Resilient European Cities: *Nature-based Solutions for Clean Water*

December 2020

The Nature Conservancy

ICLEI Local Governments for Sustainability

ecologic

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Acronyms

BMPs	Best Management Practices
CAP	Common Agricultural Policy
EC	European Commission
EEA	European Environment Agency
EU	European Union
GI	Green Infrastructure
MS	Member State
NbS	Nature-based Solutions
NbS-WS	Nature-based Solutions for Water Security
NWRM	Natural Water Retention Measures
OECD	Organisation for Economic Co-operation and Development
RBDs	River Basin Districts
RBMPs	River Basin Management Plans
SDGs	Sustainable Development Goals
SuDs	Sustainable Urban Drainage Systems
TN	Total Nitrogen
TP	Total Phosphorus
UNEP	UN Environment Programme
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive
WWF	World Wide Fund for Nature

Views from European and global stakeholders

Threats to water quality constitute a major concern for a country like Spain, with an 80 percent of its total water demand covered by surface water, recurrent droughts and a critical dependence on sound watershed management for urban supply, irrigated agriculture and protecting unique freshwater biodiversity hotspots. Exacerbated by climate stressors, diffuse pollution can pose serious challenges to human health, food security and ecological functions of delicate ecosystems. Traditionally, decision-makers have resorted to grey infrastructure to address water management challenges, but Spain is changing gears. National, regional and local authorities have started to turn their eyes to green infrastructure in order to build resilience and manage scarce resources, like quality water. I can only commend The Nature Conservancy and its partners for this very timely and rich blueprint on Nature-based Solutions for Clean Water. We will take note of innovations and lessons learned and will disseminate widely.

Teresa Ribera
*Deputy Prime Minister for Ecological Transition,
Government of Spain*

The UN Secretary General recently said air and water pollution are killing 9 million people annually, more than six times the current toll of the pandemic. The climate emergency means water quality will become more of a concern. Nature-based solutions help keep water clean, reduce flood risk, create a more resilient food system and reach net zero. But they need finance. The Environment Agency is developing ways to accelerate private investment in nature-based solutions.

Emma Howard Boyd
Chair of the Environment Agency in England

This report comes at the perfect point in time, when Europe is focusing efforts to overcome the COVID-19 pandemic whilst preparing the greener, healthier future it wishes for the next generations. Water will have to stay high on all European policy agendas, as we pursue efforts to deliver on the European Green Deal goals. Across the key four challenges our planet is facing (climate change, biodiversity loss, pollution and inefficient use of natural resources), water is the bond connecting all the dots, at the same time mankind's greatest ally, via stepped up surveillance, to enhance our preparedness and the first-in-row natural resource we should take care of, to come out of this crisis more resilient and with reduced social inequalities. Thank you for the wealth of data and ideas. I trust they will inspire many in building back better, fairer – and bluer.

Veronica Manfredi
Director Quality of Life (Air & Water, Marine Environment, Industrial Emissions & Safety), DG Environment, European Commission

This report will provide the French Biodiversity Agency with a precious source of knowledge and data in our objective to mainstream nature-based solution in the implementation of the National climate adaptation plan.

Cyrille Barnérias
European and International Director, French Biodiversity Agency

IWA is a strong advocate for the use of nature-based solutions to improve the quality and security of water and sanitation services. This report shows how the water sector can collaborate in a cost-effective way to harness nature to tackle diffuse pollution from catchment to tap.

Kala Vairavamoorthy
Executive Director, International Water Association (IWA)

The environment is too often treated like if it was an infinite resource over which no one has absolute ownership, even inside the EU, where EIB provides 90 percent of its financing. Diffuse pollution is a case in point where lack of political will to enforce the polluter-pays-principle enshrined in legislation results in impunity. As EIB we finance numerous projects that rely on nature based solutions, tackling the problem from the "benefits" angle: beneficiaries that recognise the value of nature and a clean environment drive investments at polluter level aimed at safeguarding the environment, supporting biodiversity, and ultimately, humankind.

Thomas Van Gilst
Head of Water Security and Resilience Division, Project Directorate, European Investment Bank

Nature-based solutions can be a cost-effective, sustainable approach to resolving some of the most challenging water quality issues we face in the UK and Europe. They are an important solution to our water security and climate resilience strategies across our operations. The work we've supported with external partners across multiple European countries in both urban and rural settings over the last few years has measurably demonstrated how we can enable important landscapes for our business to be healthier and more resilient from a community and river environment perspective. We commend this report as an inspiration and call to action for more organizations to join and scale this approach as we all need to strive towards a stable future for our businesses, communities and nature.

Therese Noorlander
Sustainability Director Europe, Coca Cola

Veolia is convinced of the value of nature-based solutions to tackle the challenges of protecting water resources in a context of climate change. To deploy them on a large scale, we need to work collectively on measuring their impact, an essential condition for their development.

Olivier Brousse
Director of Strategy and Innovation, Veolia

Healthy watersheds provide a natural buffer that helps ensure stability in a climate-challenged world. More and more, businesses are learning that natural landscapes are a source of resilience. When present, forests and wetlands are a natural sponge and filter. Companies need to also consider investing in nature-based solutions as a mean to protect, sustainably manage and restore watersheds co-located by their operations. Combined with their operational water quality and energy efficiency practices it is a powerful strategy toward a water and climate resilient future.

Emilio Tenuta
Senior Vice President and Chief Sustainability Officer, Ecolab

We have seen how good water stewardship requires looking beyond the pipes, concrete-lined channels and other 'hard' infrastructure within 'factory fences' and city limits to the natural systems in surrounding catchments which are crucial for maintaining good water quality. This report from TNC and partners is a timely wake-up call to a range of stakeholders, public and private, for their urgent support to collective actions on nature-based solutions.

Adrian Sym
CEO, Alliance for Water Stewardship

Diffuse pollution from soil loss and nutrients is a well-known and enduring problem the world over. It connects the health of our lands to that of our rivers, streams and ultimately of our oceans. The Nature Conservancy works to connect water sector actors, including cities, corporates, environmental NGOs, policy makers, regulators, funders and financiers to establish collective action mechanisms that are so necessary to address this issue. We see this as key to ensuring resilience and restoring nature for future generations.

Marianne Kleiberg
Europe Managing Director, The Nature Conservancy

Clean and resilient supplies of drinking water are not a matter of course any more due to rising pressures on land-use and poor land management practices. This piece of research provides much needed orientation for cities to better understand where nature-based solutions will be their most efficient allies for urban water security in times of rising uncertainties.

Wolfgang Teubner
Regional Director Europe and Managing Director, ICLEI

This report illustrates how letting nature protect our water resources from diffuse agricultural pollution surrounding European cities can lower water bills and increase recreational value of green spaces at very little cost to farmers. A must read for those interested in finding out more about what nature-based solutions can achieve

Ecologic Institute

Throughout history, cities have built their prosperity around their ability to source and manage adequate water supplies. The COVID-19 crisis highlights that such security is fragile. Disturbing the nitrogen cycle and overloading rivers with nutrients and sediment is having a profound impact on freshwater ecosystems' ability to support communities with clean, reliable water supply. It is time to intervene and this report provides an important guide to prioritise and organise collective action.

Giulio Boccaletti
Author and former Chief Strategy Officer at The Nature Conservancy

Executive Summary

The challenge: tackling diffuse pollution in European waters

Diffuse pollution is one of the key reasons European water bodies are failing to meet objectives relative to good ecological status as specified in the Water Framework Directive (WFD). As of 2015, only 40 percent of EU surface waters were in good ecological status, and 38 percent were in good chemical status. This is significant considering that around 75 percent of all water abstracted annually, and 40 percent of all drinking water consumed in Europe, comes from surface waters, such as rivers, lakes and reservoirs.

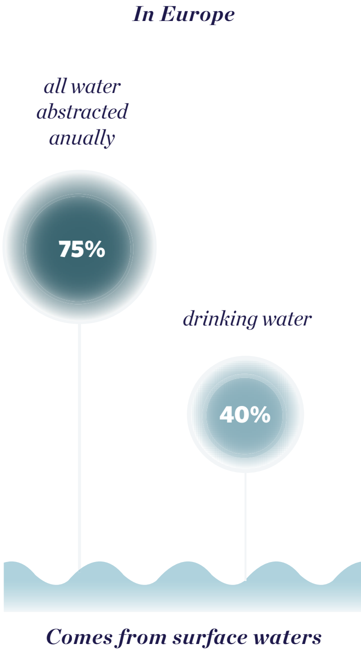
Each year, outbreaks of toxic green algae affect rivers, lakes and coastal waters and create so-called "dead zones" where no aquatic life can thrive. Such outbreaks are the by-product of dangerous increases in nutrient levels. Nutrient and soil loss have been recognised as challenges for decades across Europe and have been a key driver of freshwater biodiversity loss. With climate change, these challenges are likely to worsen: higher temperatures, lower river flows and more frequent and more violent flooding events. Sediment is one of the least well-defined pressures in the context of EU legislation, even though an estimated 11.4 percent of the EU territory is affected by moderate or high levels of soil erosion. This generates heavy sediment loads that clog riverbeds, hinder aquatic life, shorten the useful life of reservoirs and increase treatment costs. Other human-induced changes (such as dams and weirs) have modified the course of rivers and affected their natural flows.

Investing in nature-based solutions: a key part of the solution

This report examines how European cities can turn to nature-based solutions (NbS) to protect the water resources on which they depend and, in so doing, contribute to enhancing environmental quality in upstream watersheds.

Existing water supply systems in Europe depend heavily on costly grey infrastructure: most cities rely primarily on engineered solutions to secure their drinking water supplies. Even though access to water and sanitation is very high for European citizens, investment needs for the water sector in Europe are substantial. According to the Organisation for Economic Co-operation and Development (OECD), an average of EUR 100 billion was invested annually across the 28 EU Member States (MS) between 2011 and 2015. To comply with EU legislation and to make their water supply systems more efficient and resilient, all Member States will need to invest an additional EUR 289 billion in water services by 2030.

Yet, one type of investment that is not sufficiently considered at present consists of protecting, sustainably managing and restoring watersheds. These are natural infrastructure that can filter, clean and recharge water supplies to ensure the provision of sufficient, clean and affordable water for cities and other users that depend on water, including farmers, industry and the environment itself. Land use within catchment areas has a major influence on determining whether watersheds are healthy and can deliver these environmental services.



As such, watersheds are as crucial to the future vitality of cities as are the engineered systems of dams and diversions that were built over the years to ensure universal access to potable water. Cities depend on their surrounding rural areas for their water supplies: to be resilient, they need to protect the water sources on which they depend, which often means investing in rural areas far beyond their boundaries. Where these ecosystem functions have been degraded, water service providers are likely to incur additional costs to provide clean water to their citizens. Their water security may be at risk.

Turning to nature-based solutions to "build back better"

The policy and legal framework in Europe for water is well developed and conducive to investing in nature-based solutions for water security (NbS-WS). Investments have remained limited and quite fragmented, however, which is partly why environmental outcomes have not improved in line with expectations. An average of EUR 5.5 billion per year was committed to restoring and conserving watersheds in Europe over the 2014-2020 period. An estimated 99 per cent of funding for these investments came from public sources via multiple channels, including from the European Union (EU) and from national, regional or local governments. Some water service providers and cities have engaged with upstream parties in their source water catchments to support change in agriculture and forestry practices or to build artificial wetlands. But these investments have remained limited, due to regulatory barriers, high risk perception or a general lack of appreciation for what such investments can achieve.

A number of policy initiatives under the European Green Deal could significantly accelerate the adoption of nature-based solutions as part of water sector investment plans, including strategies related to biodiversity, climate adaptation and the transformation of food production systems. The COVID-19 crisis further strengthens this impetus, as Member States often see investing in nature-based solutions as a critical component of green recovery packages for their post-COVID-19 recovery plans and "building back better". The choices made today will condition our ability to achieve greater water security and resilience tomorrow, as well as to reverse biodiversity loss and establish the basis for more sustainable societies. To deliver on their promises, the right type of nature-based solutions will need to be delivered at scale in the right place: prioritising is essential.

Key findings: nature-based solutions could help address diffuse pollution in catchments serving 42 million people

These cities are home to 78.5 million people, or 15 per cent of the population of the European Union and the United Kingdom combined. This analysis allows going from an overall identification of "diffuse pollution hotspots" to a more nuanced understanding of where NbS could play a significant role to address those issues, and how to do it.

Out of 109 cities analysed in this report

63 cities

demonstrate high feasibility potential for at least one NbS and pollutant type

For each of these cities, we assess how land use change in their source water catchments generates risks linked to increases in sediment and nutrient pollution. We find that, for nearly two-thirds of assessed cities, more than half of their catchment areas has been converted to agricultural land or transformed into artificial, urban landscape. The extent of this land development suggests that natural ecosystem functions have been significantly impacted within catchments—with potential reductions in the quality of urban water supply. For the selected cities, soil loss rates are comparatively higher than the average in Europe, suggesting that development activities have resulted in increased soil loss. This may affect their ability to supply clean drinking water—potentially leading to increased operational costs and other impacts. Estimates of nutrient loads within source catchment areas also suggest widespread impacts due to development activities including agriculture.

We then examine the potential that four common nature-based solutions can have to mitigate diffuse pollution challenges and generate benefits for people and nature, when deployed at scale. The nature-based solutions under review include cover crops, riparian buffers, forest protection and reforestation.

Our analysis shows that nature-based solutions can be a feasible approach for supporting drinking water protection for many cities. According to our analysis, they have broad potential across the cities that we assess, with 63 cities—representing 42 million people—demonstrating high feasibility potential for at least one NbS and pollutant type, as shown in Figure ES-1.

FIGURE ES-1

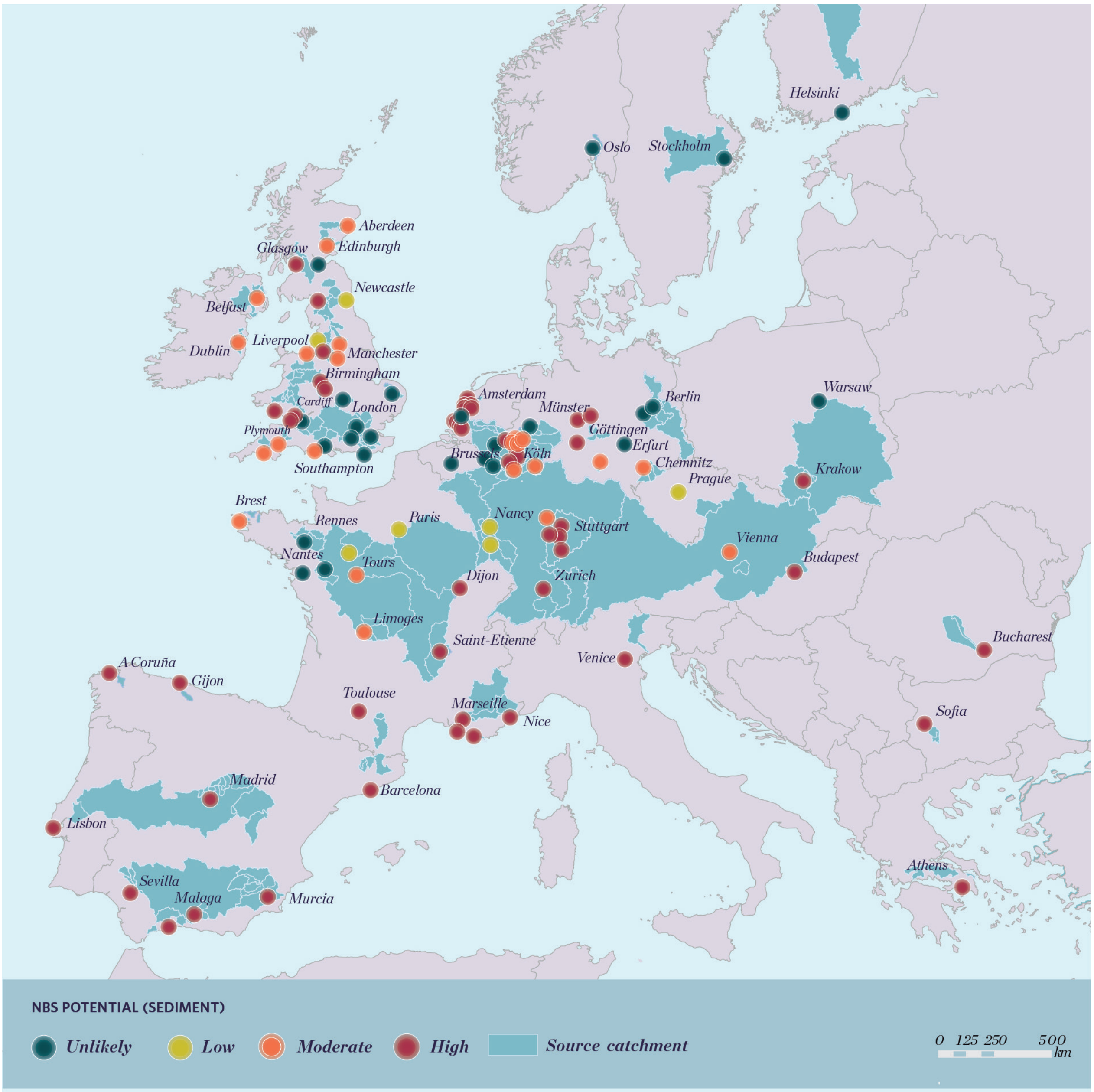
Comparison of NbS potential across different NbS and pollutant types

Source: Authors' analysis based on data from McDonald, 2016.

The maps in Figures ES-2 and ES-3 show which cities have the greatest potential for NbS to address nutrient pollution and sediment loss.

