Rivers and lakes in European cities

Past and future challenges

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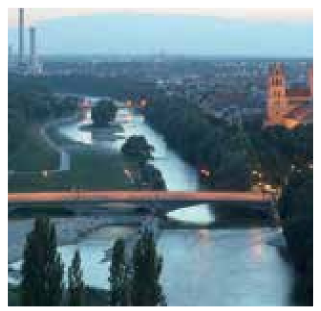

European Environment Agency

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Contents

Abbreviations **4**

Acknowledgements **5**

Executive summary **6**

1 Context and objectives of the report and methodology **8**

1.1 Context 8
1.2 Objectives of this report 9
1.3 Structure and method of the report 9

2 The fall and rise of urban rivers and lakes **11**

2.1 The importance of rivers and lakes in European cities 11
2.2 Key impacts of urbanisation 13
2.3 Rediscovering rivers and lakes in our cities 14
2.4 European policy impetus 15
2.5 City visions and strategies for water 17

3 Coping with key challenges for urban rivers and lakes **20**

3.1 Water availability and supply 20
3.2 Water quality 22
3.3 Structural changes 28

4 Lessons learned and way forward **41**

4.1 Local and catchment planning 41
4.2 Multifunctionality 42
4.3 Space for urban restoration 43
4.4 Public participation 44
4.5 Governance framework 44
4.6 Concluding remarks — looking forward 45

References **46**

Abbreviations

BOD	biochemical oxygen demand
COD	chemical oxygen demand
CSO	combined sewer overflow
ECRR	European Centre for River Restoration
EEA	European Environment Agency
ETC/ICM	European Topic Centre on Inland, Coastal and Marine Waters
EU	European Union
FP7	7th Framework Programme for Research and Technological Development
FRC	Flood Resilient City
HMWB	heavily modified water bodies
LRAP	London Rivers Action Plan
NABU	Naturschutzbund Deutschland
NGO	non-governmental organisation
NIVA	Norwegian Institute of Water Research
NWRM	natural water retention measures
OECD	Organisation for Economic Co-operation and Development
SAGYRC	Syndicat Intercommunal du Bassin de l'Yrezon
UBA	Umweltbundesamt
UFZ	Hemholtz Centre for Environmental Research
UNISDR	The United Nations Office for Disaster Risk Reduction
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive
WWTP	wastewater treatment plant

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Executive summary

Most European cities have at least one river or lake crossing their urban landscape. Over time, the settling of humans next to rivers and lakes has transformed the natural environment into the towns and cities we see today. Urbanisation has come at a cost to rivers and lakes, as they have been heavily degraded to enable development, carry waste, supply drinking water and facilitate transport and industry.

In recent decades, and after a gradual improvement in water quality due to wastewater treatment and reduced industrial activities, urban rivers and lakes have become increasingly important in the planning of urban ecology, green infrastructure, green areas and climate change adaptation in European cities.

In the European Union, there are also several policy processes that act as drivers for managing urban rivers and lakes in a more integrated way. This relates to several directives such as the Urban Waste Water Treatment Directive, the Water Framework Directive (WFD), the Floods Directive, and the Birds and the Habitats Directives, as well as other policies such as the EU Strategy on Adaptation to Climate Change, the EU Strategy on Green Infrastructure and, more recently, the Urban Agenda for the EU.

This report aims to describe water management issues related to rivers and lakes and outline the ways in which European cities develop strategies and measures to cope with the key challenges they currently face in relation to their inland surface waters. The strategies, initiatives and specific restoration measures presented in the report can serve as sources of inspiration and lessons learned.

Some major inland water management challenges in European cities are:

Water availability and supply: several European cities depend on surface waters for their drinking water supply, in several cases having to resort to rivers or lakes situated hundreds of kilometres away from the city. The design of urban water supply infrastructure still predominantly rests on an engineering and supply-led approach dating back to the first stage of urban development and industrialisation. However, to prevent urban water crises, water resources should be managed effectively at every stage; this should involve consumption reductions, new ways of collecting (e.g. green roofs) and using water (e.g. water reuse), and awareness campaigns.

Water quality: urban rivers and lakes have been heavily polluted in the processes of urbanisation and industrialisation during the last century. Looking back over the past 25 years, clear progress has been made in reducing emissions into urban rivers and lakes; this has been done through connections to sewers, the introduction of wastewater treatment and the upgrading of earlier treatment plants. However, some key challenges remain, including water quality impacts related to stormwater management and historical pollution of sediments.

Structural changes: rapid urbanisation and industrial growth have introduced new pressures on urban rivers and lakes, in the form of modifications to their morphology and hydrology (e.g. through river channelisation and straightening). This has often meant reducing the area covered by a river and floodplains with the aim to improve flood protection and create living space in growing towns. This report describes the responses of cities and towns to the impacts of physical modifications.

The case studies on urban river and lake restoration and management reviewed for this report reveal that there are several critical aspects to be considered when planning and running urban restoration activities. The report draws some important lessons learned from the case studies reviewed and frames some key contextual issues that are potentially relevant to different urban settings across Europe.

Local planning: restoring the water environment in urban areas has very important links with local planning, flood risk management and climate change adaptation measures. Local authorities can use land-use planning processes to deliver improvements to urban rivers and lakes. At the same time, such planning processes can identify stakeholder aspirations and assist in the delivery of restoration, offering an important opportunity for interested parties to become involved in the decision-making process. In this context, the planning process for and financing of restoration measures in urban areas require effective collaboration between water and city development authorities, authorities responsible for urban and spatial planning, and local residents.

Multifunctionality: in designing restoration projects for urban rivers and lakes, it is important to aim for multifunctional schemes. Multifunctional schemes contribute to the achievement of multiple benefits for different sectors. They are thus in a better position to raise funding from different sources, gain public and political acceptance and take advantage of effective cooperation between different actors in the governance setting. Multifunctional urban restoration measures are seen as win–win measures that help deliver synergies, e.g. by implementing different policies such as the Water Framework Directive (WFD), the Floods Directive and the Habitats Directive. While the strong links between restoration and flood risk management must be taken into account, it is also important to create spaces that allow citizens to experience nature. It is also clear that defining multiple benefits more accurately (both direct and indirect benefits in terms of ecosystem services) is often helpful in the decision-making process with regard to restoration projects in cities.

Space for restoration: in urban areas, where available space is limited, river restoration projects are frequently restricted. However, there may be opportunities to remove redundant structures and buildings, and to gain more space alongside rivers for restoration activities. Furthermore, because of the lack of space in urban areas, some cities have developed stepping-stone concepts for restoring their networks of water bodies. Such stepping-stone approaches involve starting restoration in the outskirts and peri-urban areas and moving step by step towards the more central urban areas, which are more challenging to restore.

Public participation: planning and execution of measures for urban river restoration should not follow a top-down approach. Public consultation and engagement with local communities have emerged as crucial steps in the planning and implementation of restoration measures in cities. Civil society and the private sector are vital for the development of cities and their hinterlands, and they will play a major role in coping with the challenges ahead.

Governance framework: in addition to engaging with the public and citizens affected by restoration schemes, it has proved equally important to establish effective cooperation between the different actors (especially government bodies and organised stakeholder groups) with a stake in and an influence on urban restoration.

Many European cities have developed broad visions and strategies to promote more integrated management of their water bodies, especially in terms of restoring their rivers and lakes. Activities on the restoration of urban rivers and lakes are likely to expand further as urban development continues and demand for a better, more sustainable quality of life increases.

1 Context and objectives of the report and methodology

1.1 Context

Europe is an urban and increasingly urbanising continent. Roughly three quarters (72.4 %) of the total EU-28 population lives in cities, towns and suburbs (Eurostat, 2015). Although the speed of urbanisation has slowed down, the proportion of the urban population to the total population continues to grow and is likely to reach more than 80 % by 2050 (European Commission, 2014a; EEA, 2015a). This will pose a range of challenges for the natural resources and ecosystems within and close to urban regions, including the rivers, streams and lakes that are part of the landscape of European cities.

In Europe, as in other industrialised parts of the world, the quality of urban rivers and lakes degraded after the 19th century owing to the increasing numbers of settlements and industries discharging untreated wastewater. Urban rivers and lakes were also structurally modified to accommodate human uses such as navigation, construction activities and flood protection.

In recent decades, and after a gradual improvement in water quality due to wastewater treatment (driven in part by the Urban Waste Water Treatment Directive (UWWTD)) and reduced industrial activities, urban rivers and lakes have become increasingly important in the planning of urban ecology, green infrastructure and green areas in European cities. In particular, river and lake restoration projects, often as integral parts of city development projects and urban planning, are often considered win–win situations: they improve flood control and ecological functions while offering recreational value and raising the quality of life in urban areas. Furthermore, integrating green and blue spaces into the design of the urban fabric reduces overheating and pollution, thus mitigating the strength and impacts of the urban heat island effect (EEA, 2012b).

Activities on the restoration of urban rivers and lakes are likely to expand further as urban development continues and demand for a better, more sustainable quality of life increases.

Around the world, there are more and more projects exploring how people will live with water in their cities in the coming decades. Cities are developing visions for safer and aesthetically more attractive city locations, built on sustainable water management principles and good practices. The Organisation for Economic Co-operation and Development (OECD) recently showcased good practices to promote a strategic vision across sectors, to engage with stakeholders and to foster integrated urban water management in cities and their hinterlands, through rural-urban partnerships and metropolitan governance (OECD, 2016).

In Europe, many examples of rivers and lakes in cities and towns that have been restored to serve different purposes already exist (EEA, 2015b, 2015d and 2016b,; RESTORE, 2013; UNISDR, 2012). Such projects are partly (but not only) driven by the objectives of key water policies, such as the EU Water Framework Directive (WFD).

In fact, in the European Union, there are several policy processes that act as drivers for managing urban rivers and lakes in a more integrated way. This is linked to the implementation of several EU directives such as the UWWTD, the WFD, the Floods Directive, and the Birds and Habitats Directives, as well as other policies including the EU Strategy on Adaptation to Climate Change, the EU Strategy on Green Infrastructure and, more recently, the Urban Agenda for the EU. These policy processes and their interplay contribute to linking water quality improvements with ecosystem protection, climate change adaptation and urban development in cities across Europe.

In addition, there is a need to strengthen the knowledge base related to the restoration of urban rivers and lakes by building on existing and ongoing research such as that carried out under the FP7 REFORM project (http://reformrivers.eu), good practice examples such as those collected in the RiverWiki (https://restorerivers.eu/wiki) and guidance such as that available on the EU natural water retention measures (NWRM) platform (http://www.nwrm.eu) and by sharing experiences through networking (e.g. through the European Centre for River Restoration (ECRR) or regional or national restoration centres).

1.2 Objectives of this report

The EEA acknowledges the importance of the sustainable use of natural resources in urban areas and has recently issued reports on resource efficiency in cities (EEA, 2015c, 2015d, and 2015e) and on urban adaptation to climate change (EEA, 2012b and 2016b). The EEA has also addressed the various perspectives on and perceptions of quality of life in Europe's cities and towns, thereby defining a vision for progress towards a more sustainable, well-designed urban future (EEA, 2009 and 2015b). The report does not cover in detail water economics, including cost–benefit analysis and policy implementation (see, for example, EEA, 2013).

In this context, the current report aims to:

- outline the ways in which European cities develop strategies and measures to cope with the key challenges they currently face in relation to their inland surface waters (rivers and lakes);
- showcase specific measures, strategies and initiatives on river and lake restoration, flood protection, stormwater management and water quality improvements in cities across Europe that can serve as sources of inspiration and lessons learned.

The report aims to reach a broad public made up of citizens across Europe and to illustrate that river and lake restoration does not necessarily take place only far away from centres of human activity. On the contrary, river and lake restoration is feasible and even desirable within the towns and cities we live in.

Therefore, the use of the term restoration in this report is not limited to 'a management process striving to re-establish the structure and function of ecosystems as closely as possible to the pre-disturbance conditions and functions' (Wagner et al., 2007). The term restoration is used more broadly to refer to activities that aim to improve the status of degraded waters, be it by improving water quality or by changing hydromorphological conditions (see wiki.reformrivers.eu), and also such activities that, in addition, aim to serve other needs and preferences of the urban population, i.e. through multifunctional measures.

This report does not seek to provide guidance on how to carry out urban river and lake restoration. The geographical and socio-economic contexts as well as the ecosystems targeted by restoration projects in cities and towns vary greatly. This means that restoration processes and methods cannot usually be implemented in the same way across different locations. Nevertheless, the report draws some key conclusions and lessons learned from good practice examples on river and lake restoration in selected European cities.

1.3 Structure and method of the report

To provide useful examples and lessons learned from real-life cases, screening of restoration strategies and projects in European cities was carried out for the purposes of this report. On the basis of this screening, 17 case studies were selected to cover a range of relevant issues and to ensure a good geographical spread. The 17 case studies are presented in separate factsheets in the annex to this report ([1]). These factsheets provide information on the key water management issues, restoration measures and strategies implemented in the case studies, the main results and benefits, and key lessons learned.

The case studies have provided evidence for and illustrated the key issues presented in the main part of this report, especially in order to reflect on the main types of restoration measures and strategies for urban rivers and lakes and to frame some of the important issues that are potentially relevant to different urban settings across Europe. In addition, other examples of water management in European cities are mentioned in the report.

Table 1.1 gives an overview of the case studies reviewed and illustrated in more detail in the annex.

Chapter 2 outlines the importance of rivers and lakes as key features of European cityscapes and describes the key impacts of urbanisation on rivers, streams and lakes. It also discusses the way we view urban rivers and lakes; their functions and services in relation to people have changed in recent decades. It also illustrates how European cities have started to develop visions and strategies for more sustainable management of their water bodies.

([1]) Please see separate file: http://www.eea.europa.eu/publications/rivers-and-lakes-in-cities/annex-rivers-and-lakes.

Chapter 3 addresses the major challenges that European cities face with regard to their urban rivers and lakes; these challenges are grouped into water availability and supply challenges; water quality issues; and structural changes, related to, inter alia, flood risk management. The chapter provides a brief review of the issues at stake, documents the key approaches to dealing with the issues and offers case study illustrations.

Chapter 4 summarises some important lessons learned from the case studies reviewed and frames some key contextual issues that are important for planning and running river and lake restoration activities in cities. This section also describes some significant challenges for the future and identifies opportunities for more effective restoration of rivers and lakes in an urban setting.

