation, and management criteria. • Tree-covered buffer strips alongside streams and the other water bodies are maintained and re-established. This measure is also mostly associated with set-asides following forest harvest, but it is also important for urban, agricultural and wetland areas.
Buffer strips and hedges	• Improves water filtration, slows surface flow and thereby promotes the natural retention of water. Can also improve water quality by reducing the amount of nitrates, phosphates and suspended solids originating from agricultural run-off. • Covers the maintenance or re-establishment of natural vegetation cover (grass, bushes or trees) at the margin of fields, arable land, transport infrastructures and watercourses.
Meadows and pastures	• Provides temporary flood water storage, increases water retention, and delays run-off by allowing greater infiltration to the soil. Can also protect water quality by trapping sediments. • Meadows and pastures provide a permanent soil cover with rooted vegetation.

Selected restoration measures	Qualitative description of the measure
Hydrology and sediment management restoration measures	
Removal of dams, weirs, and barriers	• Restores the slope and the longitudinal profile of the river, thus allowing re-establishment of fluvial dynamics, as well as sedimentary and ecological continuity. • Consists of removing barriers.
Restoration and reconnection of seasonal streams	• Favours the overall functioning of the river by restoring lateral connectivity, diversifying flows, and ensuring improved water retention of seasonal streams during floods. • Consists of maintaining and protecting the river system, its natural dynamics and its environment, recreating connection between the river and the seasonal stream, preserving flood buffer capacity, and limiting water abstraction.
In-channel habitat restoration measures	
Elimination of river bank protection	• Enhances lateral connections of the river to the floodplain, diversifies flows (depth, substrate and speed) and habitats. It is a prerequisite for many other measures such as re-meandering or widening, as well as initiating later channel migration and dynamics • Consists of removing parts of the bank protection.
Natural bank stabilisation	• Decreases degradation and erosion and increases the river's natural movement and habitat richness. It also increases the pollutant and sediment filtration process • Consists of recovering ecological components of riverbanks by reintroducing natural river bank vegetation.
Riverbed renaturalisation	Stream bed renaturalisation • Improves the erosion process, supports habitat richness and increases the travel time of water • Consists of removing concrete or obsolete constructions in the riverbed and on riverbanks and replacing them with vegetation and natural substrate.
	Riverbed material renaturalisation • Increases habitat types, improves the natural process and lateral connectivity of rivers, and supports sediment controls • Consists of recovering the nature-like structure and composition of the bed load and setting the equilibrium between coarse and fine sediment.
Coarse woody debris	• Slows water flow velocity and can reduce the peak of flood hydrographs. Retains food and provides additional habitats for aquatic life, such as refuges and spawning sites. Woody debris can also increase sediment storage in the stream and aggrade streambeds • Consists of installing logjams (woody debris) using local timber materials

Sources: Description of restoration measures are based on overviews provided by the Natural water retention measures project (NWRM, 2019) and the Restoring rivers for effective catchment management project (Reform, 2015a, 2015b)

European Environment Agency

Floodplains: a natural system to preserve and restore

2019 — 51 pp. — 21 x 29.7 cm

ISBN 978-92-9480-211-8
doi:10.2800/431107

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TH-AL-20-004EN-N
doi:10.2800/431107

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of the European Union

25 1994-2019
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