FIGURE ES-2

Cities that most stand to benefit from NbS implementation at scale for sediment reduction

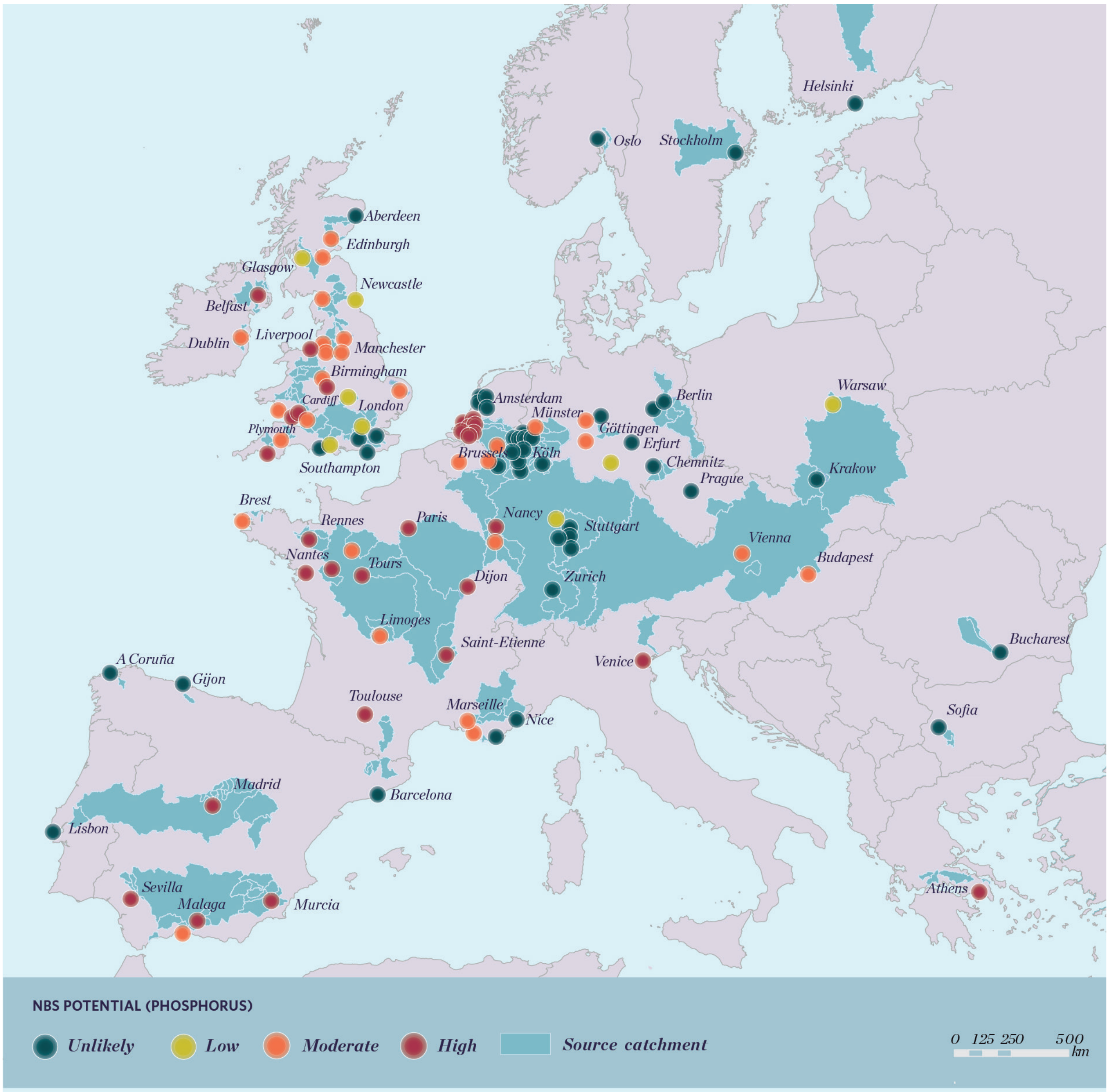


Note: The dots correspond to the 109 cities assessed for this report (see the full list in Annex C)

Source: Authors' analysis based on data from McDonald, 2016.

FIGURE ES-3

Cities that most stand to benefit from NbS implementation at scale for phosphorus reduction



Note: Dots correspond to the 109 cities assessed for this report (see the full list in Annex C)

Source: Authors' analysis based on data from McDonald, 2016.

While the costs of implementing NbS are difficult to estimate reliably at this scale, case study data suggest considerable differences in terms of costs according to NbS types, with the lowest costs associated with improved agricultural practices.

Planting of cover crops came out strongly as the NbS that has the strongest potential to address sediment and nutrient pollution at the lowest cost. This is true for sediment pollution in particular, with 44 cities showing high feasibility potential for NbS implementation that would reduce sediment pollution. Forest protection could also be an important approach for reducing (avoiding) soil loss and protecting water quality for many of these cities:

more than half of the cities in the sample have moderate to high feasibility potential for reducing sediment in waterways through forest protection.

Riparian buffers—while limited in their potential to improve overall catchment health as an individual strategy—are still an important NbS for protecting source catchments. Model results indicate that riparian buffers are limited in their ability to achieve pollution reduction at the catchment scale, where only nine cities are able to reach the 10 percent reduction target for annual sediment loads via investing in riparian buffers alone. However, at local scales, there is strong and convincing evidence that riparian buffers are highly effective at reducing sediment and nutrient pollution, with removal efficiencies greater than 70 percent for typical buffer widths (Lind et al., 2019). This suggests that, while riparian buffers alone are unlikely to achieve catchment-scale changes for most of the assessed cities, combining them with approaches that reduce pollution at source could be effective.

Cost savings for water providers can offset the costs of implementing nature-based solutions for catchment protection. This, combined with the co-benefits that they generate, means that nature-based solutions where they can deliver results at scale are a good investment for cities and water service providers looking to boost the resilience of water supplies.

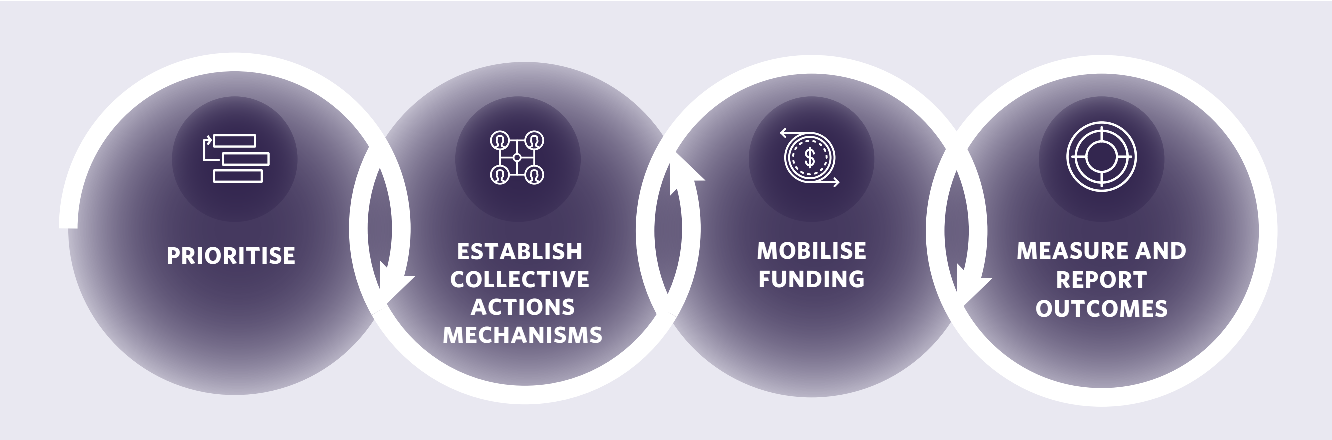
In addition to potential financial benefits for water providers and users, these interventions would generate significant co-benefits in terms of freshwater biodiversity (particularly where land development is a significant driver of species decline), carbon sequestration and avoided carbon emissions (where investments in grey infrastructure and associated energy consumption can be avoided), amenity value and positive impacts on health and well-being.

Whereas these co-benefits could not be estimated for this study at such a broad European scale, decisions to invest in NbS at the local level would need to take them into account. This would also enable mobilising different sources of funding for their implementation—for example, the sale of biodiversity offsets or carbon credits, or agricultural subsidies aimed at providing incentives to adopt agricultural best management practices (BMPs).

Summary recommendations

To deliver maximum impact on water security, nature-based solutions will need to be implemented at scale, targeting the areas where greatest results can be generated. The coming seven years (from 2021 to 2027) present a unique opportunity in Europe to demonstrate how NbS can deliver substantial improvements to tackle diffuse pollution.

This calls for a number of strategic steps to be adopted as shown on the figure below, including to prioritise where nature-based solutions can have the greatest impact, establish collective action mechanisms to enable coordinated implementation, mobilise funding and monitor outcomes.



Prioritise

NbS work better to address diffuse pollution when certain conditions are in place. European actors will need to ensure that nature-based solutions are prioritised in the upcoming River Basin Management Plans (2022-2027), as well as in the implementation of the new EU Biodiversity and Climate Adaptation Strategy. Key investors, including water companies, corporate water users, networks of cities, farmers and forest managers, NGOs, funders and financiers throughout Europe can use findings from the present report to identify where to prioritise their efforts in order to establish models of collective action mechanisms and dedicate resources. Further prioritisation will need to take place at the local level based on a broader set of criteria (including regulatory frameworks, social acceptability, alignment with local development plans, available land for NbS implementation, etc.).

Establish Collective Action Mechanisms

Even though River Basin Districts (RBDs) are in place throughout the European Union, they operate at a scale that is usually too large to enable local actors to tackle specific diffuse pollution challenges. More localized, action-orientated collective action mechanisms, such as Water Funds, can help accelerate implementation and should be established where potential for applying NbS at scale has been identified. In areas of priority, European stakeholders should establish or incentivise others to establish collective action mechanisms. We formulated specific recommendations on how this can be done.

Mobilise Funding

So far, NbS in Europe have been funded mostly through farming subsidies associated with the Common Agricultural Policy. Many other funding sources can be tapped, and this has already been the case in a number of places. For example, proceeds from water and sanitation tariffs, flood levies, land stewardship schemes, local taxes, Corporate Social Responsibility or crowd-funding schemes have been mobilized but somewhat in a disjointed manner. In addition, more innovative sources such as carbon or biodiversity credits, could generate substantial funding for NbS to improve water quality but have so far remained limited. In the context of the European Green Deal and COVID-19 recovery plans, substantial public funding will be allocated to such interventions: it will be essential for such funding to be effective that it is provided to collective action mechanisms with long-term planning in place to ensure that investments are sustained over time.

Measure and Report on Outcomes

Despite substantial investments in the past, diffuse pollution from nutrients and sediment has remained high and its impacts will worsen with climate change. Establishing collective action mechanisms with clear outcome targets will create accountability and enable better tracking of the effectiveness of NbS (and associated measures) on environmental outcomes.

1. Introduction

This report examines how European cities can turn to nature-based solutions (NbS) to protect the water resources on which they depend and, in so doing, contribute to enhancing environmental quality in upstream watersheds. Specific objectives include:

- *To identify European cities that are particularly exposed to diffuse pollution due to changes in land use and poor land management practices;*
- *To assess the potential for a selected range of nature-based solutions to mitigate diffuse pollution challenges and generate benefits for people and nature, when deployed at scale;*
- *To help water sector stakeholders, policymakers, funders and financiers identify practical ways to prioritise and deploy investments in nature-based solutions for water security (NbS-WS) in Europe.*

1.1. OBJECTIVES AND SCOPE OF THIS REPORT

This report identifies where nature-based solutions can contribute to address threats to surface water quality that stem from diffuse pollution in Europe. Diffuse pollution is one of the main reasons for which European water bodies are failing to meet objectives relative to good ecological status as specified in the Water Framework Directive (WFD). Each year, outbreaks of toxic green algae affect rivers, lakes and coastal waters. Such outbreaks are the by-product of dangerous increases in nutrient levels. They are becoming more frequent as temperatures increase and rivers dry up due to climate change and over-abstraction, thereby directly affecting freshwater biodiversity. The other key reason for poor ecological status of European water bodies relates to hydromorphological changes (such as dams and weirs) that have modified the course of rivers and affected their natural flows.[1]

At present, 60 percent of surface water bodies across the European Union (EU) do not reach good ecological status. Surface water quality can be impacted by many pollutants, including nutrients, sediment, chemicals, heavy metals, pesticide residues or microplastics (Trémolet et al., 2019). Nutrients from agricultural runoff have been a key concern for many years in Europe, leading to the adoption of the Nitrates Directive in 1991. Whilst measures have been taken to tackle this issue, levels of nutrients have remained stubbornly high, partly because once they enter the waters, they take a very long time to be "filtered out" and percolate into groundwater resources.

Previous analysis and on-the-ground experience have indicated that nature-based solutions can play a clear role to address surface water quality challenges, particularly those associated with land-use changes, such as excessive nutrient and sediment loads (Abell et al., 2017). What is less known, however, is where and at what scale NbS need to be adopted in order to make a noticeable impact on water quality at catchment scale.

A key objective of this report is to help identify European cities that could benefit from such interventions in their upstream catchment. Although much water resource planning in Europe is done at river basin or catchment scales, drinking water supply is usually organised along municipal lines throughout the continent, with some groupings occasionally in place between neighbouring cities or larger surrounding regions. Cities and municipal service providers are well placed to mobilise financial resources to ensure resilient water supplies for their citizens and are key investors in the development of water infrastructure through water tariffs and related charges.

Integrating nature-based solutions into water investment programmes can be a critical way for cities and other water users to strengthen water security, adapt to climate change and boost resilience.

1 Work is under way to identify where in-stream barriers are in place and where restoring river connectivity could significantly contribute to improving freshwater biodiversity. (See, for example, the Atlas of in-stream barriers prepared by AMBER on https://amber.international/european-barrier-atlas/.) This initiative estimated that there may be well above 1 million barriers in European rivers.

BOX 1-1

Nature-based solutions for water security and resilience

The International Union for Conservation of Nature (IUCN) defines nature-based solutions (NbS) as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2019). Sadoff and Grey (2007) define water security as the "availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies". By extension, we define nature-based solutions for water security (NbS-WS) as the NbS that can protect, sustainably manage and restore freshwater ecosystems whilst boosting water security.

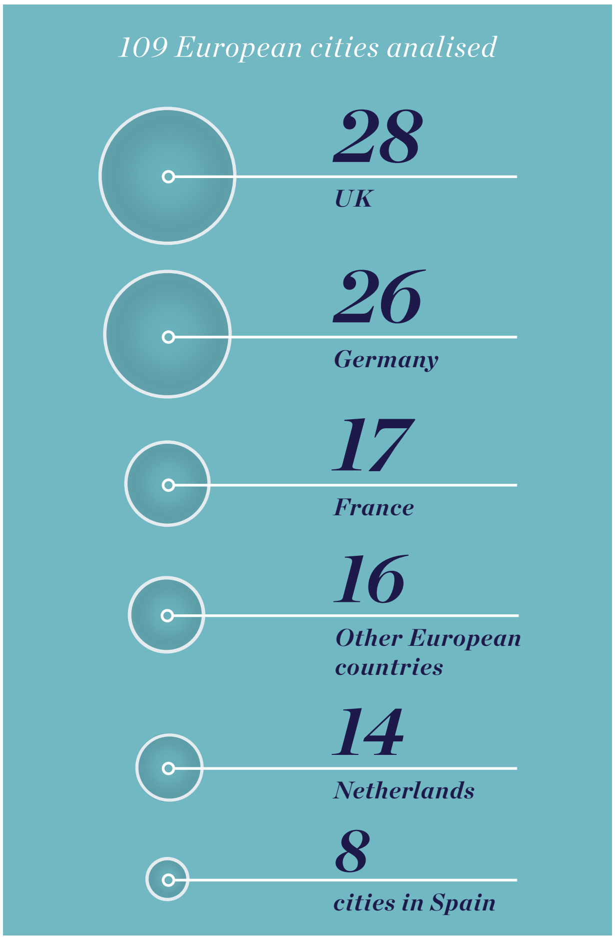
Water security can be threatened in multiple ways. Rising demands for water from multiple sectors (for human consumption, agriculture, industry and the environment) and a changing climate reduce available water quantities. Too much water in the wrong place can trigger catastrophic and destructive flood events. When the quality of surface water and groundwater is affected by pollution, ecosystems lose their ability to sustain life and water becomes unfit for human consumption, thereby increasing the cost of water treatment. Without water of an acceptable quantity and quality, the vast majority of human activities, including food and energy production, are affected—and so is the ability of ecosystems to function (Trémolet et al., 2019).

A companion report prepared by The Nature Conservancy in partnership with Ecologic Institute and ICLEI (Trémolet et al., 2019) identified the roles that NbS can play to tackle Europe's water security challenges as part of hybrid (green-grey) water investment strategies. This assessment identified key water security challenges in Europe, extracted learning from on-the-ground experiences with investments in NbS-WS, highlighted enabling conditions and barriers to scale implementation and formulated recommendations to scale up these solutions to address the full range of water security challenges in Europe.

One key recommendation in this earlier report was to identify areas where NbS could achieve more significant impacts. At present, diverse funders examine potential investment project opportunities in nature in a fragmented manner, with little coordination. To significantly scale up investment and get a mix of private and public funding and financing calls for estimating investment needs, identifying where certain types of NbS-WS can work at catchment scale and building pipelines of investable NbS-WS projects. The companion report stated: "Identifying where NbS can have a significant impact across Europe or at country or regional level would make it easier to prioritise resources and make sure the right mix of funding and financing flows where it is most needed".

The purpose of the present report is to identify priority areas for deploying NbS that can have a significant impact on reducing surface water quality challenges stemming from diffuse nutrient and sediment pollution.. This analysis allows going from an overall identification of "diffuse pollution hotspots" to a more nuanced understanding of where NbS could play a significant role to address those issues and how.

1.2. METHODOLOGY AND KEY FINDINGS



Based on an approach previously applied by TNC in other geographies, we identified 109 European cities that are significantly dependent on surface water for their water supply. These cities are home to a total of 78.5 million people, equivalent to 15 per cent of the population of the European Union and the United Kingdom. Of these 109 cities, 28 are in the UK, 26 in Germany, 17 in France, 14 in the Netherlands, and 8 in Spain, with other cities from a range of other European countries. A particular focus was placed on these countries as a more in-depth review of their water sector policy frameworks conducted previously had identified the existence of conducive policy frameworks, political appetite or previous experience with the adoption of NbS at scale (Trémolet et al., 2019). [2]

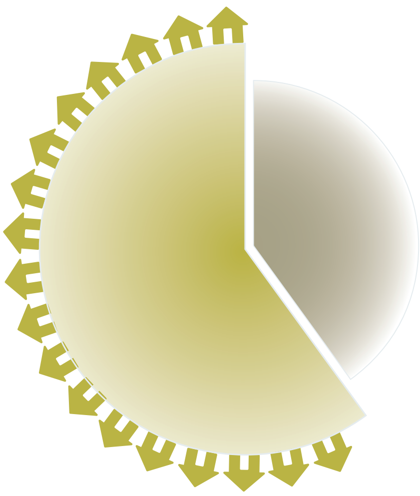
For the 109 cities, we conducted two sets of analyses: an assessment of threats to surface water sources and an evaluation of the potential for selected NbS to mitigate these threats. The methodology is presented in more detail in Annex B.

2 Although the United Kingdom has formally left the European Union, UK cities have been included in the analysis as there is a strong emphasis in the British government's post-Brexit plan to prioritise nature-based solutions to deliver commitments under the 25-Year Environment Plan.

- **To assess threats,** we used existing data from European sources on landscape changes and key pollutants that result from these changes. We summarised information on current land cover conditions and described the potential implications of these changes on urban water supplies—focusing in particular on water quality impacts. We further assessed—using established, continental scale models for Europe—two classes of pollutants that can be heavily influenced by land cover changes: elevated sediment from soil loss and nutrient pollution from multiple sources. These assessments provide a broad picture of diffuse threats to the quality of urban water supplies for which landscape management can play a vital role.
- **To evaluate NbS potential,** we leveraged models previously developed by TNC for a global analysis of source water protection (McDonald & Shemie, 2014). Focusing on a subset of NbS solutions (cover crops, riparian buffers, forest protection and forest restoration), we identified where these solutions could make a substantial difference to mitigate diffuse pollution in a cost-effective way.