Table 1.1 Case studies referred to in this report

City/town	Country	River/lake	Title of case study
Aarhus	Denmark	River Aarhus	Reopening the River Aarhus
Bucharest	Romania	River Dâmbovița	Wastewater treatment in Bucharest
Leipzig	Germany	River Luppe	Revitalisation project in Leipzig's urban floodplain forest (Living Luppe)
Leuven	Belgium	River Dyle	Flood protection/restoration of the River Dyle
Ljubljana	Slovenia	Podutik reservoir	Multifunctional flood reservoir Podutik
Łódź	Poland	River Sokołówka	Restoration of the River Sokołówka
London	United Kingdom	River Mayesbrook	Mayesbrook river and park restoration initiative
London	United Kingdom	River Quaggy	River Quaggy in Sutcliffe Park
Lyon	France	River Yzeron	Flood protection/restoration in the River Yzeron
Mérida	Spain	River Guadiana	Restoration of the River Guadiana
Munich	Germany	River Isar	Urban river restoration on the River Isar
Nijmegen	Netherlands	River Waal	Room for the River Waal
Oslo	Norway	Streams and rivers	Water in the City — the Oslo strategy for de-culverting its streams and rivers
Ruhrgebiet	Germany	River Emscher	River Emscher re-conversion
Stockholm	Sweden	Lake Trekanten, Igelbäcken stream	Stockholm water programme for improved water quality and recreational value including the cases of Lake Trekanten and the Igelbäcken stream
Tallinn	Estonia	Lake Ülemiste	Protection of Tallinn's drinking water resources: The case of Lake Ülemiste
Vienna	Austria	River Liesing, Wienfluss, Old Danube	Restoration measures and strategies for Vienna's urban water bodies

2 The fall and rise of urban rivers and lakes

2.1 The importance of rivers and lakes in European cities

Almost all cities around the world were built along waterways, or along the coast of an ocean, sea or lake. The multifaceted relationships between urban planning and water have structured and influenced the development of metropolitan areas, cities, towns, rural areas, villages and even neighbourhoods throughout history and will continue to do so (Brandeis, 2014).

Over time, the settling of humans next to rivers and lakes has transformed the natural environment into the towns and cities we see today. Urbanisation has come at a cost to rivers and lakes, as they have been heavily degraded to enable development, carry waste, supply drinking water and facilitate transport and industry.

In Europe, almost all capital cities have at least one major river or lake crossing their urban landscape (Table 2.1). The largest rivers of Europe, such as the Danube, the Rhine and the Elbe, are home to a number of cities on their main channels, on their tributaries in their wider catchments and on their estuaries.

Some of the most popular tourist city destinations in Europe are built on and strongly defined by their rivers, including Paris on the River Seine, Rome on the Tiber, Bratislava, Budapest and Vienna on the Danube, Prague on the Vltava and London on the Thames. Some European cities, such as Dublin, are characterised by a complex water landscape unknown to most visitors passing through (see box below).

In addition to the larger, better-known urban rivers, there are many small rivers and streams that have shaped the landscape of European cities, many of which have been subject to recent urban restoration schemes. Several of these smaller rivers and streams feature in the case studies in the annex to this report.

Lakes are not as common a feature as rivers in large European cities. However, there are a number of cities that have partly developed on lake shores, coasts and estuaries, where waterside areas serve as popular recreational areas and/or sources of fresh drinking water for the city. Some examples of cities with major lakes are Tallinn (Lake Ülemiste), Berlin (the Wannsee, Müggelsee and Tegeler See), Stockholm (Lake Mälaren), Zürich (Lake Zürich) and London (the Serpentine lake). Several other European capitals, such as Oslo, Vilnius and Bucharest, are connected to a number of smaller and medium-sized lakes.

Dublin: A city of three rivers

Dublin is situated at the mouth of the River Liffey, which divides the city into the Northside and the Southside. Each of these is further divided by two lesser rivers — the River Tolka, running south-east into Dublin Bay, and the River Dodder, running north-east to the mouth of the Liffey. Two further water bodies — the Grand Canal on the Southside and the Royal Canal on the Northside — ring the inner city (Wikipedia, n.d. (b)).

Photo: River Liffey, Dublin © Peter Kristensen

Table 2.1 Major rivers and lakes of the capitals of the 33 EEA member countries

EEA member countries	Capitals	Rivers and lakes
Austria	Vienna	River Danube, River Wienfluss, River Liesing
Belgium	Brussels	River Zenne
Bulgaria	Sofia	A number of rivers cross the city, including the Vladayska and the Perlovska
Croatia	Zagreb	River Sava, Jarun lake
Cyprus	Nicosia	River Pedieos
Czech Republic	Prague	River Vltava
Denmark	Copenhagen	Lakes Sortedam, Peblinge and Sankt Jørgens (originally, there was one long stream, which was dammed). Ladegårdsåen
Estonia	Tallinn	Lake Ülemiste, Lake Harku, River Pirita
Finland	Helsinki	River Vantaa
France	Paris	River Seine, Lake Daumesnil
Germany	Berlin	River Spree, River Havel, several lakes (Tegeler See, Großer Wannsee, Großer Müggelsee)
Greece	Athens	Historical rivers are the Cephissus river, the Ilisos and the Eridanos stream
Hungary	Budapest	River Danube
Iceland	Reykjavík	River Elliðaár, Lake Elliðavatn, Lake Langavatn, River Korpa, River Leirvogsá
Ireland	Dublin	River Liffey, River Tolka, River Dodder
Italy	Rome	River Tiber
Latvia	Riga	River Daugava
Liechtenstein	Vaduz	–
Lithuania	Vilnius	River Vilnia, River Neris, numerous lakes
Luxembourg	Luxembourg	River Alzette, River Pétrusse
Malta	Valletta	–
Netherlands	Amsterdam	River Amstel, River and Lake IJ
Norway	Oslo	River Alna, River Akerselva, Lake Maridalsvannet, Lake Østensjøvannet, many smaller lakes
Poland	Warsaw	River Vistula, several lakes, e.g. Czerniaków lake, the lakes in the Łazienki and Wilanów parks, Kamionek lake
Portugal	Lisbon	River Tagus
Romania	Bucharest	River Dâmbovița, River Colentina, numerous lakes e.g. Lake Herăstrău, Lake Floreasca, Lake Tei, Lake Colentina
Slovakia	Bratislava	River Danube, River Morava, several lakes
Slovenia	Ljubljana	Rivers Ljubljanica, Sava, Gradaščica, Mali Graben, Iška and Iščica
Spain	Madrid	River Manzanares
Sweden	Stockholm	Lake Mälaren, River Norrström
Switzerland	Bern	River Aare
Turkey	Ankara	River Ankara
United Kingdom	London	River Thames, St James's Park lake, Serpentine

2.2 Key impacts of urbanisation

In industrialised and developing countries in the 19th and 20th centuries, most urban rivers were channelled into canals, buried or otherwise confined. Eden and Tunstall (2006) summarise the traditional European approach to urban river management as 'bury them, turn them into canals, line them with concrete and build upon the (now protected) floodplains'. This approach was designed both to improve urban hygiene and to protect cities from flooding. In the 1950s, the growing use of cars in cities led to riverbanks being transformed into high-speed traffic lanes (e.g. in the case of the River Manzanares in Madrid and the Seine in Paris). Owing to pollution from wastewater and the fact that riverbanks became increasingly difficult to access, traditional uses of urban rivers (bathing, boating, fishing) disappeared. Cities gradually turned their backs on the rivers that they had once relied upon for their prosperity. Only major water shortages and flooding reminded local authorities and residents of the presence (or absence) of water in the city (Bruhn, 2015).

Cities and towns are frequently affected by the impacts of activities taking place in upstream rural areas, in terms of either water quality degradation (e.g. due to diffuse pollution from agriculture) or water flow changes (especially relevant to flood risk, which is increased by the lack of natural water retention upstream).

The negative impact of urbanisation on river and lake systems in European cities is wide-ranging and multifaceted. The impacts go beyond the historical issue of water pollution and extend to structural changes to the once natural rivers and lakes. The ways in which urbanisation has affected urban rivers and lakes include (based on ECRR, 2015):

- **Water quantity impacts:** decreased flow and reduced groundwater levels through abstraction, as well as increased flow from surface run-off, increased frequency of floods and reduced infiltration, affect the quantitative status of rivers and lakes in cities.
- **Water quality impacts:** wastewater discharges and increased run-off from impervious surfaces such as roads, roofs and gardens, and contamination from household and industrial stormwater overflows, degrade water quality.
- **Physical structure impacts:** artificial walls replace natural riverbanks, barriers disrupt connectivity or, in many cases, the river is hidden underground (covered rivers).
- **Geomorphological impacts:** urban rivers lack the space to erode their banks and deposit sediment or to connect to their floodplain, which leads to altered morphology. Bridges, pipes and other infrastructure alter the width and depth of rivers, and their courses are changed by straightening and bypassing.
- **Impacts on the ability to support wildlife:** natural corridors, riparian zones and in-channel habitats are lost.
- **Removal of riparian vegetation:** this reduces organic input and habitat complexity, increases river temperature and reduces bank stability.
- **Invasive species:** urban areas often suffer from introduced non-native species that become dominant and cause damage to the environment.

Urbanisation also has a notable impact on channel ecology, which is made obvious by decreased biotic richness and increased dominance of pollution- and flow-tolerant species. As urban centres have expanded in size and number, negative impacts on freshwater ecosystems have become more severe and widespread (summarised by Everard and Moggridge, 2011).

The photos below show some examples of degraded urban water bodies.

Madrid: Prioritising people over cars

After a massive highway was built on both sides of the Manzanares river in Madrid in the 1970s, nearby neighbourhoods declined and most city inhabitants avoided the region entirely. In 2003, Mayor Alberto Ruíz-Gallardón implemented his vision to bury the highways and move traffic through tunnels instead. Ultimately, the riverbanks were freed for pedestrians and more than 9 km of the Madrid Río Park were designed with playgrounds, ball parks, bike paths and a wading pool known fondly as 'the beach' (World Watch Institute Blog, 2016).

Photos: © E. Kampa (top left), © Flanders Environment Agency (top right), © Syndicat d'Aménagement et de Gestion de l'Yzeron, du Ratier et du Charbonnières (bottom left), © Wasserwirtschaftsamt München (bottom right)

2.3 Rediscovering rivers and lakes in our cities

Historically, rivers and lakes offered a popular setting for urban development because they could provide food, water, power generation, flat land for development, trade routes and transport. In medieval times, water was also frequently used for all kinds of events, including fireworks, jousts and ceremonies. Furthermore, urban rivers and lakes have functioned for centuries as receivers and transporters of household and industrial wastewater, which gradually led to their degradation, making them a source of nuisance to city inhabitants. During the 20th century, many European rivers and lakes were polluted, deteriorated and lost their significant roles. Since the 1970s, substantial investments have been made in sewers, wastewater treatment and stormwater management, and this has led to more systematic efforts to improve water quality across Europe. As a result, European rivers and lakes have gained a more positive image in cities and towns. It is now widely recognised that urban rivers and lakes can fulfil roles such as providing space for recreation and offering an aesthetically pleasing environment as part of urban regeneration. More and more cities and communities have rediscovered their rivers, streams and lakes as open spaces in the urban environment and as meeting points for social and cultural activities.

As cities change the way they view their water bodies, more opportunities arise for restoring urban rivers and lakes. Cities rediscover the value of the rivers and lakes around which they were originally organised and developed, and, in this context, many municipalities launch restoration projects. In particular, urban rivers are becoming an important focus for restoration, and this is likely to become still more prevalent as urban development continues and demand for a better, more sustainable quality of life increases.

Restoration projects offer an opportunity for future-oriented city planning and development. In recent years, more and more people have been recognising the potential for such projects to enhance quality of life. In practice, many restoration projects for urban rivers are initiated not so much with a view to improving aquatic biotic ecosystems but as part of urban regeneration projects closely associated with rivers running through cities (Bruhn, 2015). Indeed, much of the impetus for urban restoration efforts has come from the growing recognition of the range of public benefits that river restoration provides (Heathcote et al., 2002).

The types of benefits that can be delivered by improving urban water environments include:

- reducing flood risk and helping to deliver flood risk management planning;
- creating opportunities to access the natural environment, providing new open spaces for amenities and recreation, and green networks for wildlife and people;
- reducing the heat island effect;
- reducing urban water pollution by incorporating sustainable drainage schemes and remediating contaminated land; and
- improving fish passage and in-stream and riparian habitats.

Delivering these benefits can have wider socio-economic consequences, as restored urban water bodies create an attractive environment that encourages recreation, boosts physical and mental health, encourages business investment and tourism, and increases property values. This contributes to green infrastructure, local biodiversity action plans, well-being and regeneration goals (Natural Scotland, 2015). In addition, defining benefits more accurately (both direct and indirect benefits in terms of ecosystem services) often supports decision-making for restoration projects in cities.

Many restoration measures (e.g. reopening covered rivers, water quality improvements that enable bathing) have resulted in significant changes in the way citizens and visitors experience the blue elements of cities (rivers and lakes). Waterfront amenities are more and more highly appreciated, and urban river and lake restorations can be a good way of improving access to water.

The case studies reviewed in the annex to this report provide evidence of how restoration of rivers and lakes in European cities can contribute to better quality of life and urban regeneration.

2.4 European policy impetus

In the European Union, a number of legislative and policy processes have provided further impetus to manage urban rivers and lakes in a more integrated way, by means of linking water quality improvements with ecosystem protection, with climate change adaptation and, recently, with urban development.

The **Urban Waste Water Treatment Directive (UWWTD)**, adopted as early as 1991, aims to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors. Progress has been made in combating water pollution, especially in terms of wastewater effluents.

The **Nitrates Directive**, also adopted in 1991, aims to prevent pollution of groundwater and surface waters by nitrates from agricultural sources. Although the Nitrates Directive is mainly relevant to agricultural activities outside urban areas, pollution from agricultural sources impacts water quality in urban areas.

As policies that focused exclusively on the fight against water pollution revealed their limitations, the EU adopted, in 2000, the **Water Framework Directive (WFD)**. This is the main article of EU water legislation, and it reflects a shift from viewing water as a resource to viewing it as part of the environment. The WFD requires the achievement of good ecological and chemical status for **all** European surface waters, including urban rivers and lakes. The first river basin management plans implementing the WFD were adopted in 2009 and updated versions of these plans are to be drawn up on the basis of a 6-year cycle (in 2015 and 2021). Despite improved water quality in cities, there is still room for improvement in the ecological status of their rivers and lakes. Many urban rivers are still encased in concrete structures, and, along with degraded habitats, this makes achieving the environmental objectives set out by the WFD challenging.

Owing to changes to their physical structure, urban rivers and lakes are often defined as heavily modified water bodies (HMWB), as defined in Article 4(3) of the WFD, meaning that the important human uses that they serve (e.g. flood protection and transport) should not be undermined by measures taken to improve their status. At the same time, the WFD spells out minimum requirements for the restoration and ecological quality enhancement of HMWB, including those in an urban setting.

The **Floods Directive**, adopted in 2007, provides European countries with a common framework for identifying, evaluating and addressing flood risk.

Examples of the WFD acting as a driver for the restoration of urban water bodies

In several case studies reviewed for this report, the implementation of the WFD and its strong focus on restoring water bodies to achieve good status have acted as a key driver for urban restoration.

In Vienna, the projects of the city administration involving the restoration of urban water bodies aim to achieve the goals of the WFD, following the national WFD implementation strategy. Restoration projects related to the urban River Liesing, the River Wien and the Old Danube are designed to be in line with the WFD requirements and aim to improve ecological status or ecological potential.

In Stockholm, the trigger and initial driver for the city Water Programme and Action Plan for Good Water Status was the WFD and its strong focus on achieving good ecological and chemical status.

In Oslo, the WFD and its objective of restoring water bodies have increased the political will to allocate resources to a de-culverting strategy for urban streams. In particular, for the major streams, defined as water bodies according to the WFD, the de-culverting strategy is considered a solid contribution on the part of the city to ensuring the good ecological and chemical status of water bodies. The strategy is among the programme of WFD-related measures for the water area of Oslo.

The directive requires the development of an integrated approach to managing flood risk using approaches based on the scale of the river basin and working closely with nature. The first flood risk management plans focused on prevention, protection and preparedness were to be drawn up by 2015. The aim of the Floods Directive is the development of urban areas that are resilient to changes that would otherwise cause an increased likelihood of flooding.

The **Birds and the Habitats Directives** are also relevant to urban restoration, as specific restoration measures may be taken to achieve biodiversity protection objectives in urban nature reserves, including freshwater habitats.

The 2013 Commission **Communication on Green Infrastructure** (European Commission, 2013a) called upon planners to use natural measures or a combination of engineered structures and natural solutions more proactively to achieve the objectives of water and adaptation policy (see the **EU Strategy on Adaptation to Climate Change of 2013** (European Commission, 2013b). River restoration in and close to urban areas is particularly relevant to green infrastructures for reducing flood risk, especially in terms of floodplain restoration measures aiming to increase natural water retention.

Furthermore, in 2015, the Commission published ***Towards an EU research and innovation policy agenda for nature-based solutions and re-naturing cities*** (European Commission, 2015). This provided a powerful impetus for a stronger research and innovation focus and the deployment of many urban water-related nature-based solutions, such as de-culverting of piped streams and the re-creation or restoration of small city lakes and ponds. These activities aim to serve a diversity of purposes, of which climate adaptation is one important aspect.

Last but not least, an **Urban Agenda for the EU** is now in place; it is a joint effort of the European Commission, Member States and European Cities Networks to strengthen the recognition of the urban dimension by European and national policy actors. The European Urban Agenda recognises that to fully exploit the potential of urban areas the urban dimension should be better embedded within EU policies. To this end, a better working method, focused on cooperation between the EU, Member States and cities, is needed. Part of this new approach includes the development of a range of European partnerships (Urban Agenda for the EU, Pact of Amsterdam, 2016).

At the time of writing this report, a draft **Urban Water Agenda 2030** had been prepared by the European cities that convened at the Cities & Water Conference (February 2016, Leeuwarden) to discuss urban priorities in relation to water. There is growing understanding among decision-makers in European cities and regions that water is as important for cities as energy or climate, and that there are risks and opportunities related to water that will affect the economic development and prosperity of European cities in the future. The Urban Water Agenda 2030 calls for city leadership and coordination to address water challenges and exploit opportunities for smart and sustainable urban water management. The agenda identifies important water issues for cities, sets objectives for 2030 and proposes concrete actions to achieve these objectives around five core areas (Cities & Water, City of Leeuwarden, 2016):

- water efficiency — to reduce water abstraction to the level of sustainable use and to ensure good ecological status of water bodies;
- energy and resource efficiency of urban water systems;
- water quality — to ensure the quality of water for urban use and to prevent pollution of water by cities, thereby ensuring the good ecological status of water bodies;
- sustainability of urban water infrastructures;
- flood prevention and nature-based solutions.

2.5 City visions and strategies for water

The multiplicity of aspects in which urban planning and water come together shapes the evolution of the city and its surrounding areas. While this relationship has led to the deterioration and neglect of urban water bodies in the past, more recent examples from around Europe show that the adoption of new points of view on city planning can change the dynamic. In many cases, this change in perspective has either arisen from or been incorporated into a city's strategic vision. This can allow local officials and city planners to identify synergies across sectors and consider more ambitious measures. Furthermore, such city visions can help optimise actions on short-term goals while keeping mid- and long-term objectives in focus.

Many European cities have developed broad visions and strategies to promote more integrated management of their water bodies, especially in terms of restoration of their rivers and lakes. Such strategies provide a broad framework for carrying out a number of restoration projects over a relatively long planning period. There are also important links between restoration activities and local and city authority strategies for open space, green infrastructure and green networks. These strategies often require that developments include a certain proportion of open space. If well designed, this open space can create green networks for morphological restoration, wildlife and people (Natural Scotland, 2015). In this context, there are opportunities to give a higher priority to space for rivers in urban areas.

Some examples of such city strategies are the London Rivers Action Plan, the river de-culverting strategy of the City of Oslo and the Stockholm City Water Programme (see the case studies in the annex to this report).

London Rivers Action Plan

The London Rivers Action Plan (LRAP) was published in 2009 (LRAP Partnership, 2009). The main aim of this plan is to provide a forum for identifying stretches of river that can be brought back to life, by improving river channel or riparian habitats, by removing or modifying flood defence structures or by reclaiming 'lost' rivers currently buried under the surface (LRAP Partnership, 2009). In 2011, the broader city strategy Securing London's Water Future was published; it was the first water strategy for London to provide a complete picture of the city's water needs. The strategy promotes increasing water efficiency and reducing water wastage to balance supply and demand for water, safeguard the environment and help tackle water affordability problems. It also sets out how London's Mayor will help communities at risk of flooding to increase their resilience to flooding (Greater London Authority, 2011).

The restorations of the River Quaggy and the River Mayesbrook, reviewed for this report, are part of the London Rivers Action Plan.

Oslo: A changing paradigm for its rivers and streams

One of the key water management issues dealt with in the city of Oslo is the set of negative consequences caused by culverted streams passing through the city. Oslo's de-culverting strategy, Water in the City, addresses all the streams and rivers that originate in the surrounding forests and eventually cross through the city down to the Oslo fjord. Water in the City became part of a more comprehensive Strategy for Urban Storm Water Management, whose objectives include meeting the challenges posed by climate change, enhancing water quality and using stormwater as a resource in cityscapes. Within this strategy, the de-culverting programme works as an inter-agency programme coordinated by the Agency for Water and Sewerage Works, but with the involvement of three other city agencies. The focus is on the major streams, but the strategy also covers the smaller tributaries (Oslo Kommune, 2015). The stream de-culverting initiative is also linked to two major strategic city policy programmes, namely the City Ecological Programme, approved by the City Council in 2009, and the new municipal master plan, Oslo 2030, Smart, Safe and Green, adopted in 2015.

Table 2.2 Blue and green assets and features in the urban realm

Urban blue	Urban green
Wastewater reuse and recycling	Green roofs
Rainwater harvesting and recycling	Green parks, streets, squares, parking lots, etc.
Stormwater management as a new resource	Living walls systems
	Urban agriculture

Source: Based on Blue Green Dream, 2012.

In addition to developing action plans for restoring urban water bodies, several European cities (e.g. Copenhagen and Rotterdam) are developing a more water-centric overall urban design and are moving towards a blue-green city model. This entails integrating water management with urban green space provision to gain the added value associated with the connection and interaction between the blue and green assets of a city (see Table 2.2). Blue-green cities may be key to future resilience and the sustainability of urban environments and processes (Blue-Green Cities Research Project, n.d.). They aim to recreate a naturally oriented water cycle, while contributing to the amenities of the city by bringing water management and green infrastructure together.

There are also initiatives to establish so-called urban green and blue networks. The goal of urban green networks is to link natural habitats together, enabling animals and plants to move along ecological corridors connected to the city's surroundings. Urban blue networks, consisting of rivers, streams and other bodies of water in the city, can complete green networks. The Brussels Capital Region, for instance, is strengthening the ecological corridor in the region through the development of such an urban green and blue network. To ensure a more even distribution of green nature areas and to strengthen the ecological corridor between these areas, a regional development plan was drawn up to guide the gradual development of a green and blue network around Brussels. The green network connects the green areas as a ring around the urban area, and the blue network aims to improve the ecological conditions of the rivers and associated wetlands (Bruxelles Environnement — IBGE/Leefmilieu Brussel BIM, 2006). The green and blue network programme was laid out in 1995 and incorporated into 'the Brussels Regional Development Plan. New green spaces were created with 'new' objectives for the urban area: preservation of natural vegetation, restoration of pond banks, and improvement of water and soil quality. Simultaneously, efforts have been made to reconnect green spaces by reopening formerly covered rivers (Chevalier, 2013).

What drives the move towards more integrated city strategies for water?

As citizens' begin to perceive urban rivers and lakes as key historic elements of local identity and to understand the areas around them as accessible refuges from the fast pace of modern life in urban centres, the political narrative around urban water bodies is necessarily changing. The recognition of the multiple benefits that revitalising our urban water environments and reconnecting with them can bring to society has, in numerous cases, fuelled the political will necessary to transit from small-scale, isolated actions to more integrated strategies based on long-term visions of better organised, more resilient cities. For instance, in the aforementioned case of Oslo, the political determination to back the city's de-culverting strategy emerged as public and political awareness of the value of natural streams in the cityscape increased. This perception of value that was increasingly associated with urban water ecosystems stemmed not only from recognising that they could be used for recreational purposes, but also from the realisation that, in the face of climate change, they could provide greater safety and resilience through stormwater retention and cleansing capacity.

In addition to changes in local public and political awareness, policy and regulation at higher administrative levels can also be responsible for the transition towards more integrated urban development strategies, as outlined in Section 2.4 in terms of the European policy impetus. At European level, there is explicit agreement on the principles upon which an ideal European city should be based, as part of the EU Urban Agenda (Urban Agenda for the EU, Pact of Amsterdam, 2016). One of the characteristics envisaged for the European city of tomorrow is that it should be 'a place of green, ecological or environmental regeneration'. At EU level, it is also argued that urban territorial development should 'enjoy a high level of environmental protection and quality in and around cities' (European Commission, 2011).

Finally, the environmental objectives and requirements put in place by articles of legislation such as the EU WFD have locked in greater support for integrated action, both in terms of funding and acceptability. In this specific case, the WFD's aim of incorporating externalities by reconnecting the urban water cycle to the natural water cycle has a strong influence on policy- and decision-making at local level. Furthermore, the directive has provided a strategic framework that allows individual restoration efforts within river basin management plans to link up, facilitating communication and buy-in of stakeholders. The case of the Stockholm City Water Programme is a good example of how the intrinsic relationship of a city with its water environment can converge with policy frameworks at higher levels to result in enduring commitment to water protection.

Finally, increased pressures on urban water ecosystems are expected to result from climate change and its interaction with socio-economic factors such as geopolitics, economic trends, demographic change, further urbanisation and urban sprawl, among others (EEA, 2016b). This also calls for the preparation of appropriate water management strategies in the urban context to cope with impacts and increase resilience. Such strategies should carefully consider the state of the environment, society and the economy at local level (Anthonj et al., 2014) to ensure their objectives can be efficiently achieved. Furthermore, the actions planned within these strategies should go beyond addressing the direct impacts of climate change to consider the broader knock-on effects that could follow (EEA, 2016b). A good example of a city strategy taking several of these factors carefully into account is the Water Plan for Rotterdam.

Stockholm: City Water Programme and Action Plan for Good Water Status

In Stockholm, 'the Venice of the North', 10 % of the city's area is covered by water, and its many lakes are highly valued for recreational purposes. The city's affinity with water and intrinsic aquatic character resonated with the EU WFD and its strong focus on achieving good ecological and chemical status, leading to the adoption in 2006 of an ambitious Water Protection Programme (2006–2015), which set objectives for cleaner water and outlined measures to achieve this. The objective of improving water quality in the city was to be achieved in a way that preserved the recreational value of the lakes and streams. When the programme ended, progress had been made both on water quality and on increasing the recreational value of Stockholm's many water bodies.

Ongoing political ambition to reinforce local efforts towards improved water quality led to the adoption in 2015 of the Action Plan for Good Water Status to follow up on the Water Protection Programme (Stockholms stad, 2015). Within this new plan, separate local programmes of measures are planned for each water body.

The Stockholm City Water Programme and the Action Plan for Good Water Status are considered good practice examples of what can be achieved if there is strong political will to allocate funding for a major, long-term water improvement programme benefiting both aquatic ecosystems and the urban population, who are better able to enjoy the water bodies and their ecosystems.

Rotterdam: Waterplan 2

Rotterdam is Europe's largest port and also a bustling city with a strong economy and an intrinsic aquatic character. The connection with the Maas, Schie and Rotte rivers, and the multitude of canals and lakes, gives Rotterdam its identity as a water city.

However, the city's close relationship with the water environment means that the challenges of climate change, such as rising water levels, increased rainfall and increasing pressures on water quality, are particularly pressing for Rotterdam. To confront these future challenges, Rotterdam has developed Waterplan 2 Rotterdam, a plan for sustainable development until 2030 based on an adaptive approach that has multiple objectives, including coping with the increasing amounts of water that will reach the city and put its infrastructure to the test, and ensuring the attractiveness of the city through carefully thought out and versatile urban design. Waterplan 2 Rotterdam is understood as the framework for achieving the city's long-term vision, and as a forum for consultation and discussion between the multiple actors that will allow future ideas and solutions to emerge and develop (Municipality of Rotterdam et al., 2007).

3 Coping with key challenges for urban rivers and lakes

For the purpose of this report, the major challenges that rivers and lakes in European cities face are grouped into:

- water availability and supply challenges;
- water quality issues;
- structural changes to and physical modifications of rivers and lakes.

For each of these major challenges, the following sections provide a brief review of the issues at stake, document the key approaches followed to deal with the issues and provide case study illustrations.

3.1 Water availability and supply

3.1.1 Tapping water from rivers and lakes for European cities

Public water supply accounts for 32 % of total water use in Europe (EEA, 2016c). That is, roughly a third of the total freshwater abstracted in Europe is directed to households, small businesses, hotels, offices, hospitals, schools and industries. Some of the main challenges faced by urban water supply include droughts, water scarcity, seasonal or geographical mismatches between water availability and water demand, and low efficiency of water distribution networks (including leakage). In some European countries, these challenges have led to overexploitation and pollution of groundwater resources, including saltwater intrusion. This has subsequently resulted in the implementation of measures ranging from the softer — such as awareness-raising campaigns — to the more drastic — such as abstraction restrictions (De Paoli et al., 2016) and water transfers between different river basins.

To secure a reliable and safe water supply, cities have typically developed centralised systems to abstract, transfer and distribute water. Urban uses of water, including the necessary hydraulic interventions to secure a regular supply, are substantially transforming the natural ecosystems within and close to cities and are in competition with other water uses (e.g. recreation, irrigation, etc.). In turn, these other uses affect the availability of the resource for urban use by impacting its quality (Kallis and Coccossis, 2001).