Out of this selection of 109 cities, we found that 63 cities demonstrate particular promise for the adoption of nature-based solutions to tackle issues of diffuse pollution in upstream catchments. Together, these cities are home to 42 million people. Key results are presented in Annex C, which includes a complete list of analysed cities and their NbS potential.

We present this data as a challenge to the primacy of traditional grey infrastructure approaches and as an invitation to further explore their potential in collaboration with local stakeholders. It provides a good first approximation of where efforts to deploy NbS at scale to protect water sources could deliver greatest impact. It will be of greatest value to decision-makers that are looking to prioritise engagements at a European or national scale. These results cannot be extrapolated at continental scale, however, due to the lack of representativeness of the sample included in the analysis.



these 63 cities are home to
42 million people

There are inherent limitations associated with conducting an analysis at the European scale given that these solutions are specific to local contexts. All data presented for these cities should therefore be treated as exploratory. Conducting a similar type of analysis with national level datasets and additional resources could help identify priority areas for investment and help channel funding with a much greater level of detail. Similar methodologies could also be developed in future to identify priority areas to invest in other NbS to address other water security challenges, such as those associated with groundwater resources, flooding or water scarcity.

1.3. REPORT STRUCTURE

The rest of this report comprises five sections with four annexes.

SECTION 2

Section 2 places this report in the context of the European Green Deal. Investing in sustainable infrastructure will be a key plank of post COVID-19 recovery plans for any country that seeks to "build back better". Future investment needs for the water sector are substantial. The choices made today will condition our ability to achieve greater water security and resilience tomorrow, as well as to reverse biodiversity loss and establish the basis for more sustainable societies. Cities are and will continue to be at the heart of sustainable societies, hence the report's focus on identifying what can be done to strengthen their water resilience.

SECTION 3

Section 3 stresses the importance of surface water for urban water security and resilience. Cities often depend on surrounding rural areas for water supplies: when their water resources suffer, they suffer. This section outlines how cities' resilience requires them to protect the water sources on which they depend, and therefore to invest as needed in rural areas far beyond their boundaries. This section also highlights the severity of the nutrient and sediment threat to European water sources and how these challenges are likely to increase with land use changes and intensification of agriculture. It is particularly relevant for non-water sector specialists interested in better understanding why there is an urgent need for such investments.

SECTION 4

Section 4 outlines where the 109 selected cities for this analysis source their water and presents the extent to which they are affected by nutrient and sediment pollution, particularly coming from diffuse agricultural sources, based on a Europe-wide level assessment.

SECTION 5

Section 5 provides an overview of which NbS are relevant to tackle the specific challenges related to source water protection covered in this report. It sets out the mechanism of their impacts on pollution reduction and present the modelling results on the potential for NbS to reduce sediment and nutrient pollution in drinking water sources obtained from surface water for the 109 selected cities. It then compares the likely costs of these interventions to provide a rough assessment of whether investing in those solutions would make economic sense, particularly for drinking water suppliers.

SECTION 6

Section 6 presents key findings and formulates recommendations to accelerate investment in NbS for source water protection in Europe.

In addition:

- **Annex A** contains two case studies (Manchester in the United Kingdom and Madrid in Spain), with a brief description of their surface water challenges and an analysis of the role that NbS are already playing and could play to address these challenges at scale;
- **Annex B** sets out the methodology used for the analysis underlining this report;
- **Annex C** presents an overview of which cities have the potential to significantly improve diffuse pollution linked to sediment and nutrients via implementation of NbS at scale; and
- **Annex D** contains a list of references.

2. Investing in nature to protect water sources and "build back better"

Even though access to water and sanitation is very high for European citizens, investment needs for the water sector in Europe are substantial. According to the Organisation of Economic Co-operation and Development (OECD), an average of EUR 100 billion was invested annually across the 28 EU member states between 2011 and 2015. To comply with EU legislation and to make their water supply systems more efficient and resilient, all Member States (MS) will need to invest an additional EUR 289 billion in water services by 2030.

The policy and legal framework in Europe for water is well developed and conducive to investing in nature for water security. An average of EUR 5.5 billion per year was committed to restoring and conserving watersheds in Europe over the 2014-2020 period. An estimated 99 per cent of funding for these investments came from public sources via multiple channels, including from the European Union and from national, regional or local governments. In addition, some water service providers and cities have engaged with upstream parties in their source water catchments to support change in agriculture and forestry practices or building artificial wetlands.

A number of policy initiatives in the region are under way that will further encourage the adoption of NbS as part of water sector investment plans, driven by the implementation of ambitious European strategies related to biodiversity, climate adaptation and the transformation of food systems as part of the European Green Deal.

The COVID-19 crisis further strengthens this impetus, as Member States often see investing in nature-based solutions as a critical part of green recovery packages as part of their post-COVID-19 recovery plans and "building back better". The choices made today will condition our ability to achieve greater water security and resilience tomorrow, as well as to reverse biodiversity loss and establish the basis for more sustainable societies. This should entail investment to maintain the integrity of the freshwater ecosystems on which cities and their citizens depend. To deliver on their promises, the right type of nature-based solutions will need to be delivered at scale in the right place.

2.1. EUROPE'S WATER SECURITY IS FRAGILE

Countries in the European Union enjoy very good access to high quality drinking water supplies, thanks to centuries of investments in water infrastructure and sound policy frameworks. In most European countries, although progress has been steady, achieving universal access to water and sanitation services took centuries and was achieved only in the last 50 years. Progress in terms of wastewater treatment was significantly accelerated by the adoption of European directives, such as the Urban Wastewater Treatment Directive and the Water Framework Directive, which have found their way into Member States' own legal frameworks. Other key directives include the Nitrates Directive—aimed at reducing water pollution caused or induced by nitrates from agricultural sources—to protect human health and living resources and aquatic ecosystems, and the Drinking Water Directive, concerned with the quality of water intended for human consumption. The companion report, Investing in Nature for European Water Security, includes a comprehensive table of key directives relative to European water policy and examples of how they support nature-based solutions for water security (Trémolet et al., 2019).

Despite these policies, Europe's apparent water security is fragile. Many challenges to water security, for both people and the critical ecosystems on which they depend, are increasing. Water quality issues persist in the European Union, particularly with respect to high nitrates levels linked to agricultural runoff from fertilisers and pesticides. According to the European Environment Agency (EEA), as of 2015, only around 40 percent of EU surface waters were in good ecological status (or good ecological potential), and 38 percent were in good chemical status. Excessive nitrate concentrations affect over 18 percent of the area of groundwater bodies in Europe (EEA, 2018b). Soil erosion is also a relevant, although less well understood, issue in the region. About 11 percent of the EU territory is estimated to be affected by a moderate to high level of soil erosion (EEA, 2018b). Our analysis shows that this problem is particularly acute in catchment areas of source waters on which many European cities critically depend.

As of 2015

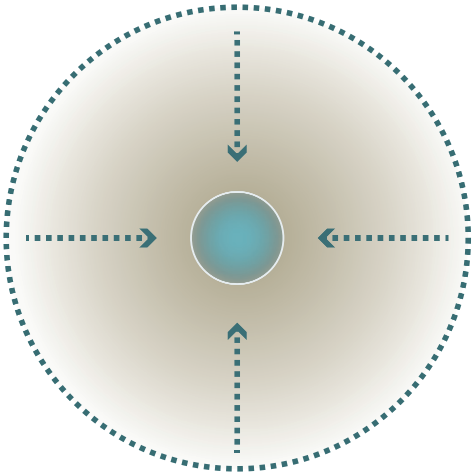
40%
of EU surface waters were in good ecological status

Pollution is reducing the quality of surface water and groundwater across Europe, affecting ecosystems' ability to function and sustain life. Available water quantities are threatened by pressures associated with a growing population, such as urbanisation and rising demand for food supplies, coupled to the effects of a changing climate.

Europe, as the rest of the world, is affected by climate change with more extreme drought and flooding events. For example, the spring and summer of 2018 were marked by a unique combination of drought conditions in central and northern Europe and unusually wet conditions in southern Europe. For example, Germany had a six-month drought in spring and summer, limiting use of the Rhine as a transport channel, while the Iberian Peninsula had a particularly wet spring. Both extremes affected crop yields, and the droughts reduced main crop yields up to 50 percent (EC, 2019a; JRC EDO, 2018).

Heat waves will become more frequent and longer in duration, with longer dry spells increasing the risk of drought, particularly in the Mediterranean region (Scocca, 2019; IPCC, 2018). In recent years, lack of water availability has been registered in various communities in Germany. For example, the summer of 2019 registered alarmingly low levels of drinking water reserves in parts of North Rhine-Westphalia and Lower Saxony (DW, 2019).

Even though water resilience is usually thought about in terms of the capacity to withstand shocks and stresses associated with water scarcity and floods, maintaining water quality and freshwater ecosystem health is an integral part of boosting climate resilience. In the context of the preparation of a new EU Adaptation Strategy (due to be published in 2021), the German Presidency of the European Council stressed the need to acknowledge "the fundamental role of water as the most affected medium by climate change, with far-reaching impacts for various water-dependent sectors" (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2020). They highlighted that water quality aspects related to droughts and floods are too often overlooked in climate adaptation policies even though such aspects are closely interlinked. For example, the impacts of poor water quality can be more acutely felt in times of water scarcity and droughts, when changes in the flow regime can dilute water bodies' dilution capacity. In addition, heavy rains, which are becoming more frequent in some regions with climate change, increase soil erosion, which in turn leads to increased nutrient and pollutant runoff into surface waters.



Global freshwater biodiversity has declined a massive

84%

in the last 50 years

While there is considerable concern in Europe for the health of aquatic ecosystems, as reflected in policies and regulation, this has not been sufficient to reverse rapid declines in freshwater biodiversity except in some limited cases. Global freshwater biodiversity has declined a massive 84 percent in the last 50 years—this is the equivalent of a 4 percent decline every year between 1970 and 2014 (WWF, 2020). Freshwater biodiversity has declined at twice the rate of other forms of life, such as marine and terrestrial life; the latter two also are affected by the way we manage our rivers, lakes, wetlands and estuaries. Freshwater biodiversity is most threatened in Europe and Central Asia (Vörösmarty et al., 2010).

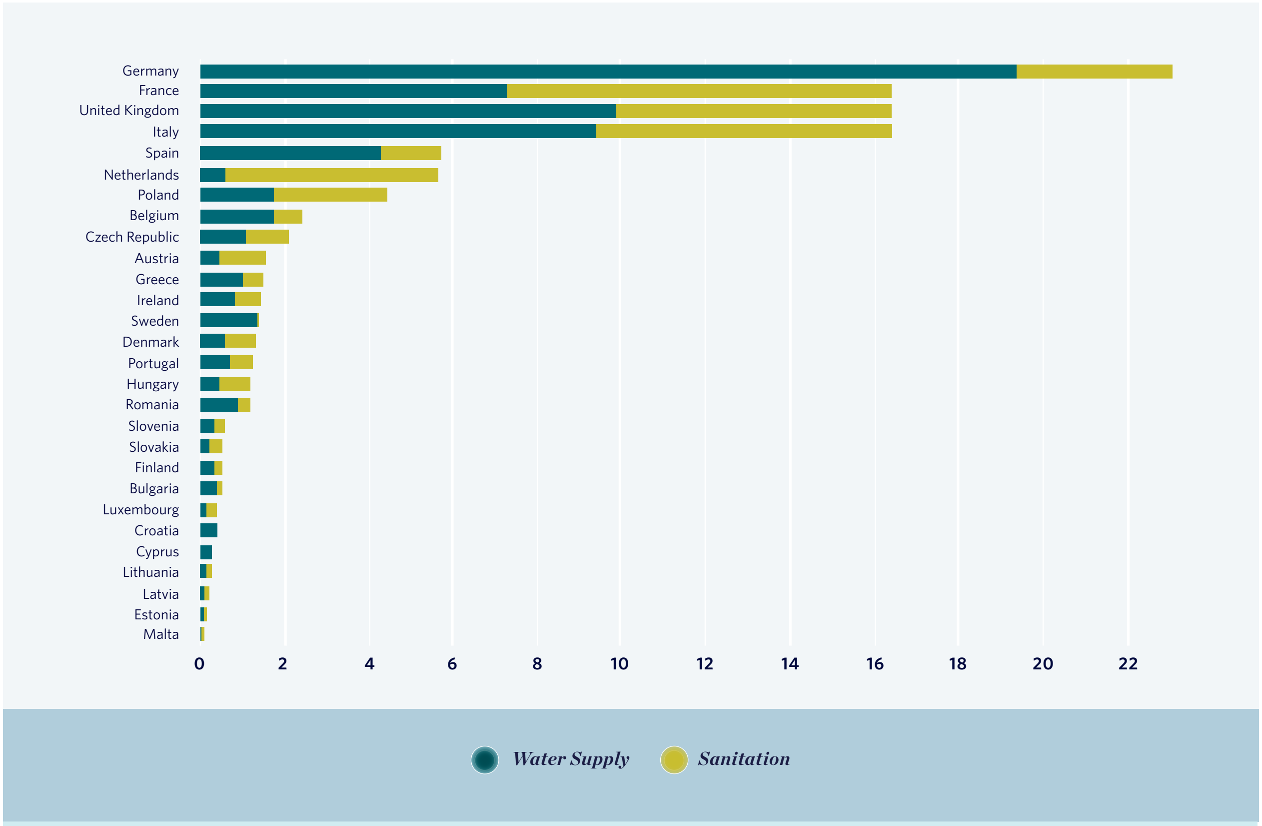
2.2. INFRASTRUCTURE SPENDING NEEDS FOR RESILIENT WATER SERVICES ARE SIGNIFICANT

Existing water supply systems in Europe depend heavily on costly grey infrastructure. Most cities rely primarily on engineered solutions to secure their drinking water supplies. This usually entails building filtration plants, pumping deeper wells, desalinating seawater, constructing dams or transferring water over long distances.

According to OECD estimates, an average of EUR 100 billion was invested annually across the 28 EU member states between 2011 and 2015, with large variations among countries as shown on Figure 2-1. The largest annual expenditures were in some of the oldest and most developed EU countries, namely Germany, France, United Kingdom, Italy, Spain and the Netherlands; all of these countries spent more on water supply than sanitation, with the notable exception of France and the Netherlands. This demonstrates the significant expense associated with renewing existing infrastructure due to ageing networks and associated operations and maintenance costs.

FIGURE 2-1

Estimated annual expenditures for water supply and sanitation per member state (billion EUR, 2011-15 annual average)



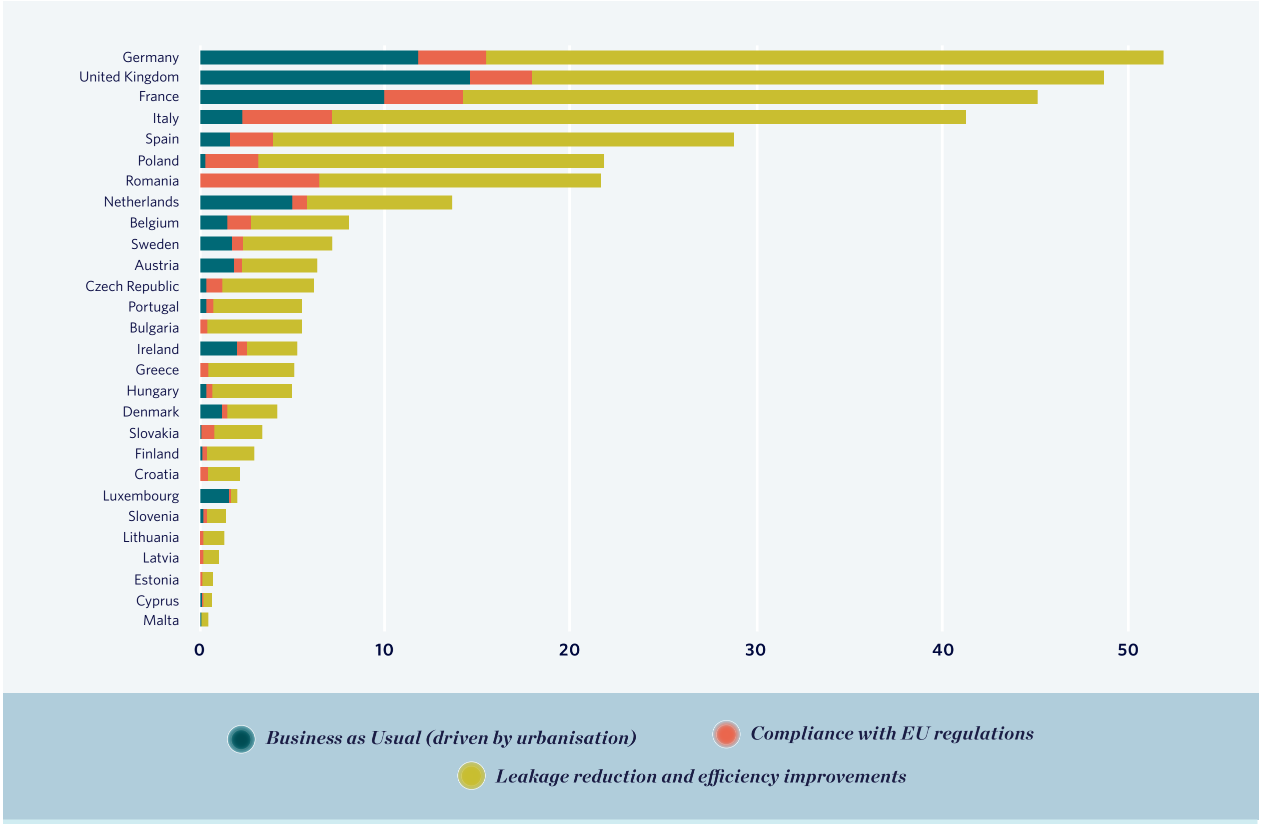
Source: OECD (2020) – based on Eurostat database

Going forward, expenditures for water supply and sanitation will need to increase significantly to enable countries to comply with EU legislation, including the Urban Wastewater Treatment Directive or the Drinking Water Directive, and to make their water supply systems more efficient and more resilient. According to OECD projections, all countries (except Germany) will need to increase annual expenditures for water supply and sanitation by more than 25 percent by 2030: Romania and Bulgaria will need to more than double their current expenditures, whereas France, Germany and the Netherlands will need to increase investments by less than a third.

Forecast additional expenditures total EUR 289 billion for all Member States between 2020 and 2030 as shown on Figure 2-2, with sanitation accounting for the largest share of this investment requirement (OECD, 2020).

FIGURE 2-2

Forecast additional expenditures required by 2030 for water supply and sanitation (billion EUR)



Source: OECD (2020) – based on European Commission and Eurostat data

2.3. NATURE-BASED SOLUTIONS COULD BOOST RESILIENCE

Deploying "grey infrastructure", such as investing in treatment plants, pipes and conveyance schemes, is often the solution most trusted by water service providers and their regulators to meet demand and comply with environmental regulations. For example, increasingly complex water treatment is applied to remove chemicals, excess sediment and nutrients, bacteria and other pollutants from source water in order to produce drinking water. However, even the best systems cannot keep up with all pollutants, and their performance in the long run does not always make them the best ones. Emerging pollutants, for example, are a growing threat. They include micro-plastics, antibiotics and endocrine disruptors, which create dangerous cocktail effects that are difficult to predict and poorly understood (Trémolet et al., 2019).

Engineered solutions are especially vulnerable to variability in the quantity and quality of source water due to land degradation, competition for water resources and climate change (Abell et al., 2017; McDonald et al., 2014). They also tend to be energy-hungry and are better suited to address specific, end-of-pipe pollution problems rather than diffuse pollution.

Building resilient infrastructure in the future will entail investing in maintaining the integrity of the freshwater ecosystems on which cities depend. Urban systems cannot be considered in isolation from the hydrological context in which they are inscribed, including the upstream catchments that provide water resources to the cities. Conserving or restoring natural landscapes around water sources is necessary to boost resilience and can create great value to cities. This can be done through nature-based solutions, while simultaneously boosting urban water security.

Nature-based solutions can be used in conjunction with grey infrastructure to deliver significant results and help lower overall total costs, with lower associated investment and maintenance costs. Many types of NbS can be deployed to address key water challenges and enhance water security, independently or combined with grey infrastructure. The role of NbS in addressing water security challenges varies depending on the type of the challenge and the kind of NbS used. Nature-based solutions can address four main types of water security challenges: surface water quality, groundwater quality, floods and water scarcity.[3] A more comprehensive assessment of whether NbS can be effective at addressing these different water security challenges in Europe is presented in Trémolet et al., 2019.

Table 2-1 presents typical NbS-WS that can contribute to alleviate surface water quality challenges. This table also identifies which NbS have been modelled in the analysis underlining this report and which are presented in more detail in Section 5.

TABLE 2-1
NbS that can help address surface water quality challenges

Intervention category	*NbS: description and associated interventions*	*Included in analysis?*
PROTECTION	*Interventions that prevent (or greatly limit) overexploitation of natural resources to achieve the long-term conservation of nature with associated ecosystem services and cultural values.*	
• **Targeted habitat protection**	Broad term for all conservation activities to protect target ecosystems. Includes preventative measures (e.g. easements, land rentals, funding of park guards) to reduce future adverse land use changes.	Forest protection
RESTORATION	*Active or passive interventions that involve returning degraded, damaged or destroyed ecosystems to pre-disturbance state. Considered synonymous with reclamation, reforestation, rehabilitation, revegetation and reconstruction.*	
• **Revegetation / reforestation**	Restoration of native habitat via either active planting (e.g. seedlings) or passive measures (creating suitable enabling environment for regeneration).	Reforestation
• **Riparian restoration**	Restoring natural habitat that act as interface between land and water along the banks of a river, stream or lake.	Riparian buffers
• **Wetlands restoration**	Re-establishment of the hydrology, plants and soils of former or degraded wetlands.	
• **Floodplain restoration**	Removing barriers along the edges of a river to re-establish its natural course and re-establish storage capacity.	

3 The European Union typically refers to those measures as Natural Water Retention Measures (NWRM), defined as "multi-functional measures that aim to protect water resources and address water-related challenges by restoring or maintaining ecosystems as well as natural features and characteristics of water bodies using natural means and processes". The NWRM platform provides a comprehensive database presenting these solutions, with technical specifications and examples of where they have been applied throughout the EU.

Intervention category	*NbS: description and associated interventions*	*Included in analysis?*
MANAGEMENT	*Natural resource management approaches other than restoration or protection. Examples include ecosystem-based fire management and actions characterized as forestry or forest management.*	
• **Agricultural & ranching BMPs**	Land management changes that reduce impacts of agricultural & ranching activities by taking steps to incorporate aspects of previously naturally occurring ecosystems. Related measures include agroforestry, edge of field buffer and silvopasture.	
• **Forestry BMPs**	Measures to protect water quality while undertaking silviculture practices; includes forest thinning, forestry under sustainable management plans.	
• **Fire Management**	Measures to protect water quality by employing nature-based solutions to reduce the frequency and intensity of fires. Includes prescribed burning, tree thinning.	
CREATED HABITATS	*Interventions involving the establishment, protection or management of artificial ecosystems. This includes non-natural tree stands created or managed to address climate impacts, artificial grasslands, created wetlands (not restored), etc. This also includes most agricultural, fisheries and livestock farming approaches, including pastoralism.*	
• **Agricultural BMPs**	Land management changes that reduce impacts of agricultural activities but do not attempt to incorporate aspects of previously naturally occurring ecosystems. Related measures include cover crops, contour farming, hedgerows, conservation tillage, agroecology and water-smart agriculture.	Cover crops
• **Ranching BMPs**	Practices that reduce impacts associated with ranching or grazing activities but do not attempt to incorporate aspects of previously naturally occurring ecosystems. Related measures include grazing management and land treatment, e.g. range seeding, brush management.	
• **Afforestation**	The transformation of areas where organized trees did not previously exist in the forest.	
• **Artificial wetlands**	Treatment systems that use natural processes involving wetland vegetation, soils and their associated microbial assemblages.	
• **Retention basins**	Storm water management systems that collect surface runoff by natural processes such as sedimentation, decomposition, solar disinfection and soil filtration.	
• **Sustainable Urban Drainage Systems (SuDS)**	Urban water management practices that are designed to align modern drainage systems with natural water processes. Examples include bioswales, green roofs, permeable pavements, sediment traps and rainwater harvesting.	

Source: Authors, based on multiple sources

Investing in those solutions can also help reconnect water users with their upstream catchments. It can allow the development of joint plans with all stakeholders in the catchment to boost resilience, support biodiversity, adapt to climate change and contribute to climate change mitigation by investing in less energy-intensive solutions, as shown on Figure 2-3. It is clear that NbS can play a key role in improving water security, protecting ecosystems and reversing biodiversity loss.

FIGURE 2-3

Nature-based solutions for water security generate multiple co-benefits

Water security

1. Maintain or improve water quality
2. Maintain or improve river flows and aquifer recharge
3. Reduce impact of flooding

Climate change adaptation

1. Reduace soil erosion
2. Soil quality improvement
3. Reduce frequency and intensity of forest fires, flooding and droughts

Biodiversity conservation

1. Landscape diversity
2. Protect and expand natural habitats
3. Limit expansion of invasive species

Climate change mitigation

1. Reduce greenhouse gases emissions
2. Carbon sequestration

Human health and well-being

1. Improve food security
2. Reduce exposure to polluting substances
3. Amenity value and recreational benefits

Jobs and social cohesion

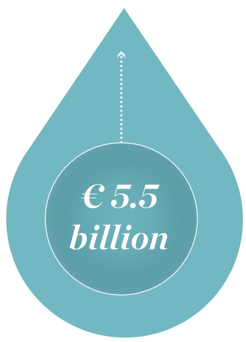
1. Create jobs particularly in rural areas
2. Promote urban-rural solidarity

Source: Trémolet et al., 2019

2.4. THE TIME HAS COME TO INVEST IN RESILIENT WATER SUPPLIES

The policy and legal framework in Europe for water is well developed and conducive to investing in nature-based solutions for water security. IIn 2000, the EU adopted the Water Framework Directive, a visionary piece of legislation with the purpose of protecting and enhancing the status of all water bodies in Europe, including groundwater and surface waters. The WFD built on several decades of water policy and brought together previously adopted directives relative to water and wastewater into a coherent framework. It established the legal framework that committed EU Member States to achieve good ecological status for all groundwater and surface waters (referred to as "water bodies"). This groundbreaking environmental legislation provided the basis for many advances, particularly with respect to treatment of point-source diffusion and the attainment of drinking water standards. It also established River Basin Districts (RBDs) throughout the European Union with the responsibility to prepare River Basin Management Plans (RBMPs) in consultation with all actors in the River Basin District. These RBMPs were first prepared by 2009 and subsequently updated in 2015 and led to the identification and hierarchisation of potential measures to reach "good status".

According to Trémolet et al. (2019), an average of EUR 5.5 billion per year was committed to restoring and conserving watersheds in Europe over the 2014-2020 period. An estimated 99 percent of funding came from public sources via multiple channels, including from the European Union—through subsidies under the Common Agricultural Policy (CAP), regional structural funds or dedicated grant funds—and from national, regional or local governments. In addition, some water service providers and cities have



per year was committed to restoring and conserving watersheds in Europe over the 2014-2020

engaged with upstream parties in their source water catchments to support change in agriculture and forestry practices or building artificial wetlands. Trémolet et al. (2019) documents 19 cases where these took place in Europe. However, many of these projects remain relatively small and scattered.

A recent fitness check concluded that the WFD is overall fit for purpose (with some room for enhanced effectiveness) and confirmed obligations to reach good ecological status by 2027 (European Commission, 2019c). This means that EU Member States need to deploy maximum efforts and accelerate investments to meet WFD targets in the next six years (the period of implementation of the next River Basin Management Plans), as opportunities for exemption will be reduced. This would enable them to restore freshwater ecosystems and avoid fines from the European Union.

A number of policy initiatives under way in Europe should further encourage the adoption of nature-based solutions as part of water investment plans. These include the EU Biodiversity Strategy 2030 and the Farm to Fork Strategy (adopted in May 2020) as well as the upcoming revised EU Adaptation Strategy and the Zero Pollution Action Plan for air, soil and water (both expected in 2021). All these instruments are part of the European Green Deal, unveiled by the European Commission in December 2019 to make countries in the European Union climate neutral by 2050 and on the path of sustainable development, including reversing biodiversity and habitat decline.[4]

- The **EU Biodiversity Strategy** tackles the key drivers of biodiversity loss, such as unsustainable use of land and sea, overexploitation of natural resources, pollution and invasive alien species. It will lead to restoring at least 25,000 kilometres of rivers to free-flowing status throughout the EU, as part of a commitment to protect 30 percent of the EU's land and oceans by 2030. The Biodiversity strategy includes plans for preparing a new Forest Strategy by early 2021. This will set out objectives to protect all ancient woodlands in Europe and to plant at least 3 billion additional trees in the EU by 2030, in full respect of ecological principles.
- The **Farm to Fork strategy** sets concrete targets to transform the EU's food system. Among other goals, it includes reducing the use and risk of pesticides by 50 percent and the use of fertilisers by at least 20 percent, as well as reaching 25 percent of agricultural land under organic farming (EC, 2020).
- The ongoing process to update the **EU Adaptation Strategy** (first adopted in 2013) provides an important opportunity to develop solutions in the context of climate mitigation; biodiversity; air, water and soil quality; and human health and well-being.
- The **Zero Pollution Action Plan for air, soil and water** will aim to strengthen implementation and enforcement on pollution and will seek improvements to the governance of pollution policies.

In addition, the European Commission is planning to dedicate at least EUR 1 billion in support of research for Green Deal priorities through its Horizon 2020 programme.

The ongoing COVID-19 pandemic is having a significant impact on water resources, services and delivery across Europe and around the world. As highlighted in a recent statement by Water Europe,[5] the COVID-19 crisis has been a wake-up call for the European Union and its Member States about the urgent need to better prepare to respond to present and future cross-boundary and cross-sectoral crises (Water Europe, 2019).

4 For more detail on the European Green Deal, consult the European Commission's website: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

5 Water Europe is the voice and promoter of water-related innovation and R&D in Europe. A membership-based, multi-stakeholder organisation, it represents over 200 members from academia, technology providers, water users, water service providers, civil society and public authorities.

The COVID-19 recovery plans announced by the European Union as well as individual Member States come with substantial spending packages focused on infrastructure and "building back better". In May 2020, the European Commission put forward its proposal for a major recovery plan, which includes a new recovery instrument, Next Generation EU, embedded within a revised long-term EU budget. Next Generation EU consists of EUR 750 billion as well as targeted reinforcements to the long-term EU budget for 2021-2027. It will bring the total EU budget to EUR 1.85 trillion. The recovery plan is fully aligned with the European Green Deal and places particular emphasis on climate protection and further sustainability goals in the areas of biodiversity, agriculture and the circular economy. Member States can submit their National Recovery and Resilience Plans at the latest by April 2021. When launching the plan, European Commission President Ursula von der Leyen emphatically stressed the level of green ambition contained in that plan.

> *"The recovery plan turns the immense challenge we face into an opportunity, not only by supporting the recovery but also by investing in our future: the European Green Deal and digitalisation will boost jobs and growth, the resilience of our societies and the health of our environment. This is Europe's moment. Our willingness to act must live up to the challenges we are all facing. With Next Generation EU we are providing an ambitious answer."*

The choices made today for investing recovery funds will have lasting impacts into the future. Investing in nature-based solutions is often presented as a key plank of many green economic recovery packages throughout the EU. A sizeable portion of these investment packages should invest in boosting the resilience of water supplies and their associated freshwater ecosystems. This would deliver significant benefits for nature and generate savings for future generations as well as provide jobs in the sector. Investing in green infrastructure can in fact be an integral part of closing the "biodiversity financing gap", highlighted in a recent joint report by TNC, the Paulson Institute and Cornell University (Deutz et al., 2020).

However, whether the economic recovery plans initiated by Member States live up to their ambitions of "building back better" remains to be seen, as pointed out by an OECD article.[6] This will require a step-change in the pace of investment in nature-based solutions, breaking away from the current approach that implements these solutions at a relatively small scale by multiple parties, in an uncoordinated manner. To be a key plank of a "green recovery", the right type of nature-based solutions needs to be deployed at scale in the right place to deliver tangible environmental outcomes. It is therefore important to identify which solutions should be prioritised and where they can make a sizeable contribution. With this in mind, this report offers a method for prioritising cities that could most benefit from nature-based solutions to address surface water quality challenges associated with nutrients and sediment.

3. Surface waters: a critical resource for European cities

In Europe, around 75 percent of all water abstracted annually, and 40 percent of all drinking water, comes from surface waters, such as rivers, lakes and reservoirs—with considerable variation from one country to another. Europe is home to 115,000 rivers (with a total length of approximately 1.2 million kilometres) and 26,000 lakes.

Watersheds perform a number of vital functions to ensure the provision of sufficient, clean and affordable water for cities. Cities depend on their surrounding rural areas for water supplies: to be resilient, they need to protect the water sources on which they depend, which often means investing in rural areas far beyond their boundaries. Watersheds as natural infrastructure are as critical to the future vitality of cities as are the engineered systems of dams and diversions that were built over the years.

Land use within catchment areas has a major influence on determining whether watersheds are healthy and can deliver environmental services—for example, filtering and cleaning water. Where these ecosystem functions have been degraded, water providers are likely to incur additional costs to provide clean water to their customers.

Nutrient pollution and soil loss have been recognised as challenges for decades across Europe and have been a key driver of freshwater biodiversity loss. With climate change, these challenges are likely to worsen, due to higher temperatures, lower river flows and more frequent and more violent flooding events. Diffuse pollution from agriculture remains a key concern, leading to eutrophication and increased frequency of toxic algal blooms and so-called "dead zones". Sediment is one of the least well-defined pressures in the context of EU legislation, even though an estimated 11 percent of the EU territory is affected by moderate or high levels of soil erosion.

3.1. FROM WHERE DO EUROPEAN CITIES SOURCE THEIR WATER?

Cities rely upon a variety of freshwater resources and frequently need to reach out beyond their administrative boundaries to secure water supplies. Source watersheds provide the natural infrastructure that collects, filters and transports water resources over large land areas. As a point of reference, although the 100 largest cities in the world occupy less than 1 percent of our planet's land area, their source watersheds—the rivers, forests and other ecosystems that supply their water—cover over 12 percent of the planet's total land area (McDonald & Shemie, 2014). The actual footprint of cities and the geographical areas on which they depend to secure their water supplies are therefore much larger than they first appear. This gives cities an incentive and a duty to engage outside of their administrative boundaries to act as good stewards of essential water resources for all.

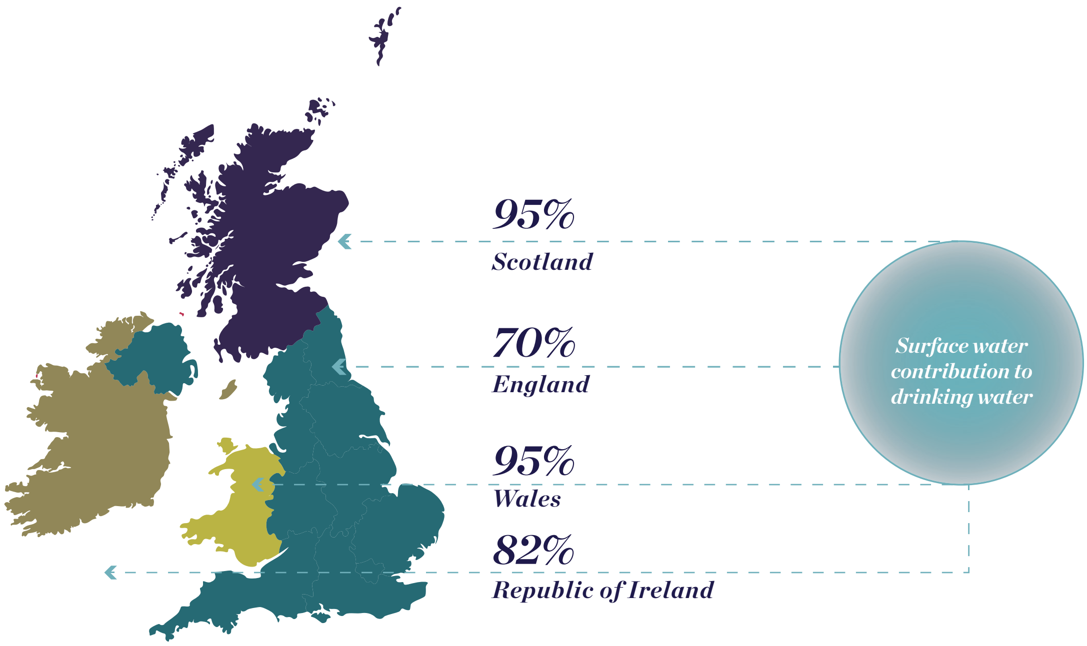
In Europe, around 75 percent of all water abstracted annually, and 40 percent of all drinking water, comes from surface waters — rivers, lakes and reservoirs — with some considerable variation from one country to another as shown on Figure 3.1. The remaining 25 percent of all water abstracted annually comes from groundwater sources (EEA, 2010). Groundwater is particularly important for drinking water supply; it is the source of 50 percent of drinking water in EU Member States, with the rest coming from desalination, bank filtration or other forms (EC, 2016). Although there are some localised quality issues with groundwater sources in Europe, overall their ecological quality tends to be better than that of surface water sources.