With growing populations and increasing demand for water, Europe's larger cities have generally relied on the surrounding regions for drinking water supply, mostly from groundwater but sometimes from surface waters. For example, Athens, Istanbul and Paris have all developed extensive networks for transporting water, often over distances ranging from 100 km to 200 km, to the water-hungry, densely populated city. Even in

Athens: Tapping water from 150 km away

Athens is located on the Attica peninsula in the central southern part of Greece. Most of Attica's water resources are not available for potable use. Surface sources are buried under concrete and groundwater aquifers are polluted (under the city) or salinised (those on the coast).

To obtain its water supply, Athens has resorted to a number of surface hydraulic works and transfers. The main water source for the city is the artificial reservoir at the Mornos river (built in 1980), which is supplemented by a regulating reservoir at the Evinos river (2002). The older branch of the hydrosystem consists of a pumping station drawing water at Lake Yliki (installed in 1958) and a number of boreholes in its vicinity and along the conveyance aqueduct. The first artificial reservoir created for the city, the Marathon reservoir (built in 1928), is now used for storage and regulation of the network supply (Kallis and Coccossis, 2002).

The rivers and lakes from which water is extracted to supply Athens are situated fairly long distances away from the city. The Marathon reservoir lies approximately 42 km away from the centre of Athens, while the Mornos reservoir (the current main water supply source) is 150 km north-west of the city.

Germany, which is a relatively water-rich country, water is transported over long distances to supply urban centres. This is the case for the city of Stuttgart, which receives its drinking water from Lake Constance, located at a distance of 160 km away.

Other European cities depend on lake surface waters for their drinking water supply, such as Tallinn. Tallinn uses Lake Ülemiste as its main drinking water reservoir and has applied several measures to protect and improve water quality in the lake.

Tallinn: Securing the supply of drinking water

Lake Ülemiste is a shallow eutrophic lake that has been the main reservoir of drinking water for Tallinn since the 14th century. The water level is controlled by a water treatment plant that supplies over 90 % of the inhabitants of Tallinn with drinking water (the rest of the population is supplied from bore wells (Tallinn, 2011). The catchment area of the lake has been enlarged from 70 km² to 1 865 km² and a complex interlinkage of reservoirs and canals has been built on the Pirita, Jägala and Soodla rivers to direct water into the lake (Panksep et al. 2009).

Lake Ülemiste is affected by water quality problems. The main problems are its high phytoplankton biomass, which means that the water requires costly treatment before it is fit for human consumption; an accumulation of thick sediment at the bottom of the lake that can re-suspend particulate matter during windy periods; and contamination from the city's airport, which is located on the eastern shore of the lake.

The main measures taken so far by the city to protect Tallinn's drinking water reservoir and improve water quality have included:

- The renewal and expansion of a sanitary protection zone around Lake Ülemiste, completed in 2009. Considering the importance of the surface water intake of the lake as a source of drinking water, expanding the sanitary protection zone by more than was required under the Water Act (i.e. 90 m) was deemed necessary. The sanitary protection zone covers Lake Ülemiste, its water intake facilities, its shore protection facilities and the immediate surroundings of the lake, which must be preserved in their natural state and where the movement of people is restricted.
- The reconstruction and extension of the shore protection dam of Lake Ülemiste, was completed between 2011 and 2012. The goal was to increase the adjustable volume of the shallow lake, reduce eutrophication of the water, stop shore erosion caused by waves and guarantee a service path for the management and inspection of the lake.
- A biomanipulation project was one of the main measures taken to protect Tallinn's drinking water reservoir (Lake Ülemiste) and improve water quality. The aim of the project was to increase the abundance and size of herbivorous zooplankton in order to control phytoplankton biomass and therefore improve the lake's water quality. Improved water quality helps to reduce the chemical and energy costs of treatment caused by high phytoplankton biomass in the water (Panksep, 2009; Panksep et al., 2009).

Photo: Southern shore of Lake Ülemiste © Sven Miller

3.1.2 Towards more sustainable water supply in cities

Considering that water around large cities is often polluted and cannot be used as potable water, a number of factors should be taken into account when seeking to reduce the vulnerability of large cities to water stress. These factors may include growing urban populations, improving lifestyles, reduced water availability due to climate change and the introduction of drinking water quality standards (EEA, 2010).

While centralised water systems have, in general, ensured adequate water supply, sanitation and drainage services in cities around the world (Sitzenfrei et al., 2013), several factors such as climate change, increasing water supply and consumption, as well as ageing water and wastewater infrastructures, increasingly pose maintenance challenges for cities.

To prevent urban water crises, water resources should be managed effectively at every stage, from the supply of clean water to its different uses by consumers. This could involve reducing consumption (e.g. by means of technological improvements, water pricing schemes and non-pricing approaches to manage water demand), finding new ways of collecting and using water (e.g. reusing rain and grey water), and reusing treated wastewater. Water management should also be better integrated into wider urban management, taking into account characteristics of the local environment (EEA, 2012c).

One of the non-technological, non-pricing measures used to manage water demand in large cities is awareness-raising campaign. This approach has been used in Europe as a prevention measure and as an emergency measure in the context of severe drought (e.g. during the severe drought that hit Barcelona in 2007–2008 (Martin-Ortega and Markandya, 2009)). Given that these types of measures commonly aim to influence household behaviour, their actual effectiveness is difficult to assess. Nonetheless, there have been interesting cases where the measures implemented could be directly associated with large-scale shifts in water demand. Furthermore, when used in combination with other water demand measures, the overall effect can be stronger. For example, accompanying the promotion of water-saving technologies with educational campaigns that provide information on their functionality and the correct way to use them can enhance the effect of the technologies (Cominola et al., 2015). The Zaragoza: Water Saving City project has resonated throughout Europe, showing what a carefully structured awareness-raising campaign with clearly defined, specific targets can achieve.

3.2 Water quality

3.2.1 Main issues

Until the end of the 19th century, water quality in rivers and lakes was generally satisfactory in most parts of Europe. Gradual deterioration was experienced around 1900 with the industrial revolution, the concentration of populations in cities and the development of industrial production. Great volumes of sewage and industrial wastewater were discharged into rivers and lakes from towns, and the self-purifying processes of recipient water bodies were not sufficient to assimilate the pollution impacts. In the decades to come, the volumes of sewage drained into rivers and lakes without any treatment were rising as a result of the increasing proportion of inhabitants living in houses connected to sewerage systems. At the same time, industrial water pollution was also increasing as the construction of industrial plants was not accompanied by the construction of wastewater treatment plants.

By the 1970s, some European rivers, such as the Thames in London, had been declared biologically dead as a result of the disposal of untreated effluents, industrial chemicals and low oxygen levels. In addition, in southern Europe, uncontrolled water pollution

Zaragoza: Water Saving City

This awareness-raising campaign, which started in 1997 and developed into a wider water-saving programme in later years, was directly associated with a 5.6 % reduction in Zaragoza's annual water consumption in 1998. That is, a total of 1 176 million litres of water were saved during the project's second year (Saurí and Cantó, 2008). The campaign was also successful in promoting significant increases in local sales of domestic appliances with built-in water savers, water-saving taps and individual water meters (European Commission, n.d.). Within the first 15 years after the start of the project, Zaragoza reduced its water consumption level by roughly 30 % (CLIMATE-ADAPT, 2014). Some of the factors cited as being key to the success of the campaign include the ability of the project leaders to align efforts by linking the issue they were addressing with other related topics; the identification and exploitation of opportunities to push the agenda forward; and gathering broad support from a wide spectrum of local actors (Rouillard et al., 2015).

Milan metropolitan area: River pollution

Photo: Lambro river © clodio/iStock

The River Lambro drains a very densely populated and heavily industrialised zone, including a significant portion of the Milan metropolitan area with a population of more than 3 million. Before the construction of a treatment plant in 2002, almost all of the sewage from the city of Milan, as well as industrial sewage, flowed untreated into the river. The Lambro is considered one of the most polluted rivers in Italy: its basin was declared to be an area at high environmental risk in 1987. Many fish species that used to live in the river have, as a result, disappeared, including, for example, the bleak (*Alburnus alburnas*), the eel (*Anguilla anguilla*), and the European perch (*Perca fluviatilis*). The situation became even worse after an environmental disaster in 2010, when a huge quantity of oil was criminally dumped into the river, causing unprecedented damage to fauna in particular (Salvini, 2011).

An EU funded LIFE projected started in 2012 (to run until 2017) with the objective of improving water quality in the Lambro river (European Commission LIFE, n.d.).

severely impacted the quality of urban rivers such as the Tiber in Rome and the Lambro in the Milan metropolitan area.

After periods of heavy rain, water quality degradation in urban rivers and lakes can increase significantly owing to overflows from the sewage network. In many European cities, the sewer systems are designed to receive both foul sewage and surface water following rainfall. These so-called combined sewer overflows (CSOs) are there to prevent overloading of sewers and wastewater treatment plants. After heavy rain, a mixture of surface water and sewage can be discharged into the water environment via CSOs. Discharges from CSOs may impact on water quality, including by introducing to bacteria and viruses that can affect human health. For this reason, there are frequent public warnings to avoid bathing in urban rivers, lakes and coastal waters after heavy rain. There is a need to properly protect CSOs through upstream measures (e.g. nature-based retention basins) and to manage them to prevent flooding and minimise adverse impacts on the environment and public health.

Across the EU, a diverse set of data on stormwater overflows is available. Although several EU Member States have an advanced understanding of stormwater overflows, a comprehensive overview of overflows at Member State (or regional) level is still not available for a large number of countries (Cools et al., 2016).

Another persistent problem of concern to citizens is chemical pollution of river and lake sediments in cities. For instance, the constant need to dredge sediment in the River Elbe and the harbour of Hamburg to allow inland water transport has, in addition to raising concerns about the impact of the hydrological changes on the ecosystem, faced the city authorities with the problem of how to dispose of polluted sediments (Leal et al., 2006). Another example is sediment pollution in Lake Rummelsburg, an oxbow lake of the River Spree, in a densely populated area of Berlin. The high level of contamination of the lake sediments with chemicals as a result of industrial activity on the riverbanks in the early 20th century is considered to be responsible for the lack of biological diversity of the lake. Nowadays, the area around the lake is gradually being developed as a residential area and is popular for local recreational use. Recent remediation measures by the city authorities, such as partial sludge removal, have not improved the ecological situation significantly so far (Dumm et al., 2015; Reifferscheid, 2013). The city of Stockholm is also taking measures to deal with sediment pollution in its lakes, e.g. of Lake Trekanten, which is a popular recreational spot close to central Stockholm.

Stockholm: Treatment of polluted sediments in Lake Trekanten

Lake Trekanten (meaning 'Lake Triangle') is a small but important recreational lake (13.5 ha) located in a very densely populated area close to central Stockholm. Although suffering from eutrophication and pollution with heavy metals and hazardous substances, the lake is extensively used for swimming and fishing by local residents. Fish restocking with rainbow trout is done regularly and crayfishing is a popular activity.

A large number of measures have been implemented in response to the lake's water quality problems. Several measures have been analytical in character and some have focused on monitoring to support analyses, while others have been of a remedial character, such as the treatment of sediments with aluminium to bind phosphorus and the implementation of a solution for the treatment of stormwater emanating from the major highway.

Photo: © Juha Salonsaari, City of Stockholm

3.2.2 The responses of cities to water quality degradation

In 2011/2012, only 14 of the 28 capitals ([2]) of EU Member States could be considered to be in full compliance with the EU UWWTD: Amsterdam, Athens, Berlin, Budapest, Copenhagen, Helsinki, Lisbon, London, Madrid, Paris, Stockholm, Tallinn, Vienna and Vilnius. A large number of European capitals are still not fully compliant with the requirements of the UWWTD: Bratislava, Brussels, Bucharest, Dublin, La Valetta, Ljubljana, Luxembourg, Nicosia, Prague, Riga, Rome and Sofia (European Commission, 2016).

Nevertheless, looking back over the past 25 years, clear progress has been made in reducing emissions into urban rivers and lakes; this has been done through connections to sewers, the introduction of wastewater treatment and the upgrading of earlier treatment plants. Implementation of the UWWTD, together with national legislation, has led to improvements in wastewater treatment across much of the European continent (EEA, 2012a). For instance, Brussels' River Zenne was notorious for being one of Belgium's most polluted rivers. All effluents from the Brussels Capital Region were discharged into the Zenne without treatment until 2000. In 2007, the completion of a second new sewage treatment plant contributed greatly to remediating this problem.

In some cities of Eastern Europe, the recent construction and operation of wastewater treatment plants has achieved reduced emissions and water quality improvements, which are linked to the implementation of the UWWTD during and after the relevant countries' accession to the EU (see the example of Bucharest, described in the box below).

In other parts of eastern and southern Europe, much progress still needs to be made. For instance, in Serbia only 16 % of the population is connected to wastewater treatment plants and the largest cities, including Belgrade, Niš and Novi Sad, release their wastewater untreated into the rivers that pass through them (Vujović and Kolaković, 2015), the Danube and the Nišava (the Sava river).

A special restoration tool used to combat eutrophication in lakes with high nutrient concentration is biomanipulation. It is often used as an additional means to efforts to reduce external nutrient loading through improved wastewater treatment or diversion of nutrient-rich inflows. A biomanipulation project has, for example, been implemented for Lake Ülemiste, which is the main source of drinking water for Tallinn, Estonia (see Section 3.1).

([2]) This assessment did not include Zagreb (still without compliance obligations) and Warsaw (could not be assessed owing to lack of data).

Bucharest: Wastewater treatment

Bucharest is situated on the banks of the Dâmbovița river, which flows into the Argeș river, a tributary of the Danube. Bucharest is supplied with water by three drinking water plants, located outside the city perimeter. The Argeș river is the main source of raw water for two of the drinking water plants, while the Dâmbovița river supplies the third water plant.

Until 2011, Bucharest discharged wastewater from more than 2 million inhabitants without treatment into the river. This wastewater (from both domestic and industrial use) had seriously reduced the quality of the water in both the Dâmbovița and Arges rivers and made Bucharest the largest polluter of the Danube in the region. The construction of a wastewater treatment plant in Bucharest began in 1985 but was abandoned in 1996 because of lack of funds. By 2000, the need for an operational wastewater treatment plant became increasingly obvious. Furthermore, Romania declared its whole territory a sensitive area according to the UWWTD, which requires all agglomerations of more than 10 000 population equivalents to have wastewater treatment plants with the highest degree of treatment, the removal of nitrogen and phosphorus.

In 2011, a wastewater treatment plant, Glina WWTP, started to operate in Bucharest and it will be further developed until 2017. After its completion, the plant will ensure the treatment of the entire wastewater flow of the Bucharest urban area and will discharge effluent that will meet the requirements of national and European legislation, thus eliminating one of the major pollution hotspots in the Danube river basin (ICPDR, 2013).

The operation of the wastewater treatment plant has significantly reduced the impact of Bucharest's urban wastewater on surface water resources. Since the operation of the plant started in 2011, total pollution removal from wastewater by the plant has steadily increased from 242 tonnes per day (t/day) to 340 t/day (Apa Nova Bucureşti S.A.; see the factsheet on the project in the annex to this report). Since 2014, total pollution removal has been even higher than that which Glina WWTP was designed to archieve.