FIGURE 3-1

Sources for drinking water in Member States (data from 2011 to 2013)

Source: Trémolet et al., 2019 based on European Commission (2016)

The breakdown between surface water and groundwater use varies substantially among and within European countries. Whereas some countries (such as Austria and Denmark) completely rely on groundwater for drinking water, others (Greece, Ireland and the United Kingdom) source most of their drinking water from surface water bodies. There are also substantial variations within countries. For example, in the United Kingdom, surface water contributes 70 percent of England's drinking water supply and accounts for 95 percent of drinking water supply in Wales and in Scotland, as both nations have abundant surface water resources.



Surface water use is prevalent in Spain. It meets about 80 percent of the total water demand and is used to irrigate over two-thirds of the total irrigated land. However, these percentages vary widely from region to region so that, for instance, in the country's Mediterranean catchment basins, surface water represents less than 25 percent of all water resources used. Groundwater resources are more significantly relied upon in times of drought, when surface water resources are less available (López Geta 2006).

In France, 33,500 catchment areas are used for drinking water. Two-thirds of catchments draw water from groundwater sources and one-third from surface water (eaufrance, 2018). Similarly, in the Netherlands about 40 percent of drinking water comes from surface water sources. By contrast, groundwater is the main source for drinking water in Germany (70 percent). Only 17 percent of Germany's drinking water comes from surface water, which has been filtrated through the ground (a process known as sand filtration), and the remaining 13 percent derives from lakes, rivers and dams. There are, however, strong regional variations within Germany. For instance, in the region of North Rhine-Westphalia, only about half of the drinking water comes from groundwater, while in Lower Saxony it is around 85 percent (Umwelt Bundesamt, 2018).

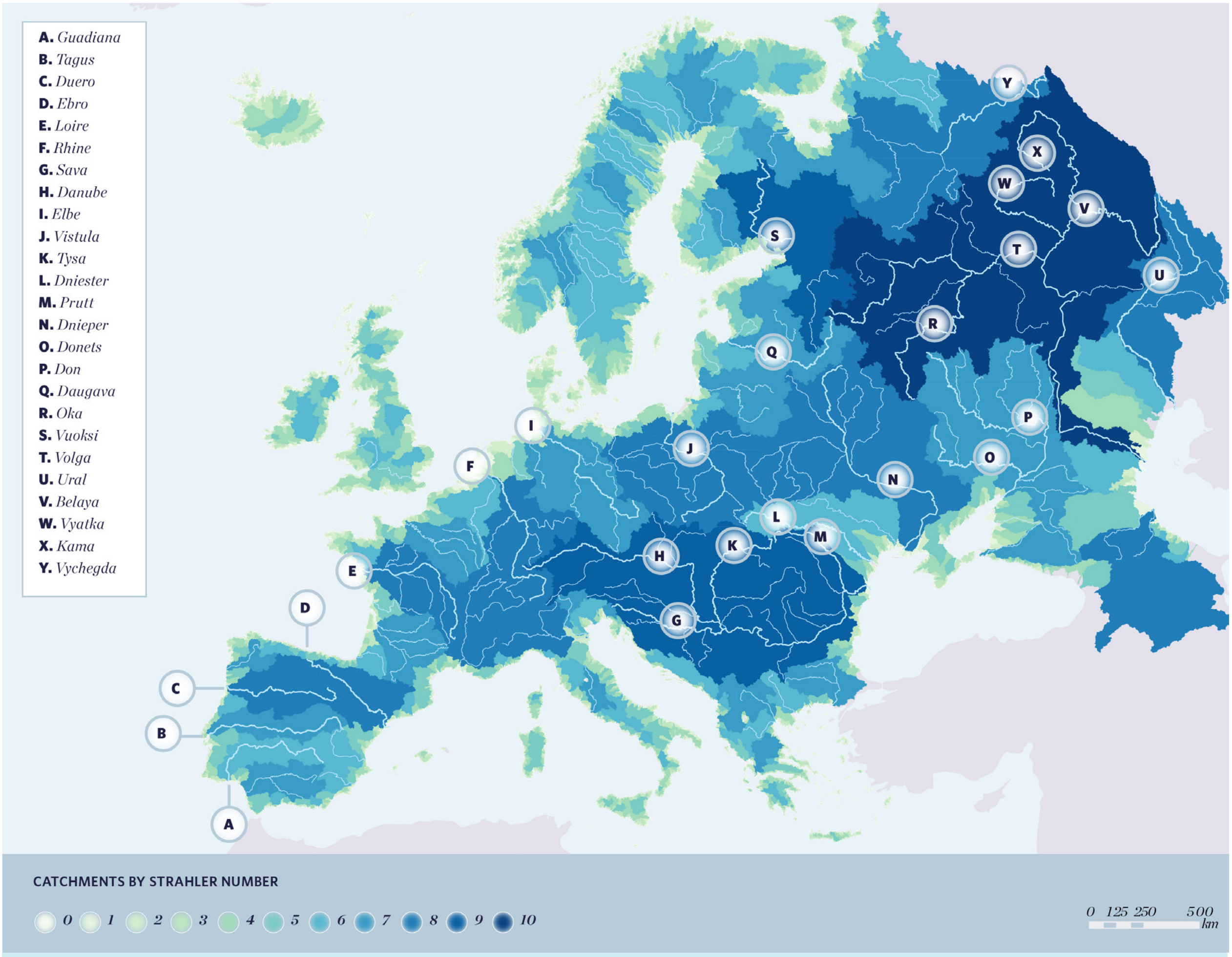
Surface water bodies and their catchments across Europe vary significantly in terms of size. Europe has an estimated 150,000 surface water bodies, including 115,000 rivers (with a total length of approximately 1.2 million kilometres) and 26,000 lakes. For the purpose of administering the implementation of the Water Framework Directive, the key piece of legislation that enshrines Europe's ambitions to restore its freshwater sources, EU Member States were required to establish River Basin

Districts as the basic unit for establishing River Basin Management Plans, which are prepared every six years. The number of districts varies significantly by country. For example, Germany counts ten RBDs and continental France only six (with five additional RBDs in French overseas territories).

Although there are numerous European river catchments, these tend to be quite small and the rivers are relatively short. Only 70 European rivers have a catchment area that exceeds 10,000 square kilometres. Europe's 31 largest rivers have catchments that exceed 50,000 square kilometres and drain approximately two-thirds of the continent. Many of them originate from the heart of Europe in Russia and Eastern Europe, such as the Dnieper, the Don or the Danube draining into the Black Sea. The catchment for the Danube spans 16 countries across central Europe and the Balkans. Other large rivers drain into the North Sea (including the Rhine and the Elbe), the Atlantic Ocean (including the Loire and the Douro/ Duero) and the Mediterranean Sea (including the Rhone, the Ebro and the Po).

Figure 3-2 shows European rivers classified based on their Strahler value, which corresponds to the number of stream branches (or tributaries) that feed into a river (Vogt & Foisneau, 2007). This number increases as the number of stream branches increase, where a larger river catchment would tend to have a greater number of branches and therefore a higher Strahler number[7]. Figure 3-2 highlights the variable size of river catchments across Europe, ranging from just 100 square kilometres for small coastal catchments to more than 1.3 million square kilometres for the Volga River. Of the 40,000 catchments that intersect European countries, the largest 20 catchments account for more than half of total catchment area—reinforcing the highly disparate scales of catchment management.

FIGURE 3-2
European river catchments



Source: Authors' map based on data from Vogt & Foisneau, 2007

7 For reference, the index of a stream or river may range from 1 (a stream with no tributaries) to 12 (which applies to the Amazon river at its mouth). The Ohio river has a Strahler value of 8 whereas the Mississippi river has a value of 10 According to some estimates, 80 percent of the streams on the planet have a value ranging from 1 to 3.

Smaller rivers are prominent in many parts of Europe, particularly in the United Kingdom, Italy and Scandinavian countries. The UK, for example, has almost 1,500 river systems comprising over 200,000 kilometres of watercourses. These rivers are characteristically short, shallow and subject to considerable human impact. River flows typically fluctuate a lot, and low flows tend to be very modest in most river basins. For this reason, UK rivers are especially sensitive to changes resulting from climatic variation or the net effect of a range of human factors, such as heavy abstraction rates and major land use change (National River Flow Archive, 2020).

Historically, many European cities have been built around rivers and lakes. These water bodies have provided not only a source of freshwater but transportation infrastructure that connects them to places from where they can source raw materials or access markets where they can sell their produce. Urbanisation has come at a cost to rivers and lakes; they have been heavily degraded to enable development, carry waste, supply drinking water and facilitate transport and industry (EEA, 2016). Because urban rivers and lakes have been heavily polluted due to urbanisation and industrialisation during the last century, many of these cities have had to expand their reach to secure water supplies through large-scale water transfers.

A city above a certain size usually draws on a number of water sources and a mix of water resource types (Gawlik et al., 2017). Examples of large cities which source their waters from distant catchments are Madrid and Manchester (see Annex A – Case Studies). In Madrid, water for the city and its entire region, serving 6.5 million inhabitants, comes from more than 11 surface water diversions in an area that spans 550,000 hectares. Manchester city, in the UK, sources its water from a reservoir through the 160-kilometre Thirlmere aqueduct. Another example is Austria's capital of Vienna, with 1.8 million inhabitants, whose natural spring water originates in the Lower Austrian Limestone Alps. The water supply system, still in operation today, was built in 1873 when the city completed the first of two water mains over a length of 150 kilometres. The city had the foresight to purchase land in the upstream watershed and, over time, established a forest-covered protection zone of approximately 700 square kilometres designated for water resource conservation.

3.2. RESILIENT WATER SUPPLIES DEPEND ON HEALTHY WATERSHEDS

Catchment landscapes perform vital functions to provide sufficient, clean and affordable water for cities. Over the last several decades, scientists and environmental managers have well established the critical links between landscapes and waterways (Allan, 2004). Human activities in the landscape directly influence freshwater systems at a variety of scales: from the local effects of groundwater withdrawals adjacent to a particular stream segment to influences of pastureland expansion over water quality conditions for an entire catchment. The cumulative decisions of individual landowners and managers contribute significantly to the overall condition of water resources—including drinking water supply—for both people and nature (Ozment et al., 2016; Abell et al., 2017; Trémolet et al., 2019). Healthy watersheds produce a wide variety of ecosystem goods and services as shown on Table 3-1.

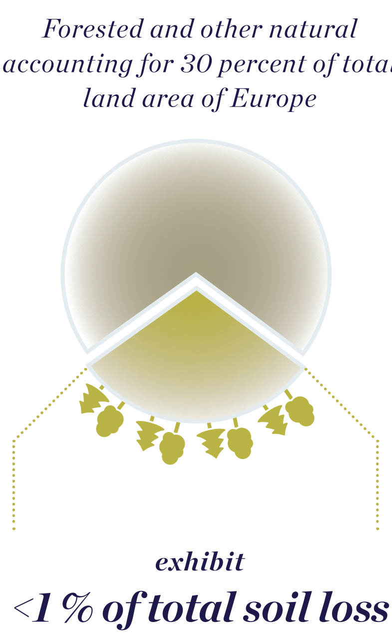
TABLE 3-1

Ecosystem goods and services provided by healthy watersheds

Category of ecosystem goods and services	*Description*
Water supplies for agricultural, industrial and urban domestic uses	Support adequate stream flows during drier summer months
Water filtration/purification	Slow runoff to retain sediment and pollutants from entering streams
Flow regulation	Promote soil infiltration and more moderate streamflow changes
Flood control	Decrease flood risk through inundation within floodplains
Erosion and sedimentation control	Retain soil through vegetation
Habitat for biodiversity preservation	Protect natural habitat and stream corridors
Climate stabilisation	Support carbon sequestration within plants and healthy soils. Regulate heat and provide cooling
Fisheries	Support aquatic species through protection of flows and water quality
Timber and other forest products	Enable healthy forests to grow
Recreation/tourism	Provide natural areas for recreation, enjoyment and mental health benefits
Cultural, religious, inspirational values	Have an intrinsic value that needs to be protected

Source: Adapted from Postel & Thompson (2005)

The loss of natural landscapes—forests and grasslands—means the loss of vital ecosystem functions such as sediment control. For example, the loss of naturally forested areas in a catchment can alter the timing of runoff as well as potentially increase erosion and sediment within streams (Daily, 1997). Natural ecosystems such as forests, grasslands and wetlands provide a natural regulating function for the hydrologic cycle, from reducing the impact of heavy rainfall on soil erosion to aiding with infiltration of water into the soil, regulating high peaks and base flows. The science is reasonably clear about the benefits of natural land cover for downstream flows, and about the negative impacts of deforestation and land cover conversion in general (Abell et al., 2017). In Europe, forested and other natural or semi-natural areas exhibit the lowest rates of soil loss, accounting for 30 percent of total land area but less than 1 percent of total soil loss. The loss of natural areas to cropland production is therefore one of the largest drivers of increased soil erosion, accounting for more than two-thirds of overall soil loss (Panagos et al., 2015).



Agricultural activities, in particular, can have major impacts on water quality through runoff containing fertilisers and agrichemicals. The global growth in agricultural output has been achieved mainly through the intensive use of pesticides and chemical fertilisers. The expansion of agricultural land has amplified this trend. Agriculture accounts for 70 percent of water abstractions worldwide and plays a major role in water pollution. Farms discharge large quantities of agrochemicals, organic matter, pharmaceutical drug residues, sediments and saline drainage into waterbodies. The resultant water pollution creates demonstrated risks to aquatic ecosystems, human health and productive activities (United Nations Environment Programme, 2016).

Watersheds as natural infrastructure are as critical to the future vitality of cities as are the engineered systems of dams and diversions. Within the context of drinking water supply, landscapes provide a number of essential services to the benefit of cities. In particular, catchment areas that are largely intact can be "particularly effective at moderating runoff and purifying water supplies" (Daily, 1997; Postel & Thompson, 2005). Natural vegetation can slow runoff, helping to attenuate high river flows while also increasing water infiltration into soils and underground, which "slows the flow" and reduces the impact of floods. As a result, cities have a major stake in ensuring the continued health and function of these catchment areas.

These two ecosystem functions—moderating flow and filtering water—are the primary way that catchments influence drinking water supplies. In particular, the water filtration function of catchments can have important implications for drinking water providers (Postel & Thompson, 2005; McDonald & Shemie, 2014; Abell et al., 2017). For example, where naturally forested areas have been converted to cropland, the ability of the landscape to

Agriculture accounts for
70 % of water abstractions worldwide

filter runoff is likely to have been significantly decreased. Further, where conventional agricultural practices are used, croplands are likely to contribute additional pollutants to adjacent waters (Trémolet et al., 2019).

Where ecosystem functions have been degraded, drinking water providers are likely to incur additional costs. In the case of increased sediment, water providers may need to use greater amounts of water filtration material such as flocculants to deal with higher sediment loads. In cases of severe catchment degradation, such impacts can jeopardise the continued function of water supply systems. Fertiliser runoff can lead to harmful algal blooms that can potentially render drinking water supplies unusable (Clark et al., 2017; Trémolet et al., 2019). In other cases, impaired water quality conditions can mean additional capital investments to treat degraded drinking water supplies (Postel & Thompson, 2005; Abell et al., 2017; McDonald & Shemie, 2014).

Land management decisions within catchment areas can play a major role in determining whether watersheds are healthy and able to deliver services they have always delivered, including drinking water supplies. Catchment areas function as a vital natural infrastructure for providing sufficient and affordable drinking water supply to European cities (Ozment et al., 2016). Where landscapes are highly developed and agricultural practices are not well managed, it is expected that cities will face degraded drinking water quality. Gaining a good understanding of the status and condition of these catchment areas can help drinking water service providers effectively manage both natural and built infrastructure.

The need to tap relatively distant surface water sources to secure drinking water supplies forges a strong connection between cities and their water source catchments. When a city's water sources are expansive and remote, ensuring its water security demands attention well beyond the confines of its boundaries.

3.3. WHY ARE NUTRIENT POLLUTION AND SEDIMENT A THREAT TO FRESHWATER ECOSYSTEMS?

Nutrient and sediment pollution pose particular challenges for the provision of drinking water supply by increasing costs, reducing service reliability, and impacting the performance of built infrastructure. These pollutants can also pose direct and indirect threats to freshwater ecosystems: degrading aquatic habitat, altering food webs and threatening the persistence of native species (Allan, 2004; Abell et al., 2019).

NUTRIENT POLLUTION

Nutrient pollution in water—namely excess nitrogen and phosphorus—can originate from diverse sources including agriculture, industry and households. Such sources may exist as discrete locations (point sources) or from widely distributed locations across large areas (diffuse emissions). Principal sources of nutrient enrichment include point source emissions from urban wastewater treatment plants and industrial facilities, and diffuse emissions from agricultural production and industrial and vehicle emissions (EEA, 2018a; EEA, 2015).

The majority of **nitrogen** on the planet exists in its nonreactive molecular form, which organisms (including most plants) cannot directly use. [8] Although reactive nitrogen is a necessary component of life on Earth, excessive release

8 Reactive forms of nitrogen are those capable of cascading through the environment and causing an impact through smog, acid rain, biodiversity loss, etc. The nonreactive form of nitrogen is N2 and makes up about 80 percent of our atmosphere. This form of nitrogen does not contribute to the environmental impacts noted above.

of this compound can result in serious damage to humans and our environment (Holmes et al., 2019). Since the Industrial Revolution, human activities have led to an extremely high rate of transformation of this elemental form into reactive forms, disrupting the balance of the nitrogen cycle.

One of the major causes of excessive nitrogen levels in our waters is the use of fertilisers to enhance agricultural yields. Although this process enables higher outputs and efficiency in food production on one side, the alteration of the nitrogen cycle has become one of the major pressing environmental issues of our time. On a global scale, the negative consequences of this alteration are becoming increasingly obvious (Erisman et al., 2019).

Phosphorus, like nitrogen, is a fundamental element for all life on the planet—including for the formation of DNA. High concentrations of phosphorus in the water derive from agriculture runoff and discharges from wastewater treatment plants. Phosphorus is a common ingredient in commercial fertilisers as well as in household products such as laundry detergents. The main sources of nutrient enrichment with nitrogen and phosphorus include point source emissions from urban wastewater treatment plants and industry and diffuse emissions from agricultural production and atmospheric depositions (EEA, 2018a; EEA, 2015).

Since phosphorus is usually present only in small amounts in the natural environment, even small increases in dissolved phosphorus in water can negatively affect water quality and disrupt the balance of ecosystems—particularly within freshwater ecosystems (Allan, 2004).

When too much nitrogen and phosphorus contaminate water bodies, these can cause excessive growth of algae. This phenomenon is called eutrophication: the decomposition of the algae overgrown because of excessively enriched waters lowers oxygen levels and creates turbid waters. This creates an inhospitable environment for living organisms, leading to habitat degradation and reduced biodiversity as aquatic insects and everything that feeds on them—including fish, birds, water shrews and otters—are all negatively affected. Excess nutrients can lead to so-called "dead zones", areas with almost no oxygen where aquatic life is destroyed. Toxic algal blooms can impact human health and impair the use of water for drinking, bathing and fishing.