According to the WFD-compliant monitoring results for water bodies located on the Dâmbovița river (downstream from the Glina WWTP discharge) and on the Arges river (the last water body before the river discharges into the Danube river), the concentrations of organic and nutrient pollution indicators have significantly decreased in the last 5 years, showing an improvement in the rivers' water quality. It should be emphasised that in the receiving Dâmbovița water bodies, reductions in concentrations of organic substances (chemical oxygen demand (COD) and biochemical oxygen demand (BOD)) of approximately 50 % have been registered, while total nitrogen and total phosphorus concentrations have decreased by approximately 30 % and 60 % respectively ([3]).

The project has also contributed to increasing the public's awareness of the polluting effects of wastewater and their responsibility to protect river ecosystems.

Oslo: Return of the salmon to its rivers

Most rivers and streams in the city of Oslo had a long history of poor water quality until the early 1980s. This was reflected in low benthic diversity and the absence of fish. At the end of the 1970s, considerable efforts were made to limit industrial discharges, pollution episodes and urban runoff, resulting in a substantial improvement in water quality. This improvement in water quality resulted in major changes to the benthic fauna and fish populations of the rivers, especially the River Akerselva, which runs through the city centre. The Atlantic salmon, which had become extinct in Oslo in the mid-1800s, returned to the Akerselva in 1983. Atlantic salmon and sea trout now spawn in the lower reaches of the River Akerselva, and the river supports juvenile populations of these salmonids (Saltveit et al., 2013).

Photo: Jumping salmon in the River Akerselva, Oslo
© Dan P. Neegaard

([3]) Information provided to the EEA by National Administration Romanian Waters.

Improvements in the water quality of urban rivers and lakes due to reduced emissions and wastewater treatment have been beneficial for river and lake ecology. In many European capitals, the flagship species salmon has returned to the rivers. In Paris, the wild salmon has returned to the Seine after an absence of nearly a century. The salmon is not the only fish making a comeback in the Seine. The number of fish species in the Seine has increased significantly since 1995 because of the improvement in water quality made possible by a new water purification plant (The Telegraph, 2009). In London, there has been a significant improvement in water quality in the last 40 years and more than 100 species of fish have been found in the Thames estuary in recent years, many of them within the city of London (McCarthy, 2010). Other examples include the return of the salmon to the once heavily polluted River Tolka in Dublin after an absence of 100 years; the salmon has also returned to the rivers of Oslo (see box). In Sweden, recreational salmon fishing is once again possible in downtown Stockholm, where it had to be stopped in the 1960s because the fish had become inedible owing to heavy pollution.

Many cities across Europe have also taken specific measures to reduce wastewater discharges from CSOs after heavy rainfall. In Copenhagen, the improvement in water quality resulting from such measures has even enabled recreational bathing in its harbour.

In the city of Aarhus, Denmark, to reduce discharges from CSOs, new rainwater retention basins were created and an integrated real-time control system set up to allow for coordinated operation of the sewer systems and wastewater treatment plants. These actions are part of a large urban restoration project, which also involved uncovering the River Aarhus to reconnect it to the city landscape. Similarly, in the city of Lódz, Poland, measures to counteract stormwater overflows and quality degradation in the Sokołówka urban stream have been combined with a restoration programme for the river and its valley. In London, the Lee Tunnel has been constructed to capture 16 million tonnes of sewage mixed with rainwater and prevent it from overflowing into the River Lee each year. The tunnel is the deepest ever constructed under London and forms a key part of the largest expansion of London's sewerage network since the 1860s (Thames Water, 2016).

Copenhagen: From sewer to harbour swimming pool

In Copenhagen, Denmark, many years of investment in the sewerage system have revitalised the harbour. For decades, the discharge of wastewater from sewers and industrial companies had a major impact on the water quality in the city harbour. The water was heavily polluted. In 1995, 93 overflow channels fed wastewater into the Copenhagen harbour and the adjacent coastlines. Since then, the municipality has built rainwater reservoirs and reservoir conduits, which can store wastewater until there is enough space in the sewerage system. This has resulted in the closing of 55 overflow channels. Today, wastewater is discharged into the harbour only during very heavy rainfall (DAC & Cities, n.d.).

Municipal investments in modernising the sewerage system and expanding the city's wastewater treatment plants have revitalised the harbour of Copenhagen. The first public harbour bathing area opened in 2002, and in 2016, there were there are five such areas. An established online warning system calculates and monitors the water quality in the harbour (DHIgroup, n.d). If the water quality is poor, the swimming facilities are closed immediately.

Aarhus: Rainwater management to prevent combined sewerage overflow events

The River Aarhus serves as a natural structure connecting the centre of Aarhus, Denmark's second largest city, with the port. To respond to the severe pollution of the river and to promote infrastructure development, the River Aarhus was converted into a covered concrete channel in the 1930s. In 2010, about half of the water in the river consisted of treated wastewater, and around 55 CSOs discharged into the river (Basso, 2010).

The city authorities have implemented a series of measures to uncover the river, with the purposes of enhancing the aesthetics of the city, promoting recreation, improving climate adaptation and flood protection, and reducing the frequency of sewage overflows during extreme rainfall events. These measures included the establishment of two upstream lakes to reduce nitrogen and phosphorus flows into the Bay of Aarhus, the construction of new rainwater retention basins and the implementation of an integrated real-time control system to allow for coordinated operation of the sewer systems and wastewater treatment plants. In addition, a water quality early warning system was installed in Lake Brabrand, River Aarhus and the harbour (Stahl Olafsson et al., 2015). So far, these measures have resulted in a significant change in the way citizens and visitors experience the river, which now forms a blue corridor lined with new waterfront amenities, and the harbour, where bathing is now safe (Aarhus Municipality, 2008; Hvilshoj and Klee, 2013).

Łódź: Stormwater retention and ecological quality improvement

The River Sokołówka is a small urban stream running through the northern part of the city of Łódź, the third largest city in Poland. The catchment spans urban areas as well as agricultural and natural areas. In the early 1930s, the upper reaches of the river were straightened, deepened and partially canalised. The main channel of the urban stream was converted into a collector for 50 stormwater outlets. These developments resulted in adverse effects on the urban and surrounding ecosystems, and the Sokołówka and adjacent rivers were polluted with discharge from combined sewage and stormwater overflows several times per year.

Most of Łódź's rivers function as a part of the city's combined sewerage system. During heavy rains, the rivers intercept water from overflows and rainwater. A shortage of stormwater retention reservoirs is one of the causes of pollution of the city's biggest river, the River Ner, which receives combined sewage from the entire city.

The ongoing problems related to pollution, overflows and ecological degradation drove the city to investigate options for stormwater retention and for improving the ecological quality of the rivers, thus creating a friendlier and healthier public space.

The city of Łódź has implemented a comprehensive urban development programme for water and river restoration, which has involved the restoration of the River Sokołówka. A sequential stormwater sedimentation biofiltration system was implemented, which prevents the influx of pollutants into the river during high flows (Zalewski et al., 2012). Five retention reservoirs were constructed to increase river retention and pollution absorption capacity. These measures went hand in hand with development plans for further rehabilitation of the river valley (Wagner and Breil, 2013).

As a result of the measures taken, the river and its valley have become an attractive residential and recreational area that has contributed to the positive economic development of the wider area (Wagner et al., 2007). The creation of new green areas as part of the restoration activities has had a positive influence on the quality of the inhabitants' life and on their health. The restoration of the Sokołówka river has been used as a case study to gather experience that can then be used for further projects to restore other streams and rivers crossing the city. The pilot projects implemented by the city of Łódź have played an important role in creating visibility, interest and cooperation, and as such have been vital in the scaling up strategy of the project.

Photo: Zgierska pond in the urban catchment of the Sokołówka river after restoration © Anita Waack-Zając

3.3 Structural changes

3.1.1 Key impacts of physical modifications

Rapid urbanisation and industrial growth, in addition to increasing demand for water and increased water pollution, have introduced new pressures on urban rivers, in the form of modifications to their morphology and hydrology.

In the past 150 years, riverside areas have been subject to structural changes such as channelisation and straightening. These have taken space away from rivers to improve flood protection and create living space in growing towns. Consequently, water quality deteriorated and recreation and amenity uses were lost.

In many towns and cities, rivers and streams have been covered with concrete and rerouted into sewers, drains and culverts as urban areas have grown. In some European capitals, several artificial canals have been added to the river network, for example in Berlin, whose landscape is shaped by several important canals (the Teltow canal, Landwehr canal, the Berlin-Spandau ship canal and Hohenzollern canal).

Physical modifications result in urban river spaces suffering from a lack of several functions, as illustrated in Table 3.1.

Lakes within cities have also been physically modified as their natural shores have been replaced by concrete structures and/or their hydrology has been modified to serve human uses.

The next sections describe the responses of cities and towns to the impacts of physical modifications on their rivers, streams and lakes in recent decades. This report distinguishes between activities aimed at hydromorphological restoration, mainly of rivers and streams of medium or small size; activities of de-culverting covered streams and rivers; and restoration of urban water bodies with strong links to flood risk management. In practice, all these types of activities are closely connected, and they often take place simultaneously in the context of the same restoration scheme.

3.3.2 Hydromorphological restoration of urban rivers and lakes

Since the 1980s, in several parts of mainly western and northern Europe, an increasing number of river restoration projects have been developed and realised in urban areas. Many of these have been based on the insight that attention to ecological aspects of river maintenance can result in the creation of attractive open spaces and the establishment of a more natural landscape. A multitude of benefits related to urban river restoration have been recognised in particular:

- leisure and recreation for residents, nature experience for individuals, enhancement of city aesthetics;
- flood control and protection;
- climate change adaptation, e.g. related to retention areas, which create space for the river, and

Table 3.1 Impacts of physical modifications on the functions of urban rivers

Functions of urban river spaces	Impacts of physical modifications
Ecological functions	Lack of habitat and biotope network function
	Lack of permeability/passability
	Lack of retention areas
	Pollution and contamination
Social functions	Lack of accessibility of rivers and streams
	Lack of attractive open spaces next to water
	Inadequate perception of rivers by the public
Spatial functions	Separation of urban spaces and rivers owing to technical infrastructure
	Neglected areas along rivers
	Blurring of the natural boundaries of urban landscapes (monotonous landscapes).

Source: Based on Bender et al. (2012) and further modified.

measures addressing impacts such as urban heat islands or stormwater;

- freshwater ecology and cross-linking of habitats, creation of retreat areas for endangered species, enhancement of biodiversity.

Since the adoption of the WFD in 2000, urban river restoration has been partly driven by the goal of reaching good ecological status or potential, including in the case of physically modified stretches of rivers in urban areas.

In densely populated and industrialised areas in particular, the restoration of urban rivers contributes to improving the quality of the environment and increasing quality of life. Urban rivers are often the only functioning or potential reservoirs of biodiversity and open spaces in cities. Therefore, the active protection and restoration of such areas is a fundamental practice for shaping cities' spatial order and for sustainable development (Bender et al., 2012).

Much urban river restoration concentrates on small rivers and streams, which are often developed in the context of broader city strategies on restoration. The small River Mayesbrook in London, for instance, has become a flagship urban restoration project as part of the London Rivers Action Plan. After restoration (creation of riverside wetlands, woodland planting, the creation of new meandering channels and improvements to the riverbanks), the River Mayesbrook achieved good ecological status in accordance with the WFD. The restoration of the Igelbäcken stream in Stockholm has greatly improved habitat characteristics for the rare stone loach fish species, this result has been effective in communicating the benefits of restoration actions in Sweden.

London: Enhancement of the community space and the natural landscape through restoration of the River Mayesbrook

The restoration of Mayesbrook Park in east London is a flagship project for the London Rivers Action Plan, published in 2009, the first ever plan for restoring all of London's rivers (see Section 2.5). Before its restoration, run-down sports facilities, two polluted artificial lakes and a straightened, realigned and fenced river sunk into a deep concrete channel made up the landscape at Mayesbrook Park (Natural England, 2013). The Mayesbrook was characterised in the Thames River Basin Management Plan 2009–2015 as one of the worst water bodies in the area, failing to achieve good ecological potential as a result of hydromorphological modifications, poor water quality and low ecology. The main driver for the restoration project on the River Mayesbrook was the identified need for revitalisation of the park where the river is located, as well as for water quality improvements. The restoration of the River Mayesbrook and Mayesbrook Park was also identified as a measure to improve hydromorphology and water quality in the first river basin management plan for the Thames river basin district.

The main aims of the restoration measures were to enhance the community space and achieve a more natural landscape that, at the same time, could become a model for climate change adaptation in a city environment. The river restoration measures included the creation of a new floodplain (1.5 ha) and of riverside wetlands, woodland planting, the creation of new sinuous water channels and the regrading of riverbanks.

Photo: Reach on the River Mayesbrook over a year after restoration, showing rapid morphological recovery with vegetated banks and mid-channel bar formation © Environment Agency

After restoration, the river is showing rapid morphological recovery and improved ecological resilience, helping the water body progress towards good ecological potential.

In addition to the ecological benefits, the restoration of the River Mayesbrook has provided many other benefits, such as health benefits, improvement in the quality of life and well-being of the local inhabitants, improved safety through greater park usage, socio-economic benefits to local sports clubs and the provision of an educational resource for the local schools. A published assessment of the ecosystem services provided by the restored River Mayesbrook estimated a substantial lifetime benefit-to-cost ratio of GBP 7 of benefits for every GBP 1 of investment (Everard et al., 2011). The study emphasised the social and health aspects — the improvement in the quality of life and well-being of local communities — as the most important benefits of the intervention.

Stockholm: The Igelbäcken stream — important for ecology and recreation

Photo: Stone loach © City of Stockholm

The Igelbäcken is, in a city context, a relatively undisturbed stream. It is considered one of Stockholm's most ecologically valuable rivers and provides access to nature and recreation for a huge number of inhabitants in the north-western parts of Stockholm.

The stream has a unique population of the (for Sweden) rare stone loach fish species, which has become an iconic indicator species of the stream and is widely used in communications to stimulate restoration and other environmental measures. Previously implanted signal crayfish are believed to impair the preconditions for stone loach. Fishing is prohibited in the stream. Restoration efforts in the River Igelbäcken have included re-meandering parts of its stretches and adding bottom substrates such as gravel and stone. The purpose of these measures was to increase the turbulence in the water and achieve better oxygenation. Trees and shrubs have been planted along the river to increase shadowing and lower the water temperature during hot summer periods. In 2006, the City of Stockholm established the Igelbäcken Cultural Reserve. The nearby municipalities of Solna and Sundbyberg have formed reserves for their parts of the Igelbäcken valley. Within the inter-municipal Igelbäck Group, collaboration between municipalities, the County Administrative Board and several non-governmental organisations (NGOs) has been conducted over 15 years.

Some urban restoration projects target the recovery of floodplain ecosystems from historical river regulation and drainage (EEA, 2016b). An example of such a project comes from Leipzig in Germany, where ongoing restoration efforts on the urban River Luppe aim to improve the floodplain dynamics, increase the quality of habitats for plants and animals, and maintain and increase ecosystem functions and services for people.

Despite the potential benefits of hydromorphological restoration both in ecological and recreational terms, restoration of urban rivers and streams is not always as feasible or desirable as similar restoration activities in rural areas. Flood risk protection of densely populated areas in downtown parts of cities remains a priority and is, at the same time, a barrier to extensive restoration projects (EEA, 2016b). Because of such limitations, the administration of the city of Vienna follows a stepping stone approach to improving the hydromorphology of rivers. Using this approach, restoration starts from the outskirts of the city and moves into the city step by step, as the urban sections of rivers are more difficult to restore.

Leipzig: Revitalisation of an urban floodplain forest

The city of Leipzig is situated between the floodplains of the Weiße Elster, Pleiße and Parthe rivers, which form a green belt classified as a significant central European floodplain ecosystem resulting from widespread floodplain forests. Interventions such as river regulation measures, extensive dyking and the drainage of agricultural and pasture fields have had significant impacts on the floodplain. Furthermore, the creation of the Neue Luppe (New Luppe) river section to serve flood protection in the 1930s also had several effects. Former river sections were cut off and could no longer provide the floodplain forest with water. As a result, the formerly water-rich floodplain landscape now suffers from a massive drop in the groundwater table and is drying out. Today, the area consists of many dry river beds without connectivity and there has been a reduction in the number of dynamic floodplain ponds and oxbow lakes. Among other problems, this is a threat to the biodiversity of the floodplain forest and related ecosystem services. At the same time, the floodplain of Leipzig has an important function as a recreational area and contributes significantly to the quality of life of the city's residents.

The revitalisation project Lebendige Luppe (Living Luppe) is one of the largest projects on floodplain and river restoration in central Germany, and it started in 2012. The objective is the revitalisation of more than 16 km of a former river course in the floodplain ecosystems. Dried-up river arms of the formerly water-rich floodplain, especially of the Luppe river system, are to be filled and reconnected again with water to create a continuous water landscape. The aim is for significant floods to reach large areas of the floodplain via the new river course. The intention is to achieve inundation of at least 30 % of the floodplain area via the new river. The groundwater table should be stabilised and raised by about 1 m in most parts of the project area. The project is considered part of a mosaic of different measures needed to achieve more extended revitalisation of the floodplain in the future, and it has been planned as a no-regret measure (Scholz et al., 2016).

Major flood events in January 2011 and in June 2013 inundated most of the project area and showed that, as a result of the Lebendige Luppe project, the floodplain is able to fulfil its function of protecting the city against inundation.

The idea for the restoration of the Luppe river system and the revitalisation of the floodplain was based on preparatory work of Green Ring Leipzig, an initiative of Leipzig and the neighbouring municipalities for a number of projects to enhance the environmental character of the city (see http://www.lebendige-luppe.de/ for more information).

Photo: Lebendige Luppe: the Heuwegluppe in an inundated state © Maria Vitzthum

Vienna: A stepping stone approach to river restoration

Vienna, Austria, is crossed by three main rivers (the Danube, the Wien and the Liesing), which were heavily modified in the 19th century to protect the city from floods. As a result of the changes in hydromorphology, problems with eutrophication arose. Most of the water bodies in Vienna are HMWB, so the environmental objective according to the WFD is to achieve good ecological potential in most cases.

In recent years, the Vienna city administration has started to execute a series of projects on all three rivers, with the goal of achieving good ecological potential of urban water bodies, reducing eutrophication and enabling migration of fish and benthic invertebrates by removing migration barriers where possible. Measures executed were targeted at restoring the river bed and semi-natural riverbanks, reintroducing meanders, replacing bed drops with bed sills to remove migration barriers and enhancing wastewater treatment. In improving the hydromorphology of the rivers, the administration has started activities from the outskirts of the city and is moving into the city step by step, bearing in mind that the urban sections of the rivers are more difficult to restore, partly because of the lack of space in urban areas. For the urban stretches, master plans have been developed in each case for the entire stretch; implementation started with the River Liesing (2015–2021) and will continue with the River Wien in the next WFD period (2021–2027). The restoration is expected to continue until 2027.

Photos: River Liesing before restoration (left) and after restoration (right) © MA 45/Webel (left), © MA 45/Wiener Wildnis (right)

3.3.3 Uncovering Europe's hidden rivers

Urban rivers are frequently culverted and diverted to enable urban development. The extent of historically culverted rivers in some European cities is considerable. For example, there is an entire network of rivers culverted under central London (Barton, 1992), many of which were once noted for their rich fisheries (Walton, 1653). Examples of covered rivers in major European cities include the River Bièvre in Paris, the River Fleet in London, the Ladegårdsåen in Copenhagen, and the Zenne in Brussels.

The result of covering rivers is that in many urban areas, local communities may be completely unaware of the existence of a river or a stream running beneath streets, buildings or open spaces (Wild et al., 2011).

Culverted rivers are widely considered to exhibit very low ecological integrity, owing to darkness or reduced light levels, habitat modifications, geomorphological changes, and increased diffuse and point source pollution, especially as a result of misconnections into surface water sewers. The darkness and other effects of modifications to the rivers often prevent the passage of fish, just as weirs do (Wild et al., 2011).

Awareness of the problems associated with culverted rivers has increased significantly over the last decade. For example, the London's Lost Rivers project has documented dozens of tributaries of the Thames that flow largely underground as a subterranean tangle of unseen streams.

De-culverting (or 'daylighting') rivers involves opening up buried watercourses and restoring them to more natural conditions. Projects can vary from the very simple — removing the 'roof' of a culvert and retaining the existing bank walls and natural bed material — to the major reconstruction of both bed and banks using soft bioengineering measures and river restoration techniques (Wild et al., 2011).

De-culverted rivers and streams are at less risk of floods due to underground blockages or collapse, and it is easier to spot and tackle sources of pollution when you can see the water. People can see and enjoy the wildlife that de-culverted streams support, with knock-on positive effects for health and well-being, education and recreation. Open rivers and streams can also help to reduce the urban heat island effect; they can be (and are) used to drive regeneration in downtown areas (theFreshwaterBlog, 2014).

In western and central Europe, there have already been several cases of reopening covered rivers. In Berlin, large parts of the Panke urban stream were covered or moved to underground pipes during the past 200 years. Now, the restoration of this urban stream is being planned to return the stream to its natural structure (Der Tagespiegel, 2015).

In the outskirts of Paris, a section of the River Bièvre has recently been reopened in Fresnes park. This was an important step that has enabled local residents to rediscover this riverside area (ECRR, n.d.). Indeed, projects to reopen urban rivers are often connected to initiatives to enhance the aesthetics of the city and actions to improve surface water quality.

In Aarhus, the city authorities decided in 1989 to uncover the urban river, which was initially covered to its full stretch across the city because of water pollution from sewage and general waste, new traffic requirements and ambitions to develop the town into a modern city (see Section 3.2.2).

In the city of Leuven, covered branches of the River Dyle have been opened up, as part of a bundle of activities by the city and the Flanders Environment Agency to enhance the role of rivers in the fabric of urban life lived near the water. Opening up the river and the creation of green riverbanks within the city improved the structural quality of the river and made it more attractive for flora and fauna (even within the city). The realisation that open watercourses in the city create significant added value is growing, not only in public administrations, but also among private project developers.

In Brussels, about 400 m of the Woluwe stream, which had been enclosed since the mid-19th century, and

London: The de-culverted Quaggy — a multifunctional blue-green city space

The Quaggy river is 5.6 km in length and crosses London's Sutcliffe Park, a large area of open parkland. For years, the Quaggy was culverted at Sutcliffe Park, and local residents only became aware that a river was there when their homes flooded more frequently as development in the floodplain increased. From 2003 to 2007, a project to de-culvert the Quaggy was implemented in a multidisciplinary scheme combining flood risk management with river restoration to benefit the local community.

The project was a case study in the London Rivers Action Plan (2009) and entailed the establishment of a new 'low-flow' meandering channel through the park, following the Quaggy's original alignment. The previous culvert was retained, enabling it to take excess water during extreme flood events. Flow between the two watercourses is now regulated by a sluice. To provide further flood water storage, the park itself was lowered and reshaped to create a floodplain capable of storing a maximum of 85 000 m^3 of flood water. Boardwalks, pathways and viewing points were designed to encourage access to the river and ponds, all of which were integral parts of the scheme. Furthermore, the project employed a community liaison officer to interact with schools, colleges and local charities, who also became actively involved in the delivery of the project.

The project has been successful in reducing flood risk for the surrounding area, as well as in reconnecting people to nature (after the restoration, park visits increased by 73 %). The implementation of the project as part of a wider catchment scheme has enabled other habitat mitigation measures in more constrained environments downstream to be implemented.

Photos: River Quaggy before and after restoration © Environment Agency its banks have been restored in recent years. This has created an open natural stream and a green corridor that is also part of the region's green network. The project also involved the separation of stormwater and sewage flows and therefore reduced the undesirable dilution of the influent to the Brussels wastewater treatment plant (OECD, 2007). The opportunity to proceed with the reopening of the Woluwe stream arose after the Brussels Central Region Blue Network programme was set up (partly to link up with the existing Green Network programme).

In the United Kingdom, specific policy has been developed to prevent culverting, promote the removal of these structures and restore urban rivers to a more natural condition. A few rivers have already been reopened, such as the formerly 'lost' River Quaggy, whose course was recently brought back to the surface as part of the broader London Rivers Action Plan. Its restoration entailed breaking the river out of a narrow concrete channel and recreating a functional floodplain as part of an attractive parkland landscape. The project had the effect of decreasing local flooding and achieving an additional integrated set of biodiversity, leisure, amenity and educational benefits, contributing to the regeneration of the area (Everard and Moggridge, 2011). Since its restoration, the Quaggy has become a major feature of Sutcliffe Park in south London.

In Zürich, a clean-water concept for separating uncontaminated water from sewage channels has been extended into a stream restoration concept (the Zürich Stream Daylighting Program). The goal was to daylight as many streams as possible, realigning them on the surface to increase ecological and recreational values within the urban area of the city of Zurich (Conradin and Buchli, 2004).

As mentioned in previous sections, a strategy dedicated to de-culverting streams has been developed in the city of Oslo. The Oslo de-culverting strategy has succeeded in recovering the value of natural streams and in retaining and cleaning urban stormwater, thus leading to improved water quality in the city's larger streams.

Oslo: De-culverting streams

Most of the streams passing through Oslo on their journey towards the Oslo fjord were culverted in the 19th century as they entered urbanised areas, in order to reduce water pollution and allow for infrastructure development.

The city of Oslo has developed a dedicated strategy for de-culverting its streams. The implementation of the strategy, which focuses on the major streams (the River Akerselva and the River Alna) but also covers smaller tributaries, started in November 2013. In some cases, where de-culverting took place in public parks and green spaces, it was possible to raise substantial additional financing, allowing the development of blue-green solutions with high aesthetic and multifunctional values. As an example, the Bjerkedalen valley section of the Hovinbekken stream was awarded the City of Oslo Architectural Prize in 2015. In the segment of the Hovinbekken stream where the Bjerkedalen Valley is located, trout now swim.

Photo: Bjerkedalen Valley © Tharan Fergus, Oslo Municipality, Water and Sewerage Works

3.3.4 Restoration to manage urban flood risk

Flood events in European cities: Causes and challenges

Flooding in inland urban areas has two main causes: failure of the urban drainage network to remove rainwater fast enough, causing accumulation; and flooding by an adjacent river as a result of rainfall in the catchment upstream. The former may be associated with insufficient system capacity by design and/or operation, as well as with the poor physical condition of the infrastructure. The latter can be exacerbated by urban growth and land use change outside the main urban area (i.e. upstream peri-urban and adjacent rural areas), as precipitation that was previously absorbed or slowed down by vegetated land can then run off on the sealed surface of suburban infrastructure and through bare winter fields (Heathcote et al., 2002). In those cases where the two processes converge, severe flooding may ensue in highly populated urban centres.

Inland flood events can be classified and described based on the source of the run-off water (e.g. rainfall, snowmelt or a combination of both) as well as the intensity and duration of the associated rainfall. Cities located close to mountainous areas can also be affected by several other types of flooding, such as flash floods that occur as a result of the rapid accumulation of run-off waters from the higher upstream areas (caused by extreme rainfall, cloud bursts, landslides, the sudden break-up of a dyke or the failure of flood control works). Around the world, the majority of cities are located towards the lower end of river catchments and in coastal areas, often

Dresden: Recent flood events

In August 2002, triggered by a long period of intensive rainfall in central Europe, the Elbe river and one of its tributaries, the Weißeritz, flooded parts of Dresden as well as downstream villages. Reaching 9.40 m, the water level was the highest on record since 1275 and exceeded the former maximum of 8.77 m, which was recorded in 1845 (Grollmann and Simon, 2002, as cited in Ulbrich et al., 2003). The cost of the damage was estimated at EUR 80 million for community services, EUR 300 million for flood protection infrastructure, about EUR 45.6 million for agriculture and forestry, all this on top of the damage to the central railway station, as well as other public and private buildings (EEA, 2016b). This was an event that affected several countries in central Europe, and the total economic loss across the region affected by the floods amounted to over EUR 14.5 billion (Ulbrich et al., 2003). A renewed threat surged in late May 2013, when prolonged and intensive rain visited the city once more. The water reached similar levels to those registered in the 2002 events, putting to the test the flood prevention and flood risk management measures that had been implemented after the centennial flood. Overall, severe consequences for the city were avoided thanks to better, quicker and more effective official communication; effective use of mobile and stationary protection walls; and increased retention capacity and appropriate run-off pathways (UNU, 2013).

Lyon: River restoration to reduce flood risk and restore the aquatic environment

The River Yzeron is a tributary of the River Rhône and drains part of the urban area south-west of the centre of Lyon. The catchment of Yzeron can be divided into an upstream area that is steep and predominantly rural, a middle area that is less steep and peri-urban, and a downstream area that is densely urbanised. During heavy rainfall, the river is capable of producing extremely high flow rates and resulting in dangerous flooding in the urbanised downstream areas (http://www.riviere-yzeron.fr).

After two major floods in 1989 and 1993, an intercommunal union, bringing together 20 municipalities, was made responsible for the management and implementation of a river contract, with the aim of protecting the city from flooding and restoring the aquatic environment.

Established in the late 2000s, the Yzeron ecological restoration project has several objectives', and it incorporates various sustainability elements (Cottet et al., 2014). The River Yzeron is being restored in several steps: a small section was restored in 2012 and a larger section has been under restoration since 2014.

The restoration project involves the removal of concrete culverts and the revegetation of the banks in order to foster a wildlife corridor with flora and fauna. The simultaneous widening of the river and the construction of two dams will improve flood control during rainy periods. In parallel, works are being conducted by Lyon Métropole (formerly Greater Lyon) on the combined sewer system, to reduce overflows and emissions during rainy weather.

making them vulnerable to all these types of flooding, sometimes in combination (Huntley et al., 2001).