High concentrations of phosphorus in the water derive from ***agriculture runoff and discharges from wastewater treatment plants.***

SEDIMENT LOAD

Sediment is an essential and integral natural element of the hydromorphology of rivers, lakes, and estuarine and coastal systems. Hydromorphology refers to the physical character and water content of water bodies: it is a critical determinant of the ecology of these systems, providing and supporting habitats as well as nutrients for aquatic plants, invertebrates, fish and other organisms. Changes in sediment balance can also affect the nature of coastal areas, shifting the balance between coastal erosion and the replenishment of the coastline by silty rivers.

Excessive sediment loads can have detrimental impacts on the quality of surface waters. Sediment can affect river habitats by clogging up the interstices on riverbeds, which hinders fish spawning and the survival of eggs. Sediment can also transport environmental contaminants, such as chemicals, nutrients and faecal indicator organisms in sediment particles (EA, 2015).

Increases in sediment loads have important implications for watershed health and drinking water supplies for cities. Elevated levels can alter the management regime of engineered infrastructure. This can shorten the life of the infrastructure for water storage and conveyance and increase the costs of water treatment. In extreme cases, such as those following catastrophic wildfires, elevated sediment can entirely disrupt water supply from affected sources.

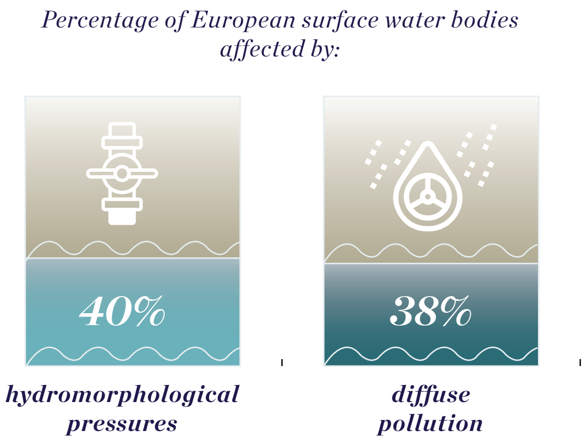
Some land management activities can lead to soil erosion and increase the supply of fine sediment into the receiving surface waters (EC, 2019b). Land use activities in this category include harvesting timber, especially through clear felling; giving livestock unrestricted access to rivers; late harvesting, causing soil compaction; and overgrazing in upland areas. Industry may cause associated problems: contamination of sediment (and transport of such contaminants) or colour problems through mining activities, industrial discharges (suspended solids from sewage treatment works) and atmospheric deposition of industrial pollution (EA, 2015).

Sedimentation in water sources can increase with land use changes: forests are converted into croplands, land is flattened to make way for more intensive agricultural practices, hedgerows and ancient farming terraces are eliminated. Catastrophic fires can also increase sediment flows and affect river water quality, particularly in the Mediterranean mountain regions where autumn rainstorms often follow summer wildfires, causing soil runoff and landslides (Trémolet et al., 2019).

3.4. HOW SIGNIFICANT ARE NUTRIENT POLLUTION AND SOIL LOSS IN EUROPE OVERALL?

Nutrient pollution and soil loss have been recognised as challenges for decades across Europe. Yet these challenges persist and are expected to increase over time. Despite improvements achieved in surface water quality in recent decades, Europe's surface water bodies continue to face significant challenges. The environmental objective of key EU legislation, such as the WFD, the Urban Waste Water Treatment Directive (UWWTD) and the Nitrates Directive, has yet to be met fully. As of 2015, only around 40 percent of EU surface waters were in good ecological status (or good ecological potential), and 38 percent were in good chemical status (EEA, 2018b). Among the main significant pressures affecting the status of surface water bodies, hydromorphological pressures and pollution from diffuse sources are the most widespread (affecting 40 percent and 38 percent of water bodies, respectively).

Nutrient enrichment of Europe's freshwaters is a significant concern. Diffuse pollution from agriculture, in particular, remains a major cause of poor water quality (EEA, 2015a). Overall levels of fertiliser use



associated with intensive agriculture remain high, especially in some agriculture-rich areas such as the Netherlands, Belgium, Germany, France and Northern Italy. Large variations exist among Member States in terms of nitrogen and phosphorus surplus. Of great concern is the growing use of fertiliser in the last few years (EEA, 2018a) because of a slight growth in usage amongst Member States that most recently joined the EU.

Eutrophication is an increasingly common phenomenon in Europe. For example, in 2013, blue-green algal blooms (linked to cyanobacteria) appeared in some European lakes aided by warm weather, relatively calm conditions and a considerable level of nutrient pollution in some areas. When levels of blue-green algae are dangerously high, authorities must inform swimmers because the algae can cause rashes after skin contact and illnesses if swallowed (EEA, 2013). Other examples include coastal areas in the Brittany region in France, Wales in the UK and the Mar Menor in southern Spain (see Boxes 3-1 and 3-2).

BOX 3-1

Eutrophication in Welsh rivers linked to intensive chicken farming

In Wales, phosphate, nitrogen and ammonia pollution are causing serious damage to sensitive habitats, rivers and air, according to a statement from Wales Environmental Link (WEL), a network of 30 environmental and countryside organisations.

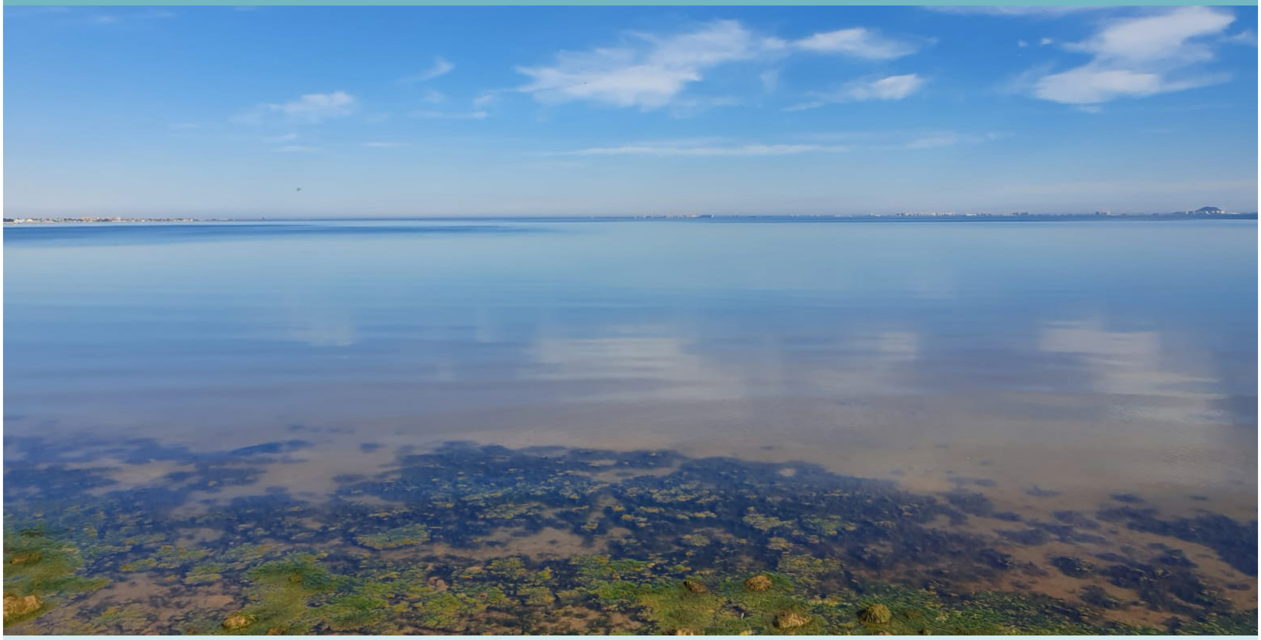
While "point source pollution" from large intensive chicken and pig units is regulated, diffuse pollution, which occurs when pollutants disperse into air and waterways, is not monitored. This phenomenon is linked to manure from livestock units which is then spread onto land and runs into rivers, triggering eutrophication.

According to Colley (2020), the proportion of phosphate in the lower Wye coming from agriculture has doubled since 2014, and the river is failing on permitted levels of phosphate under the EU habitats directive. This prompted a coalition of environmental organisations to call on authorities at national and local levels to take action and to impose a moratorium on the development of new intensive farming units in the area (as this is also practiced in parts of the United States). The authorities are reviewing nutrient levels in rivers in Wales and are in the process to develop updated national guidance to support various authorities in fulfilling their planning responsibilities as well as a set of pollution regulations.

Source: Colley, 2020

BOX 3-2

Eutrophication in the Mar Menor (Spain) linked to intensive agriculture



The Mar Menor is a salty lagoon in the south-east of the autonomous Community of Murcia, Spain. With a surface area of nearly 170 kilometres and a coastal length of 70 kilometres, it is separated from the Mediterranean Sea by La Manga, a sandbar 22 kilometres in length.

This area has great ecological value and, since 1994, it is included on the Ramsar Convention list for the conservation and sustainable utilisation of wetlands. The Mar Menor is also part of a Specially Protected Area of Mediterranean Importance and is a Special Protection Area (ZEPA in Spanish) for bird life. For several centuries, permanent settled populations have existed on its perimeter with fishing and salt mining activities. Moreover, as in the rest of Spain, mass tourism has urbanised a large part of its coast since the 1960s.

A significant event for the territory was the establishment of the Tajo-Segura Water Transfer in the 1970s. This enabled the development of a very strong agriculture in the watershed of the Campo de Cartagena. The area has become known as the "orchard of Europe".

This global context of economic development around the lagoon has generated multiple activities, including ten marinas, fishery and aquaculture, and salt production, that affect its natural balance, generating a complex set of management issues in the area. The impact of intensive agriculture has particularly affected the lagoon, with the use of desalinated water to complement water from the inter-basin transfer, remodelling the terrain with heavy use of fertilisers and pesticides.

Since summer 2015, the existence of an intense process of eutrophication has substantially changed the traditional blue colour of its water to green, and turbidity has increased dramatically. Pollution in 2016 was reportedly so severe as to render the area close to ecological collapse. The poor ecological status of the water body is due to agriculture pollution and intense urbanisation – still, in 2019, thousands of fish and crustaceans appeared dead on the banks of the asphyxiated lagoon, with three tons of dead animals having to be removed by local authorities.

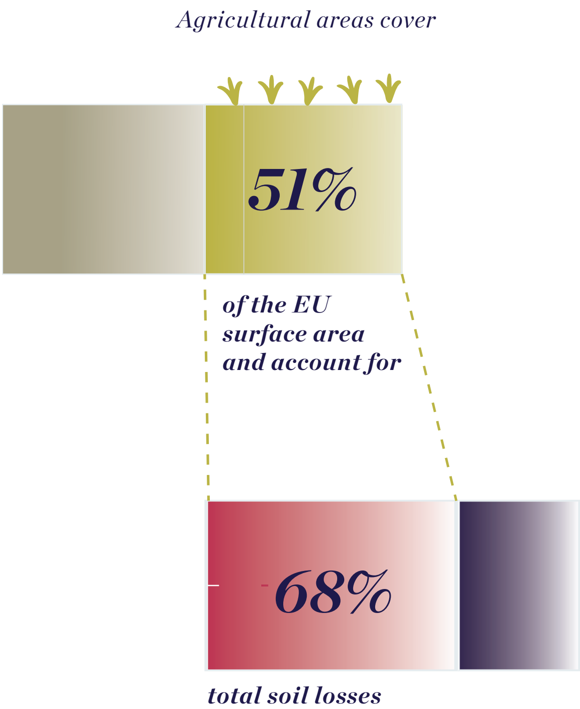
The responsible authorities, including the River Basin Authority (Confederación Hidrográfica del Segura), the Ministry for Ecological Transition and Demographic Challenge, the government of the Murcia region and local municipalities, are supporting individual measures to address these issues. Some of these include nature-based solutions such as the restoration of coastal wetlands and agricultural BMPs.

Source: Authors, based on various sources

An estimated 11.4 percent of the EU territory is affected by moderate to high levels of soil erosion. This is more than five tonnes of sediment per hectare per year. Many land management practices (linked to agriculture, livestock, forestry) also lead to soil erosion and sedimentation of surface waters. More targeted work is needed to improve the understanding of the role and impacts of sediment runoff on water quality. Agricultural areas (arable lands, permanent crops, grasslands and heterogeneous agriculture lands) cover 51 percent of the EU surface area and account for 69 percent of total soil losses (Eurostat, 2018).

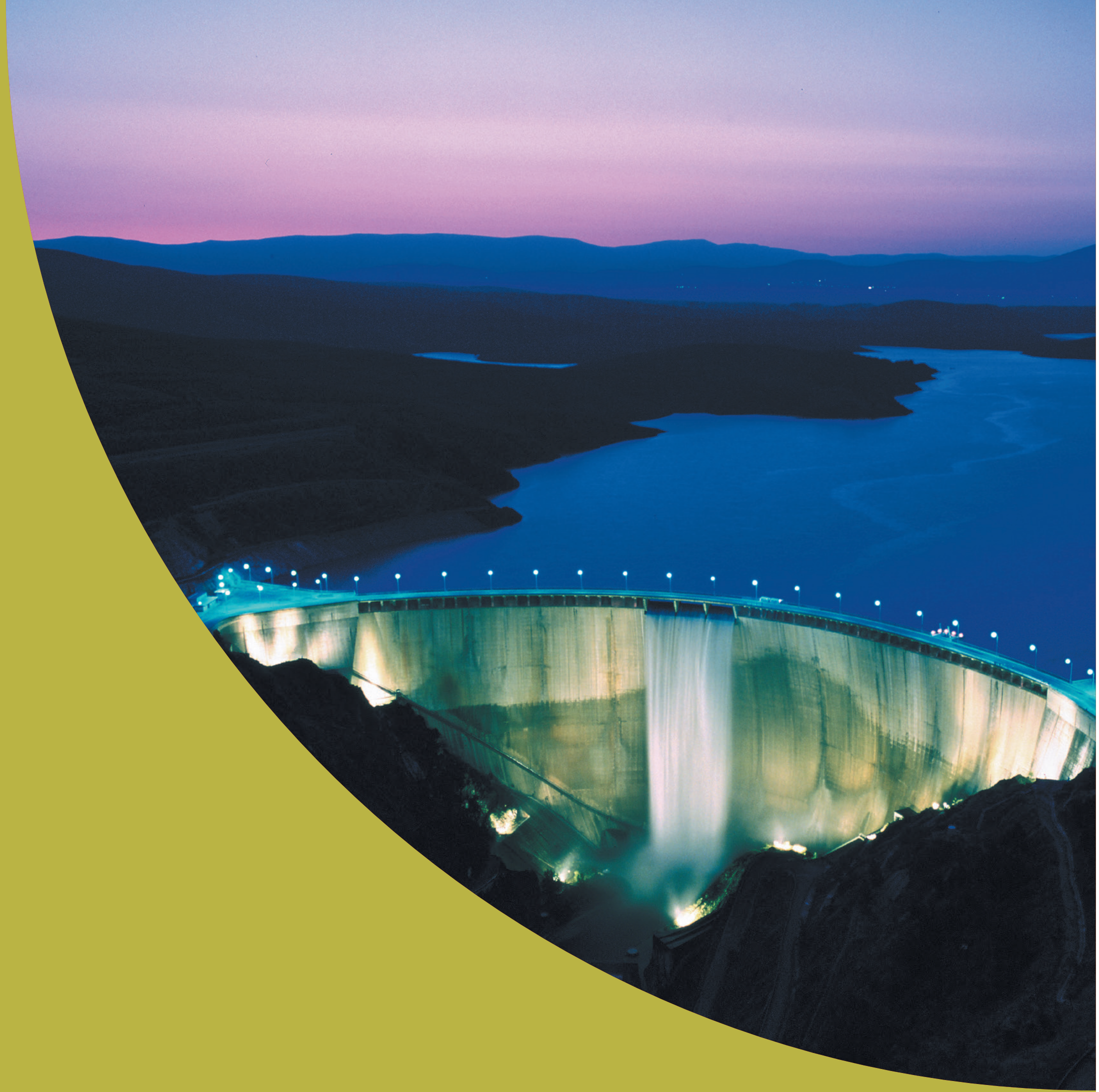
Sediment is one of the least defined pressures in the context of EU water legislation. Because the EU lacks overview data on sediment pressures on surface water, there are no European projections of how this challenge is likely to develop in the future. A recent IPBES report showed that land degradation (partly caused by sediment runoff) is a significant problem worldwide, one that is likely to worsen unless adequate measures are adopted (IBPES, 2018).

An example of this issue in Europe can be found in the catchment area serving Greater Manchester, in the UK (see Annex A for details). The city and its region are served by United Utilities, one of the largest utilities in the UK. The area surrounding its reservoirs is generally characterised by sediment runoff issues. The city´s Thirlmere reservoir has historically experienced turbidity during storm events. In 2015, for instance, the reservoir was so badly affected by flood runoff that United Utilities, the water company serving the city, had serious trouble dealing with high levels of turbidity in the reservoir: it was forced to put the reservoir out of service for a period of time.



Industrial pollution and agricultural activities have damaged many habitats around the catchment areas, and years of drainage of the uplands has caused peat bogs that are 5,000 years old to dry out and erode, releasing sediment into watercourses and tonnes of carbon dioxide into the atmosphere. The utility´s approach for tackling the problem was to start a programme to address pollution at the source and share expertise about how land is best used and managed across the region.

This report seeks to encourage more widespread adoption of this kind of approach. The following sections seek to identify which NbS could have greater potential in addressing issues associated with nutrient and sediment pollution.



4. Surface water challenges for selected cities

We examined in more depth the surface water challenges for 109 cities which together are home to 78.5 million people, or 15 per cent of the population of the European Union and the United Kingdom. Most of these depend on more than one surface water source for drinking water. The majority of these sources are located well beyond the boundaries of the cities themselves. The combined footprints of their catchment areas dramatically outsize the jurisdictional boundaries of the cities.

Our analysis suggests that built infrastructure has been effective in securing adequate water quantity. By contrast, the assessment of land use within their source catchment areas shows that, for nearly two-thirds of assessed cities, more than half of their catchment areas has been converted to agricultural land or transformed into artificial, urban landscape. The extent of this land development suggests that natural ecosystem functions have been significantly impacted within catchments with potential reductions in the quality of urban water supply.

For the selected cities, soil loss rates are comparatively higher than the average in Europe, suggesting that agricultural activities have resulted in increased soil loss. This may affect their ability to supply clean drinking water—potentially leading to increased operational costs and other impacts. Estimates of nutrient loads with source catchment areas also suggest widespread impacts due to agricultural activities. For the majority of selected cities, agriculture appears to be the dominant source of nitrogen and phosphorus pollution in Europe.