In the urban context, sealed surfaces short-circuit the natural water cycle and increase the rate at which run-off water reaches the drainage network, saturating the system and intensifying floods (Anthonj et al., 2014). These more intense floods have become more frequent in recent decades, and they have major implications for the quality of life in urban areas, as they shut down basic infrastructure and interrupt economic activity; in more extreme cases, they destroy homes, businesses and public infrastructure (EEA, 2016b).

Many European cities have to deal with flood risk management issues on a regular basis and most of them have a history of catastrophic flood events. For example, in 1910 Paris was hit by a disastrous flood, as a result of which the River Seine rose 8 m above its ordinary level. Thousands of Parisians evacuated their homes as water infiltrated buildings and streets throughout the city, shutting down much of Paris's basic infrastructure (Wikipedia, n.d. (a)). The recent flood episode of June 2016 shook the city once more, with the river level rising to 6.1 m above its ordinary level and shutting down transport and electricity systems.

In early 1995, large areas of cities located along the Meuse river in the Netherlands found themselves under water. Heavy rain events combined with snowmelt from the mountains raised the river's water level, flooding areas around the city of Maastricht and south of the city of Nijmegen. Around 75 000 people living along the Meuse and Waal rivers had to be evacuated (ESA, n.d. (a)).

Dresden is another city that has repeatedly suffered the impacts of flooding, with the latest major events taking place in 2002 (a centennial flood) and 2013.

Floods can be a particularly difficult form of disaster to cope with because the vast amounts of water that they leave behind can aggravate the immediate damage caused and extend the period needed for recovery. Apart from the immediate damage to infrastructure and property, crop destruction and disease are also common impacts of flood events (ESA, n.d. (b)). In cities, extreme flooding events can have a number of impacts, including material, economic and health impacts (EEA, 2016a). Therefore, there is consensus that urban areas need to be made more resilient to flooding, especially in the face of climate change.

Nijmegen: Room for the River

In the east of the Netherlands, a sharp bend within the course of the River Waal coincides with the location of the city of Nijmegen. The limited space for the river to discharge all the incoming water, especially during extreme events, results in a dangerous bottleneck. This has already caused major flooding events in the past (1993 and 1995) and continues to pose a threat (Gemeente Nijmegen and i-Lent, 2015).

Under the Room for the River programme steered by the Dutch government, an integrated initiative is under way to reduce flood risk in Nijmegen by moving an existing dyke 350 m inland, digging an ancillary channel to give the river more room and building bridges across the new channel. These measures will be combined with the creation of a river park and the redevelopment of waterfront areas, encouraging the further development of the city and providing new opportunities for leisure and recreation. The milestone water safety of this project was reached in December 2015. The long-term involvement of a range of stakeholders, the commitment of the local government, and extensive planning and assessment efforts have gained the necessary public support required for implementation of the project to begin (STOWA, n.d.).

Photo: © Municipality of Nijmegen

Nijmegen has linked the river project to plans to expand the city on the northern banks of the River Waal. The new city bridge over the river and the Room for the River project will change the lie of the land. In future, instead of turning its back on the river, Nijmegen will embrace it. In 2011, the plan received the Waterfront Award in New York. In addition to increasing high water level protection, Room for the River has been a catalyst for urban planning (UNESCO-IHE, 2013). The new river park created on the River Waal as a result of the Room for the River interventions in Nijmegen serves as a new public space (more than 80 ha) in the heart of the city, where the people of Nijmegen and Lent can enjoy the water on a daily basis, do sports and experience the floodplains.

At present, European cities also face specific climate change challenges that are increasing and will continue to increase flood risk in urban centres. Projections show that, in a warmer climate, there would be a further increase in the risk of river floods in many western and central eastern European areas and of urban drainage flooding in particular in western and northern Europe (EEA, 2016a; 2016b; 2012c). In this context, appropriate run-off pathways should be ensured when elaborating new development plans and when defining urban drainage systems' capacity. This should help to enhance the resilience of urban centres to future flood events and reduce their social and economic impacts.

In urban centres where buildings encroach on the edges of rivers, flood risk has often been managed by encasing rivers in concrete with many culverts. These constraints result in river maintenance difficulties and reduce the ability of channels to cope with increasingly heavy summer rainfall. Many concrete-lined channels were designed to accommodate major flooding (i.e. every 20–30 years). This may no longer be adequate owing to predicted climate change impacts. For this reason, flood risk managers are now increasingly committed to creating space for flood water where possible through river restoration activities (LRAP Partnership, 2009).

Munich: Restoration of riverbanks and opening of the city towards its river

Hydraulic regulation measures introduced in the 19th century resulted in a gradual degradation of the ecology, flow conditions and water quality of the River Isar flowing through Munich. These modifications also increased the risk of flooding and damage to properties located at lower altitudes, as well as limiting public access to the river (Arzet and Joven, n.d.; RESTORE, 2013).

In response to these issues, the Isar Plan was launched in 1995 as an initiative that integrated the goals of flood protection, ecological restoration, landscape design and recreational use (Arzet and Joven, n.d.; Reiss-Schmidt, 2014). An 8-km stretch of the river that cuts across the city of Munich has been re-natured (Arzet and Joven, n.d.; Wulf and Schaufuß, 2013), with measures including restoration of the riverbanks, improved access routes and setting the flood defences back from the riverbank. The benefits of the project included improved discharge of flood water/lower risk of flooding, an almost natural river flow, enhanced aesthetics, better access for visitors, improved water quality and a restored habitat that supports local fauna and flora (City of Munich DUPBR, 2005; RESTORE, 2013).

Water quality in the River Isar has improved to the point where the water meets bathing water standards, thanks to wastewater treatment plants. In addition, flood protection measures have been integrated with an attractive landscape design. As a result, large numbers of people visit the River Isar, especially during the summer, and Munich is now a city with an 8-km bathing site.

Photos: River Isar after restoration © Wasserwirtschaftsamt München

Responses to urban flood risk: Links to river restoration

Increased urbanisation brings higher concentrations of people, economic activities and assets, subsequently resulting in higher disaster risks (UNISDR, 2012). In terms of flood risk and resilience to flooding, the importance of strategic planning and design becomes evident when the main causes of floods in inland urban areas, as described above, are taken into account. The design, operation and maintenance of the urban drainage network, as well as the mode and direction of the city's expansion are all variables that can be controlled or at least influenced by strategic planning. In this context, strategies and measures to protect and restore natural areas, especially in those parts of a city at higher risk of flooding, can be key to reducing disaster risk and ultimately the impacts resulting from catastrophic flood events.

Leuven: Increasing resilience to floods

The flooding of the Dyle River in the city of Leuven has always been an issue, as the naturally occurring steep slopes and historical deforestation upstream of Leuven lead to rapid increases in flow rate and water level during high precipitation. Floods occurred after heavy rainfall or after sudden thaws following cold winters, resulting in the river overflowing. The most extreme flooding event in its recorded history took place in 1891; a third of the city was flooded, and that event remains a reference point for the river's destructive potential. Since then, flooding events (e.g. in March 1947, leading to extensive flooding in the upstream municipality) have been a regular occurrence, prompting a number of interventions.

In the 1970s, the measures to protect the city of Leuven began with the design of traditional hydraulic solutions, in particular a large flood reservoir in the Neerijse valley upstream of Leuven. Poor water quality and agricultural land use (still very important in that period) required that the flood reservoir take up no more space than was absolutely necessary. During the design period of this traditional hydraulic solution, growing environmental awareness led Leuven to explore more nature-based solutions that took the ecological health and landscape value of the river valley into consideration (La Rivière, 2014).

Using new modelling software and taking into account ecological requirements, the protection measures were tested, yielding successful results. The tested measures included a controlled flood reservoir in Egenhoven and natural, uncontrolled flood zones in the Neerijse valley (La Rivière, 2014).

Under this new approach, instead of implementing a hard engineered solution with artificial flood reservoirs, the natural processes have been restored, resulting in 'wet' valley floors along the River Dyle upstream of Leuven. Infrastructure works have been kept to a minimum and are intended to 'guide' the river rather than contain it (La Rivière, 2014).

In addition to the provision of areas to store water upstream of Leuven, it may be possible to slowly enhance the capacity of the channel network within the city over the years, providing that there is sufficient support within Leuven. Although the capacity enhancements will be relatively small, when they are combined with flood-resistant and -resilient constructions, they will help to reduce the amount of storage required upstream. Under the EU project Flood Resilient City (FRC), the Flanders Environment Agency implemented a number of measures to enhance the capacity of the channel network within the city. The existing quay walls were improved to maintain discharge capacity in the city centre. This was done in close contact with the riparian owners. Thus, they became more aware of the river flowing next to or close to their houses. At one location, it was possible to build a terrace alongside the river and a small park for people to enjoy. During high water, the terrace can safely flood. This increases the capacity of the river in the city centre. In addition, the terrace helps to make more people in Leuven aware that the Dyle is a living river and that there is an ongoing threat of flooding (floodresiliencity.eu (n.d)).

Photos: Terraces alongside the River Dyle in Leuven © Flanders Environment Agency

Cities can carry out a number of actions to enhance their protection from flood damage. These include 'grey' flood protection and appropriate urban design, but also green solutions, such as providing more space for city rivers. In urban areas where appropriate spatial planning and disaster risk reduction efforts are undertaken (e.g. sensible building codes are developed and respected, human settlements are established away from floodplains or steep slopes, and infrastructure and services are suitable), the consequences of flood events and other disasters are kept to a minimum (UNISDR, 2012). Sustainable urban drainage, stormwater management and green roofs are also long-term approaches to managing surface and groundwater by reducing the rate and volume of run-off.

As part of the United Nation's Making Cities Resilient campaign, the City of Venice developed a plan that encompassed structural and bio-geomorphological elements for flood protection. The plan includes a broad spectrum of measures ranging from greener solutions such as the reconstruction of wetlands and reclamation of polluted sites through softer solutions such as flood monitoring, an early warning system and public awareness raising to more traditional interventions such as city pavement elevation and urban maintenance (UNISDR, 2012). In several other European cities, flood protection measures are combined with the restoration of riverbanks and the redevelopment of waterfront areas to support recreation and green urban planning.

The need to address the risk of flooding has in fact been one of the main triggers for restoration activities in the case studies reviewed for this report. For example, persistent flooding events (often resulting in substantial and costly damage) have triggered restoration activities in the urban areas of the River Waal in Nijmegen, the River Quaggy in London, the River Isar in München, the River Dyle in Leuven and the River Glinščica, connected to the Podutik reservoir, in Ljubljana.

Mérida: Restoration of the River Guadiana

In Mérida, capital of the region of Extremadura in Spain, the overall area adjacent to the Guadiana river was suffering from progressive environmental degradation caused by invasion of the river margins by the adjacent landowners, uncontrolled excavations for the extraction of gravel and sand, dumping of debris and rubbish, and degradation of the natural vegetation. While the urban section of the river suffered from these problems to some extent, further issues were also prevalent. One of them was the presence of urban infrastructure very close to the river, which called for their protection from floods. Furthermore, the Montijo dam (a dam constructed for irrigation purposes and located downstream of the city) caused frequent oscillations of the river's water level, subsequently resulting in dramatic visual impacts on the urban landscape. This became an issue partly because Mérida is a historic city with an important archaeological and monumental heritage (declared a UNESCO World Heritage site in 1993). Some elements of this heritage are closely related to the river, such as the monumental Roman bridge, the longest (c. 800 m) Roman bridge that still stands today.

Photo: River Guadiana at Mérida after the restoration measures © Confederación Hidrográfica del Guadiana

In the late 1980s the Confederación Hidrográfica del Guadiana (Spanish Water Authority in the Guadiana river basin area, part of the Ministry of the Environment) decided to act in the area to solve, or at least mitigate, the series of problems faced by the city and its river. In the urban areas, the project allowed the riverbanks to be properly integrated with the city, paying special attention to the aesthetic and archaeological aspects and taking advantage of them to provide citizens with new green zones (parks), which in turn are compatible with occasional flooding and prevent the improper use of the areas adjacent to the river. The restoration project on the River Guadiana was linked to the Urban Plan of Mérida.

Urban integration was one of the most important targets of this restoration project and was achieved to a large extent. Most of the urban riverbanks have become parks or riverside promenades, allowing an adequate transition between the city and the river and improving the environment surrounding the existing monuments. The restoration measures have been widely accepted by citizens, who make much use of both the urban and suburban restored areas for sports and recreation (e.g. walking, trekking, cycling, fishing and kayaking).

Very often a city's current layout, with its existing infrastructure and settlements, may hinder the implementation of measures such as floodplain widening and de-culverting of urban streams. The complexity and financial burden often associated with major maintenance and upgrading works on the urban drainage network can also constrain a city's scope of action. However, the increased frequency and intensity of flood events will continue to make clear the need for disaster risk reduction measures in many European cities. In situations where an increase in flood protection is necessary, but the scope for action within the city's boundaries is limited, combining inner-city measures with planning on a larger scale to include nature-based solutions in upstream areas can be an alternative. The measures taken to increase resilience in the city of Leuven, historically challenged by flooding, offer a good example of this.

Resilient cities should be well integrated into their surrounding hinterlands through green and blue infrastructure (i.e. forests and other natural areas, rivers, lakes, parks, green roofs, etc.), providing people with the opportunity to reconnect with nature despite ongoing urban growth. A good example of this type of multifunctional approach, linking flood risk reduction objectives with the protection of a city's heritage and increased quality of life through the integration of the wider landscape, is the restoration of the River Guadiana in the city of Mérida.

4 Lessons learned and way forward

The case studies on urban river and lake restoration reviewed for this report reveal that there are several critical aspects to be considered when planning and running urban restoration activities. This section summarises some important lessons learned from the case studies reviewed and frames some key contextual issues that are potentially relevant to different urban settings across Europe. These are aspects related to local planning processes, the multifunctionality of urban restoration, the availability of space for urban restoration, public participation and the involvement of multiple actors. This section also describes some significant future challenges for the restoration of rivers and lakes in an urban setting.

4.1 Local and catchment planning

Restoring the water environment in urban areas has very important links with local planning and with flood risk management. Local authorities can use land use planning processes to deliver improvements to urban rivers and lakes. Strategic development plans and local development plans are produced by planning authorities with input from a wide range of stakeholders. Such plans can identify aspirations and assist in the delivery of restoration, offering an important opportunity for interested parties to become involved in the decision-making process (Natural Scotland, 2015).

There is a particular need to make strong connections between spatial planning, WFD requirements (see next section) and flood risk management, as well as the requirements stemming from climate adaptation and mitigation measures. Urban planning should also take into account historical records on past floods.

In this context, the planning process for and financing of restoration measures in urban areas require effective collaboration between water and city development authorities, authorities responsible for urban and spatial planning, and local residents.

Several examples illustrating such collaboration and links to local planning and spatial planning processes can be found in the cases reviewed for this report.