4.1 SELECTED CITIES GET WATER FROM NUMEROUS AND OFTEN REMOTE SOURCES

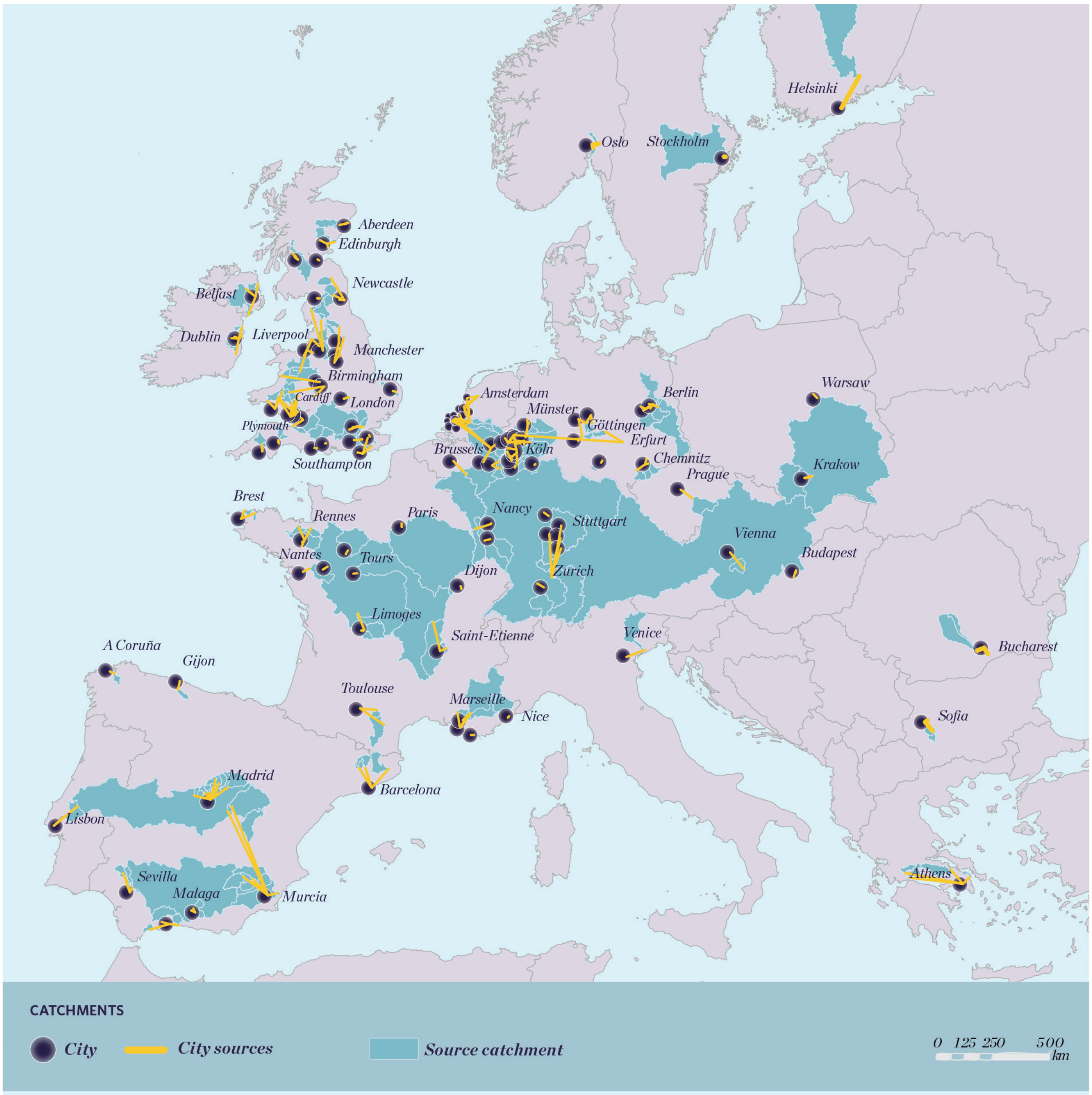
For the 109 cities for which this report conducted more in-depth analysis, water sources are often numerous and remote. Figure 4-1 shows all surveyed cities and the catchment areas for their main water sources in light blue. For these cities, surface water sources vary widely in number, size and proximity. Straight lines indicate where a physical transfer is necessary from a distant catchment to transport water to a given city.

Most of the selected cities depend on more than one surface water source for drinking, the majority of which lie well beyond the boundaries of the cities themselves. More than two-thirds of them depend upon more than one surface water source for public drinking water supply. In some cases, a single city may depend upon more than a dozen different water withdrawal locations. London, for example, withdraws surface water from up to 20 locations to meet its drinking water demand.

The proximity of cities to their sources is also worth noting. Typically, greater distance suggests the need for more conveyance infrastructure (and therefore greater incentive to protect this larger infrastructure investment). For the selected cities, the typical (median) surface water source is some 25 kilometres from the city centre. In some cases, however, these distances can be far greater: for a quarter of the cities in our sample, water withdrawal locations are more than 50 kilometres from the city centre.

FIGURE 4-1

Selected European cities and their drinking water source catchment areas



Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

Source: Data collected by Ecologic and The Nature Conservancy (2019) from multiple sources

The combined footprints of the catchment areas dramatically outsize the jurisdictional boundaries for selected cities. The landscape footprint of these catchments does vary substantially. If we consider the aggregate spatial extent of all catchment areas for a given city, we observe that total catchment areas range from 25,000 hectares to more than 20 million hectares. For these selected cities, the typical (median) catchment area is approximately 400,000 hectares—roughly one-tenth the area of Switzerland. For cities that withdraw water closer to headwater sources, catchment areas are likely to be smaller. By contrast, for cities like Amsterdam, where withdrawals are taken from large rivers far downstream, the total catchment area can be immense (more than 16 million hectares).

The potentially large size of these catchments further suggests the need to prioritise efforts for water suppliers to manage these areas to boost the resilience of drinking water supplies. Given the multitude of competing priorities that European water utilities face, they need planning and decision support tools to direct investments towards areas and activities with the greatest potential benefits (Gawlik et al., 2017).

4.2. BUILT INFRASTRUCTURE HAS BEEN EFFECTIVE AT SECURING ADEQUATE WATER QUANTITY

For the selected cities, assessment of water availability suggests that built infrastructure has been effective in securing adequate water quantity. Using a global model of current water availability and demand developed by the Universities of Kassel and Frankfurt, we examined water depletion for the selected cities (Döll et al., 2001; Brauman et al., 2016).

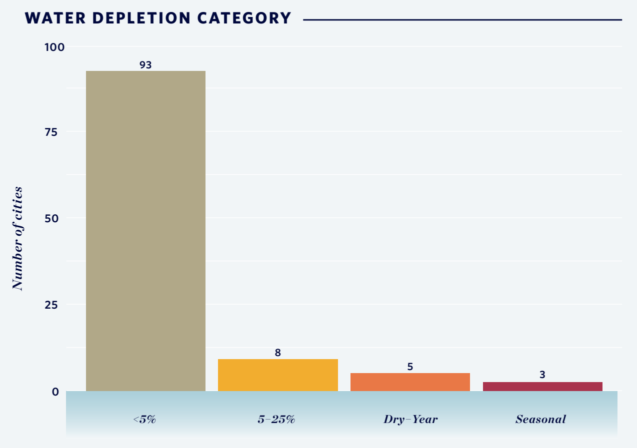
Water depletion is defined as the ratio of consumptive water use relative to total water availability. This provides an indication of where water—for both people and aquatic ecosystems—is likely to be scarce. Water depletion is a particularly useful indicator since it considers both annual and seasonal scarcity. A city would face "annual water depletion" when consumption-to-availability is greater than 75 percent. Seasonal depletion would occur when consumption-to-availability is greater than 75 percent for at least one month per year. Dry-year depletion suggests seasonal depletion occurring for at least 10 percent of the modelled period.

Results for the selected cities suggest that water scarcity is not a critical threat at present, as suggested by Figure 4-2 (where water depletion categories are presented in order of increasing severity from left to right). No cities were identified within the most severe water depletion category, annual depletion. Seasonal water scarcity is an expected risk for three Spanish cities in our sample (Granada, Murcia and Sevilla) whilst dry-year depletion is expected in Sofia (Bulgaria), Lisbon (Portugal), Bucharest (Romania) as well as Madrid and Malaga in Spain.

While recent history suggests that water availability[9] is not currently a critical risk for most cities, it is expected that future water availability will be affected by changing climatic conditions, with some regions potentially experiencing significant decreases in precipitation (Bisselink et al., 2018). This suggests that now is a crucial time for cities to invest in safeguarding their water supply resources, including by taking account of future changes in water availability in their planning and focusing efforts on other aspects of water resilience, including those related to water quality.

FIGURE 4-2

Estimates of water availability for surface water source catchments indicate low water quantity risks



Source: Authors' analysis based on data from Brauman et al., 2016

9 Defined as water that is lost to evaporation, transpiration, incorporation into products or crops, human or livestock consumption, or otherwise not available for immediate use (USGS, 2020)

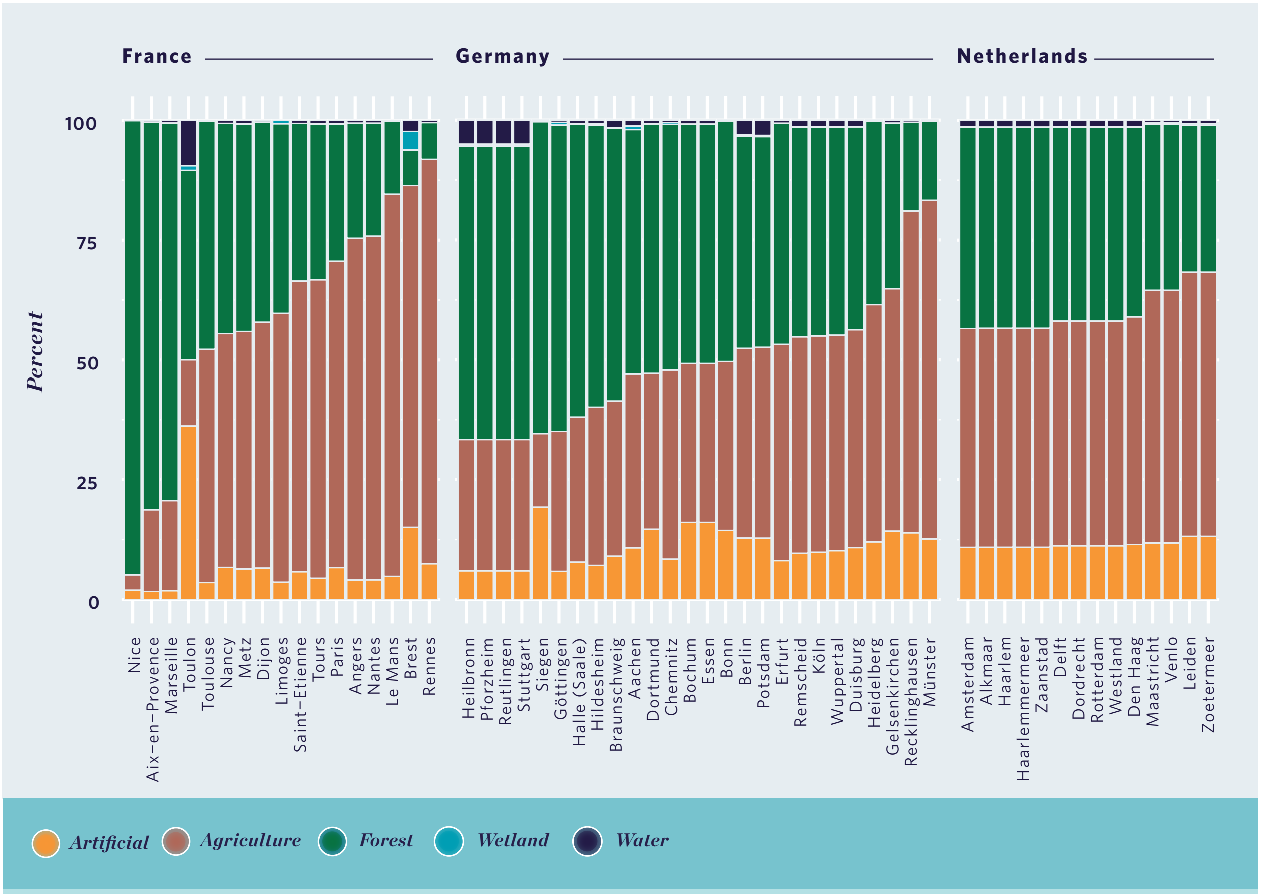
4.3. BUT THEIR SOURCE CATCHMENTS FACE SIGNIFICANT LAND USE PRESSURES

Given the strength of the connection between landscape condition and surface water quality (see Section 3.2), an assessment of land use and land cover within selected cities' source catchment areas can provide a valuable indication of whether they are likely to face surface water quality challenges.

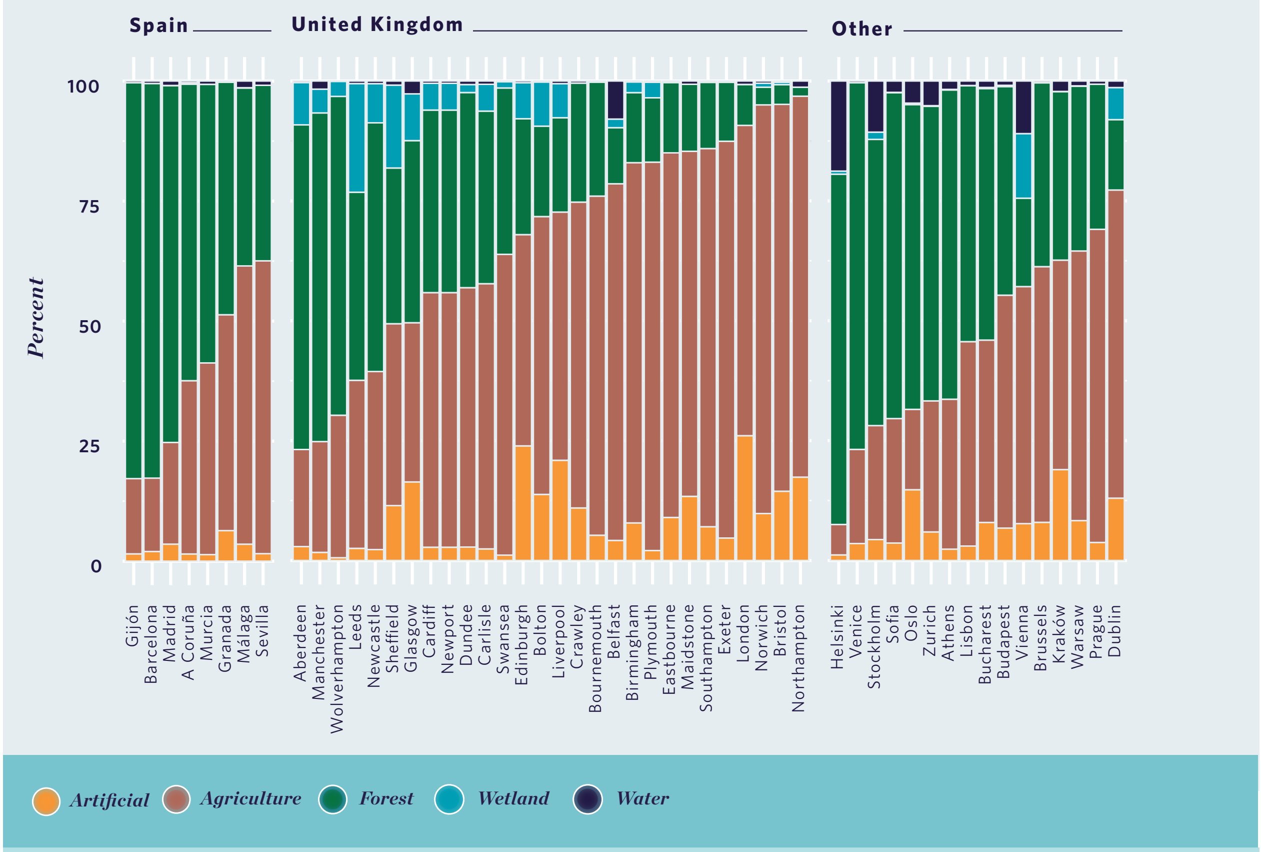
Using data from the Copernicus Land Monitoring Service for the most recent year available (2018), Figure 4-3 presents broad land use/land cover classifications for the selected cities (CORINE Land Cover - 2018, 2020). It shows the significant impact of human pressures—linked to agriculture and urban development—within the cities' catchment areas, suggesting that agricultural and other economic activities within these areas are likely to be important determinants of surface water quality conditions.

FIGURE 4-3

Land use in source catchment areas for selected cities



Source: Authors' analysis based on data from Copernicus Land Monitoring Service (2020)

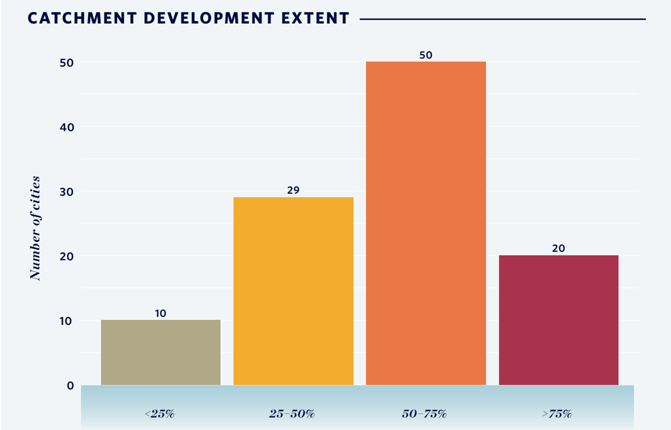


Source: Authors' analysis based on data from Copernicus Land Monitoring Service (2020)

For nearly two-thirds of the cities in the sample, more than half of their catchment areas have been converted to artificial or agricultural land.[10] While forested areas are prominent for some catchments, human-developed landscapes dominate across all cities assessed. In the United Kingdom, for example, agricultural and urbanised areas (Figure 4-4) account for more than 66 percent of catchment areas on average. By contrast, developed areas account for approximately half of catchment areas for cities surveyed within Germany.

FIGURE 4-4

Overview of catchment extent for selected cities



Source: Authors' analysis based on data from Copernicus Land Monitoring Service (2020)

10 Artificial areas include urbanised areas, roadways and railways, ports and other industrial sites. Agricultural areas include all farm and pasture areas, including annual crops, orchards and agro-forestry.

The intensity of land use activities varies quite substantially between catchments. Within catchment areas assessed in the United Kingdom, for example, pastureland is the dominant agricultural use type, whereas arable and permanent crops dominate within catchment areas of Spain. Even within similar types of agricultural areas, the specific type of agricultural production can lead to divergent impacts on adjacent wetlands and streams (Stoate et al., 2001). As a result, while the aggregate picture of catchment areas for the cities in the sample strongly suggests significant human influence over surface water quality conditions, the potential magnitude of the impacts of land use activities will vary depending on the intensity of such usage.