- The city of Leuven's spatial development plan treated the Dyle river as a separate structure of great importance as part of a blue-green corridor throughout the city. The main aim was to enhance the way the watercourse was experienced. General principles such as more water storage, improved water quality and erosion measures were also integrated into the plan. In addition, cooperation with project developers made it possible for the Flanders Environment Agency to do more in terms of restoration in the city centre with less money. The project developers were responsible for opening up covered parts of the river and working out the design of the blue-green corridor. The Flanders Environment Agency participated in the river enhancements.

- In the city of Nijmegen, the main factor that influenced the selection of the interventions on the River Waal, i.e. moving the dyke back from the riverbank and digging a second river channel in the resulting new area of floodplain, was the possibility of combining them with a larger city redevelopment project. In fact, the restoration project has created a catalyst for an integral development of the area, including a new residential neighbourhood on the new island created on the River Waal and on the north shore, the revitalisation of the other shore at the old city centre and the creation of a unique new river park.

- In the city of Mérida, the restoration project on the River Guadiana was linked to the Urban Plan of Mérida.

- In the city of Łódź, the ability to motivate urban developers to consider innovations linked to stormwater management in development projects has been an important aspect for stream and river restoration. The restoration of the River Sokołowka and its valley showed that local town plans (spatial development plans) are basic tools for the right investments (green infrastructure, water retention, biologically active areas) to achieve the return of the valley to its natural form.

- Ongoing urban restoration projects also show that, as well as opportunities, there are also many challenges ahead when it comes to linking restoration with other planning processes. In the city of Leipzig, there are still considerable planning challenges to be overcome on the way to full revitalisation of the Leipzig floodplain, because the interests of other water users and owners must be taken into account (flood protection authorities, hydropower producers and urban sanitary environmental engineering). It has also become clear that the required floodplain dynamic cannot be achieved through the measures of the restoration project alone (Lebendige Luppe).

4.2 Multifunctionality

In designing restoration projects for urban rivers and lakes, it is important to aim for multifunctional schemes. Nowadays, water management increasingly includes ecological concerns and working with natural processes. This is in line with the objective of the 7EAP' to protect, conserve and enhance the Union's natural capital'. It is also consistent with Target 2 of the EU's Biodiversity Strategy, which aims to ensure maintenance of ecosystems and their services by establishing green infrastructure and restoring at least 15 % of degraded ecosystems by 2020 (European Commission, 2014b).

River and lake restoration, in connection with other projects such as rainwater harvesting and wetland spaces for city development and urban planning, offers mutual benefits: improving flood control and ecological functions while offering recreational value and raising the quality of life in urban areas.

Multifunctional urban restoration measures are seen as win–win measures that help deliver synergies, e.g. to implement different policies such as the WFD, the Floods Directive and the Habitats Directive. Such win–win restoration measures can more easily gain public and political acceptance and secure (co-)funding from multiple sources.

- In the London Rivers Action Plan, there are several examples of multipurpose restoration. For instance, the design of the restoration of the Quaggy was driven by a multidisciplinary scheme, which enabled wider community and environmental benefits to be achieved. Demonstrating multiple benefits has enabled a wider range of funding sources to be approached for future schemes. Similarly, in the case of restoring the Mayesbrook Park in London a 'mosaic' funding model could be applied, with numerous funding partners collaborating to deliver multiple benefits through the project.

- In addition, in the case of the Oslo city strategy for de-culverting streams and rivers, an important lesson learned from the development and implementation of the strategy was that it is very important to consider multifunctionality. Several ecosystem services were considered and helped to justify the de-culverting efforts in Oslo throughout the past decades, with improved urban stormwater handling as a starting point. In addition, several other services required due attention in the implementation of such a strategy, in order to ensure good and operational inter-agency cooperation within the city administration (including the agencies responsible for the implementation of the WFD and planning agencies seeking to maximise the usefulness and attractiveness of green areas). When de-culverting projects took place in public open spaces, substantial additional financial resources could in some cases be provided that allowed the development of blue-green landscape solutions with high aesthetic and multifunctional value.

- In the case of the River Dyle, it was possible to integrate the objectives of the Floods Directive with those of the WFD by carrying out natural flood protection measures upstream of Leuven to reduce flood risk for the city. In addition, a large part of the valley upstream of Leuven is designated as a Natura 2000 area; therefore, measures taken there for flood protection had to take into account the natural importance of the valley. Most of the land upstream of the city is government property and it could be used in multiple ways by combining flood protection and nature protection objectives.

- In Ljubljana, a reservoir was redesigned in a multifunctional way to address pollution and flood risk issues as well as for nature conservation reasons.

- In the heavily industrialised and urbanised area of the Ruhr in Germany, a master plan has been adopted for the restoration of the River Emscher (Master Plan Emscher Future). This addresses several objectives in an integrated way, especially water quality degradation, flood prevention, river restoration and urban landscape design that serves to enhance the lives and recreational activities of people.

Ljubljana: The multifunctional Podutik reservoir protecting against pollution and floods

The Podutik reservoir, constructed in 1986 to protect part of the Ljubljana urban region from floods, receives water from the Glinščica river and stormwater from the nearby settlements. The reservoir is facing water quality problems, as it is affected by occasional overflows from leaking septic tanks, polluted tributaries and urban run-off from gardens, parking places, etc. (Griessler Bulc et al., 2015).

In 2001, the Glinščica river, as a main recipient of the water from the Podutik reservoir, was found to be increasingly toxic. With the objective of providing additional flood prevention and pollution mitigation, from 2006, under the Environmental Action Programme of Ljubljana (2014–2020), the authorities started to implement green infrastructure in the catchment of the Glinščica river. Part of the Podutik flood reservoir was redesigned as a multifunctional flood reservoir with enhanced ecosystem services, provided by a constructed wetland and a new, meandering river bed.

The redesign of the Podutik reservoir as a multifunctional flood reservoir has enhanced water quality and contributed to nature conservation, as well as encouraging recreational and educational use (Grant, 2016). Efforts to include civil society and provide education have contributed to public awareness and have stimulated communication between public authorities, polluters and end-users of the flood reservoir.

The redesign of the Podutik flood reservoir is also used as a demonstration site. As Podutik is the first multifunctional flood reservoir in the Ljubljana urban region, and indeed in Slovenia, it is used to outline new perspectives for future developments in water management and flood prevention.

4.3 Space for urban restoration

In urban areas, where available space is limited, river restoration projects are frequently restricted. However, there is potential to deliver improvements in physical condition, along with significant environmental and social benefits, by using innovative approaches. For example, in Munich, the flood corridor of the River Isar offered some space and thus could be integrated into the Isar restoration project.

Towns and cities are continually changing and it is this process of change that provides opportunities for restoring river and lake environments. For example, there may be opportunities to remove redundant structures and buildings and restore derelict land alongside rivers in order to improve local amenities and the local environment (Natural Scotland, 2015).

Furthermore, because of the lack of space in urban areas, some cities have developed stepping-stone concepts for restoring their networks of water bodies. First, restoration interventions are easier to plan and implement in the outskirts and peri-urban areas than in downtown districts. When it comes to restoration combined with flood risk management, this may even be necessary, as flood retention should be achieved before the flood reaches the city centre. Second, restoration in the centre of large cities can be time-consuming, costly and technically difficult in terms of both planning and implementation. To deal with such difficulties, the city of Vienna has adopted a stepping-stone approach to restoring its urban water bodies. The activities started in the outskirts of the city, where the conditions were easier. For the more central urban stretches, which are very difficult to restore, master plans will be developed in each case for the entire stretch, and implementation will take place in phases (starting with the River Liesing (2015–2021) and continuing with the River Wien in the next WFD planning period (2021–2021)).

The case studies reviewed for this report also show that urban restoration projects can be facilitated when the land in question is in public hands. In the city of Łódź, restoration measures are being implemented on land that belongs to the City or other public owners, which makes the implementation process more efficient. Similarly, in Leipzig, large parts of the project area for the revitalisation of the Luppe are already in public ownership, especially forest sites. Transformation of arable land into land uses better suited to a floodplain, such as grassland, remains a major challenge, as compensation areas have to be found. In the case of the River Guadiana (Mérida), one of the goals of the restoration project was to increase the public areas on the riverbanks. Obtaining new land close to the river to develop the restoration activities was necessary, and this was achieved by means of expropriation (in accordance with Spanish law).

4.4 Public participation

Planning and execution of measures in urban river restoration should not follow a top-down approach. Public consultation and engagement with local communities have emerged as crucial steps in the planning and implementation of restoration measures in cities. Civil society and the private sector are vital for the development of cities and their hinterlands, and they will play a major role in coping with the challenges ahead.

Several examples of public participation processes are available in the case studies reviewed for this report.

- In Leipzig, a major communication process has been established to show the extent to which the Lebendige Luppe project can mitigate the negative effects of the loss of floodplain functioning in the Leipzig area. As a result of the interventions of NGOs, nature conservation experts and scientific experts, the objectives of the project have been enlarged to restore more flood dynamics in the river than originally planned. In parallel, a floodplain management forum has been created to develop future river and floodplain restoration measures in the Leipzig floodplain context.

- In London, owing to the high public profile of the Mayesbrook restoration and Mayesbrook Park regeneration works, considerable pre-project engagement was undertaken to raise awareness of the potential gains in natural capital and social benefits. In particular, work with local school groups and awareness-raising and stakeholder engagement activities were led by key partners. Formal public meetings were held regularly to inform local residents and businesses at key planning stages. These efforts ensured good knowledge exchange with local residents and park users (e.g. in relation to potential changes to the existing landscape that would affect individuals or families), as well as allaying concerns and identifying the best available solutions without compromising the scheme's objectives.

- In Nijmegen, many of the regional partners and stakeholders were extremely critical of and opposed to the national Room for the River plan, which was to be implemented for the River Waal. The proposal to move the dyke into Lent provoked widespread public opposition and demonstrations. In this case, the key to creating win–win solutions was to align the national goals, such as on water safety and nature development, with those of the regional stakeholder groups.

- In Munich, public consultation increased the acceptability of the project on the restoration of the River Isar. From the start of the Isar Plan in 1995, the public was asked to participate in the planning process. People were interviewed about the new river and their preferences and the results of those interviews formed the guidelines for the planning process.

- In the case of redesign of the Podutik flood reservoir in Ljubljana, efforts to include civil society and to organise information events contributed to awareness of the multifunctionality of the reservoir. Consultation activities also counteracted the lack of communication of different end-users of the area of the flood reservoir, in particular with regard to maintenance.

- In Oslo, experience gained through the city's stream de-culverting strategy also shows that it is important to engage the local communities surrounding the stretches being de-culverted. This requires a proper stakeholder analysis prior to the start of the work and the subsequent engagement of stakeholders. De-culverting projects that include complementary non-water-related components may add substantial welfare benefits and improvements in quality of life to local residents, with good local participation. Conversely, they may result in conflict-ridden projects if they are not well received and if good participatory processes are not in place.

4.5 Governance framework

In addition to engaging with the public and citizens affected by restoration schemes, it is just as important to establish effective cooperation between the different actors (especially government bodies and organised stakeholder groups) with a stake in and an influence on urban restoration. At the same time, there is a need for effective cooperation between different administrative levels, including in the drafting and implementation of strategic documents, in relation to which extensive public consultation processes should be organised.

- In the restoration of the River Isar (Munich), the level of cooperation achieved between all stakeholders involved within the Isar Plan was excellent and a key success factor for the project. An interdisciplinary Isar Plan working group was set up, with members from the State Office of Water Management Munich and the City of Munich (different departments). Based on the joint scoping work carried out by this group, the development goals for the project were defined. The City Council and district councils were involved as the project progressed, as was the Isar Alliance, a group of NGOs.

- Similarly, in the city of Łódź, stakeholder involvement through a Learning Alliance has driven the success of the restoration initiative for the River Sokołówka. It has also created links strong enough to last beyond the lifetime of the initiative and to sustain the upscaling of research results. Because the focuses of the research remained flexible and responsive to stakeholder needs, stakeholders participating in the initiative were able to really take advantage of their involvement. The Learning Alliance provided a well-structured framework to identify needs, develop capacities, define common goals and align the efforts of multiple actors towards achieving them, and communicating decisions and achievements.

- In the restoration of the River Guadiana in Mérida, cooperation between governmental organisations (state, region, city) was absolutely fundamental, because of the many different aspects concerned. The approach taken has been replicated in similar projects.

- In Leipzig, the governance framework of the Lebendige Luppe floodplain revitalisation project is also very challenging because of the multifunctionality of the floodplain in an urban setting. There are many actors involved, given that the river network in and around Leipzig is a heavily managed system. The planning phase has to bring together many actors responsible for flood and river management, nature conservation, forestry and agriculture, the neighbouring public, NGOs and politicians; different levels of local and regional authorities and agencies are also involved.

4.6 Concluding remarks — looking forward

The main challenges faced by European cities and towns in terms of managing their rivers and lakes have recently been transforming. Owing to improvements in water quality in the past decades, there is now increasing emphasis on improving the physical structure of urban rivers and lakes. In addition to benefiting water ecology, this new focus helps to create aesthetically pleasing open spaces and deal with new challenges such as adaptation to climate change. Having said that, we need to keep in mind that water quality problems are not yet fully resolved in all urban centres around Europe, and they remain a major challenge in several cities. There are still open issues in terms of compliance with European urban wastewater treatment requirements, as well as in terms of stormwater management and chemical pollution of sediments.

Urban rivers and lakes are water systems where different water management issues and social needs come together and need to be dealt with in an integrated way. For this reason, it is critical to aim for multifunctional urban restoration schemes. Urban river and lake restoration cannot be designed using a single-objective approach, e.g. to achieve the environmental objectives of EU water policy. Instead, other objectives need to be taken into account, such as improving the quality of life of citizens, linking water body restoration to urban regeneration schemes and delivering multiple benefits, such as flood protection and recreation. This can prove crucial in gaining political, social and financial support. Decision-making for restoration projects in cities can also be supported in the future by providing more accurate definitions of the expected benefits (both direct and indirect benefits in terms of ecosystem services).

The value of restored urban rivers and lakes has been presented in terms of creating opportunities for leisure, recreation and aesthetic enhancement of the city. At the same time, because of the attractiveness of restored water bodies in an urban setting, action needs to be taken at the planning level to minimise the risk of privatisation and overexploitation of areas close to restoration schemes. There is a need to balance the right of citizens to gain access to water with the rising prices of private property in newly developed areas on the waterfront.

Future restoration of urban rivers and lakes also needs to be better balanced and coordinated with interventions in the broader catchment. Cities and towns are frequently affected by the impacts of activities taking place in upstream rural areas, in terms of either water quality degradation (e.g. due to diffuse pollution from agriculture) or water flow changes (especially relevant to flood risk, which is increased by the lack of natural water retention upstream).

Last but not least, because of the complexity, multifunctionality and social relevance of river and lake restoration in urban centres, designing transparent public participation processes and efficient governance structures to accompany urban restoration strategies and projects remains a challenge.

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