The extent of this land development suggests that natural ecosystem functions have been significantly impacted in the catchments from which these cities draw their source water. As noted in Section 3, natural landscapes perform vital functions in support of water supply provision. Identifying where catchment development is likely to drive impaired surface water conditions—or, alternatively, where continued protection of natural landscapes is likely to protect good surface water conditions—can help prioritise investments in nature-based solutions to restore ecosystems health.

4.4. SOIL LOSS AND NUTRIENT POLLUTION SUGGEST SIGNIFICANT IMPACT OF AGRICULTURAL ACTIVITIES

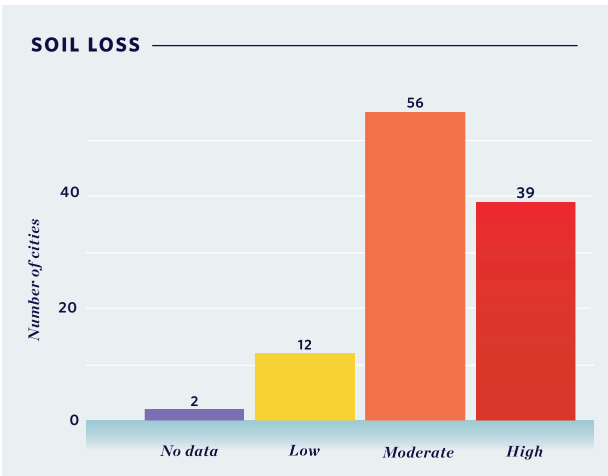
SOIL LOSS

Given the potential impacts of excess sediment for drinking water supply, we assessed potential soil loss from overland runoff for the selected cities. While land development and, in particular, agricultural production can cause soil erosion into streams and wetlands, not all displaced soil will be exported to waterways. Depending on local conditions—including soil type, slope, precipitation, vegetation and proximity to streams—some portion of eroded soil is likely to resettle on the landscape prior to reaching a stream or lake. Accordingly, it is necessary to account for this 'net' soil erosion, whereas 'gross' soil erosion estimates are likely to lead to significant overestimation of soil loss (Panagos et al., 2015).

Borrelli and co-authors estimated net soil loss rates at the European scale using a spatially explicit model of sheet and rill erosion (Borrelli et al. 2018). This RUSLE-based model has been calibrated to field measurement data from 24 catchments distributed across Europe. We used this data set to calculate average soil loss rates in order to compare across catchments and cities, assigning relative categories (low, moderate and high) which correspond to percentile breaks observed in watersheds across Europe (see Annex B for details).

We found that for more than one-third of assessed cities, soil loss rates in their water source catchment areas are considered high when compared to other European catchments (that is, greater than 75th percentile), as shown on Figure 4-5.

FIGURE 4-5
Overview of soil loss categories in selected cities' water source catchments

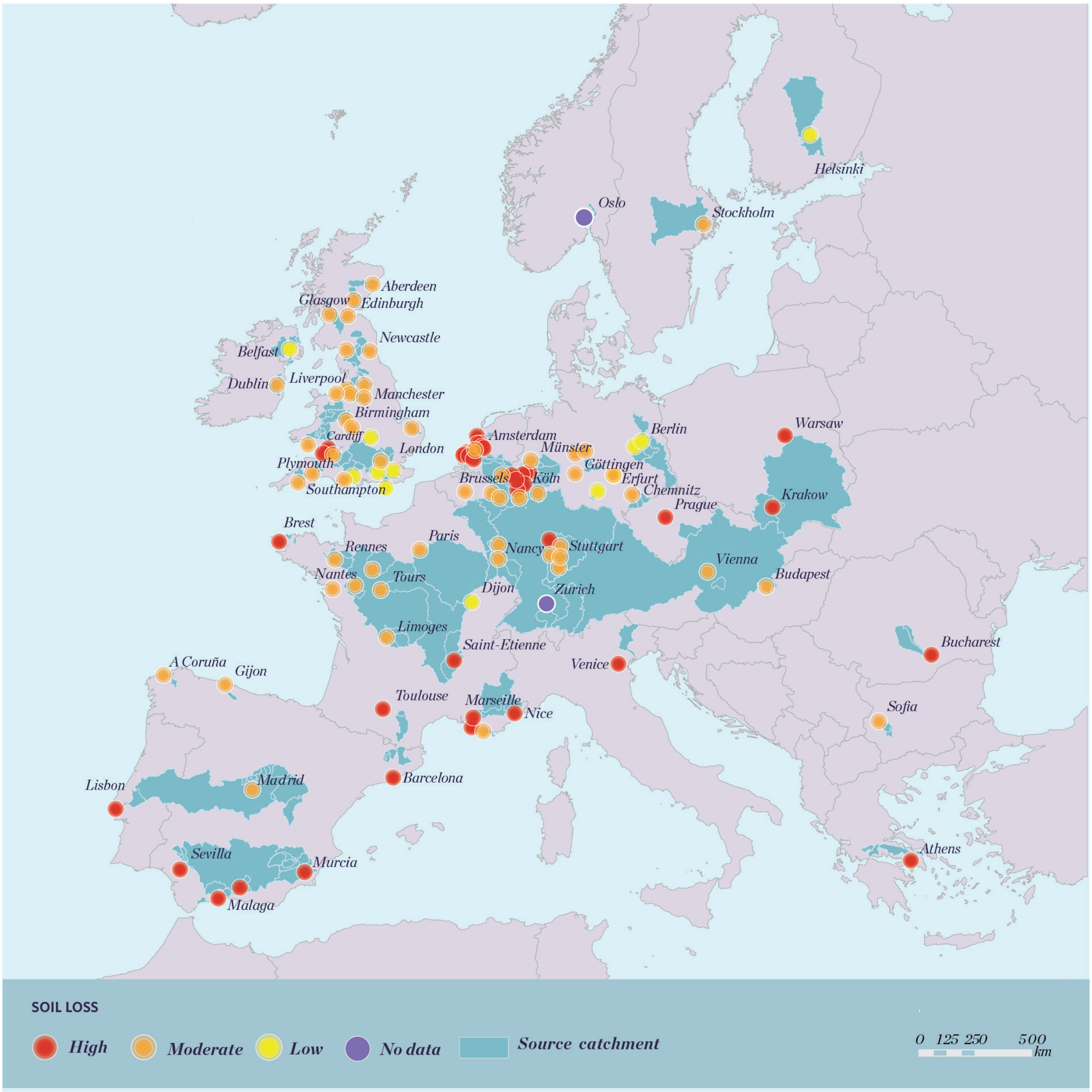


Source: Authors' calculations based on data from Borrelli et al. (2018) as published by the Joint Research Centre/ European Soil Data Centre

Figure 4-6 presents a comparison of average annual soil loss rates across the selected cities. The cities and catchment sources that are particularly affected are predominately located in the South of the Iberian Peninsula, southern France, the Netherlands and the region of Northern Westphalia in Germany. As a result of these high soil loss rates into rivers, lakes and reservoirs, drinking water providers for these cities may face increased operational costs as well as other repercussions, such as increased maintenance of conveyance and storage infrastructure.

FIGURE 4-6

Comparison of soil loss rates for selected cities



Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

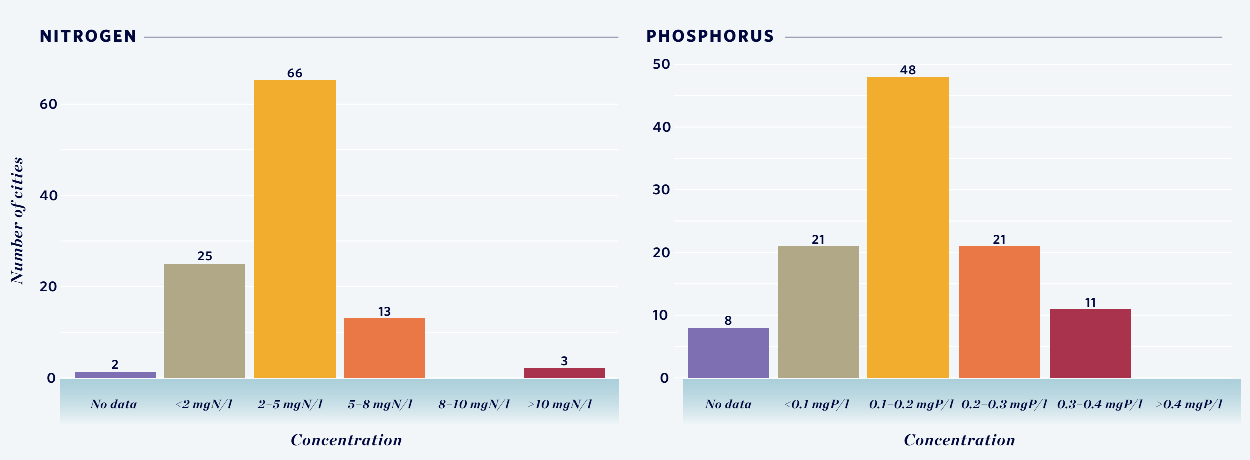
Source: Authors' calculations based on data from Borrelli et al. (2018) as published by the Joint Research Centre/European Soil Data Centre

While these results suggest that catchment soil loss may be a challenge for many of the selected cities, this is only a partial picture of soil loss into streams and lakes. Other landscape processes (such as landslides and bank and gully erosion) and instream conditions can also contribute significantly to a stream's total sediment load. These other processes are not accounted for within the RUSLE-based model, so soil loss may be underestimated in some catchments. In central Italy, for example, modelled sheet and rill erosion may account for less than 10 percent of annual sediment yields—other processes that were not modelled are likely to account for the other 90 percent (Borrelli et al., 2018). Where these other landscape processes contribute relatively more or less, the significance of overland soil loss—and, therefore, the relative importance of land development activities such as agriculture—will be correspondingly affected.

NUTRIENTS

Estimates of nutrient concentrations within source catchment areas suggest widespread potential for adverse pollution impacts as shown in Figure 4-7. We observe that, for most cities, total nitrogen (TN) and total phosphorus (TP) concentrations are elevated above the lowest concentration category. While the desired limits for instream concentrations vary according to location conditions and regulations, the concentrations observed here suggest that most source catchment areas face elevated risks of eutrophication within their waterways (Sutton et al., 2011).

FIGURE 4-7
Overview of nitrogen and phosphorus pollution levels for selected cities



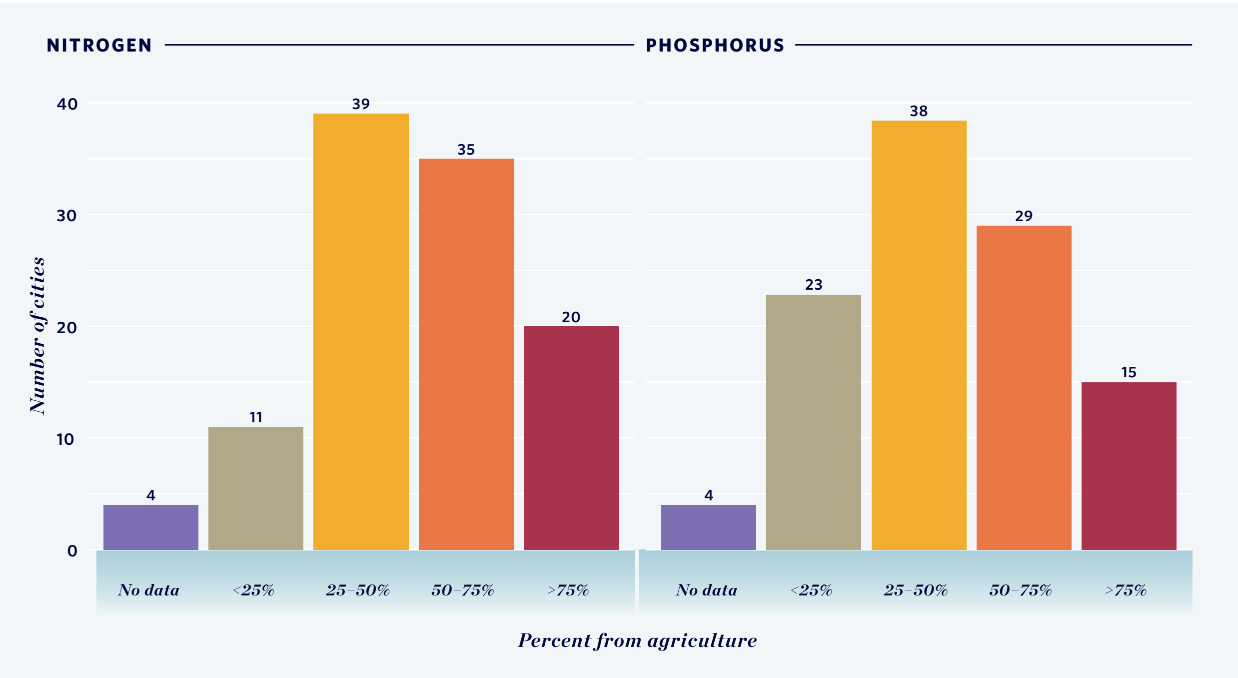
Source: Authors' analysis based on data from Grizzetti et al. (2012)

Figures 4-8 and 4-9 summarise data on nitrogen and phosphorus for source catchment areas for each of the 109 cities. As noted previously in Section 3, nutrient pollution—specifically nitrogen and phosphorus—can be significantly affected by land use activities, particularly due to agricultural activities. The GREEN model developed by B. Grizzetti and co-authors (2012) estimates nitrogen and phosphorus loads across Europe—including from both point (such as wastewater) and diffuse (such as agriculture and atmosphere) sources—and accounts for elements of both overland and instream attenuation. We associated each city with estimates of instream concentrations for total nitrogen and total phosphorous at the outlet of modelled catchments—that is, the drainage point for each catchment. By associating cities and their catchments with estimates of nutrient loads, we are able to assess the degree to which urban water supply may be impacted by nitrogen and phosphorus pollution—as well as inferring the primary sources of this pollution.

Agriculture is a significant driver of nutrient pollution for selected cities' source catchment areas. For 40 percent of the cities, agriculture accounts for more than half of nitrogen and phosphorus pollution, as shown on Figure 4-10 below. For modelled catchments for 15 cities, agriculture is likely to account for more than 75 percent of nitrogen and phosphorus pollution. For these cities and catchments, this suggests that any efforts to address nutrient pollution should strongly consider the potential for improved agricultural practices. Where water quality in these catchments is impaired, addressing point-source emissions through traditional 'grey' infrastructure approaches alone may be insufficient to achieve target environmental outcomes.

FIGURE 4-10

Estimated proportion of nutrient pollution attributable to agricultural activities for selected cities

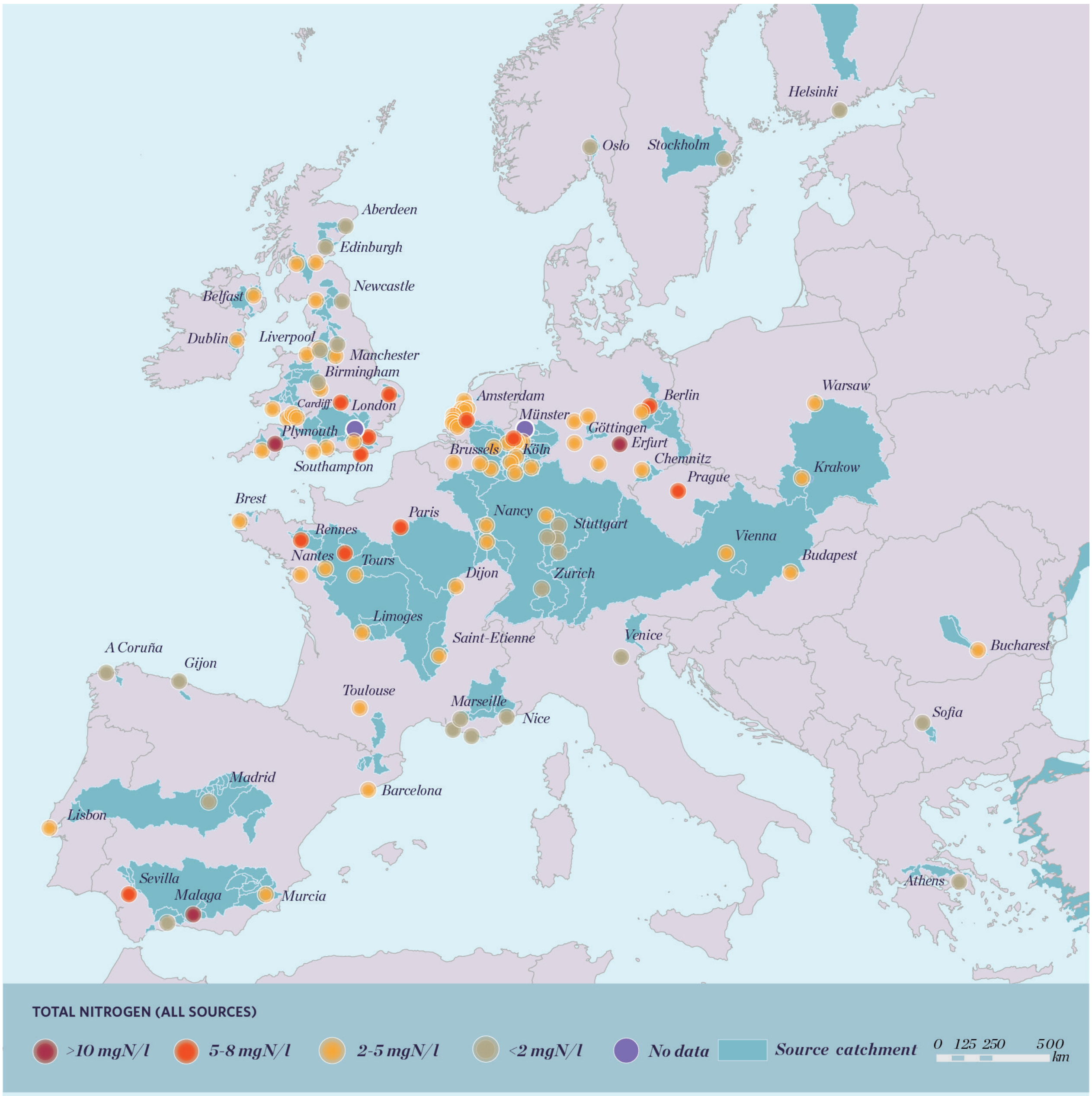


Source: Authors' analysis based on data from Grizzetti et al., 2012

While agriculture may be a major driver of nutrient pollution in many source catchments, the significance of this pollution will depend on local conditions. These results indicate that agriculture plays a dominant role in driving nutrient pollution for many source catchment areas, but this type of assessment does not necessarily suggest how much pollution mitigation might be needed. In addition to uncertainties related to the underlying data, specific nutrient limits for these surface waters will vary according to local conditions and designated use classifications. For example, while drinking water quality criteria establish limits on nitrogen and phosphorus, local conditions may warrant management of TN or TP loads well below these limits in order to meet other environmental performance criteria, such as avoidance of harmful algal blooms (Poikane et al., 2019).

FIGURE 4-8a

Estimate of instream total nitrogen concentration

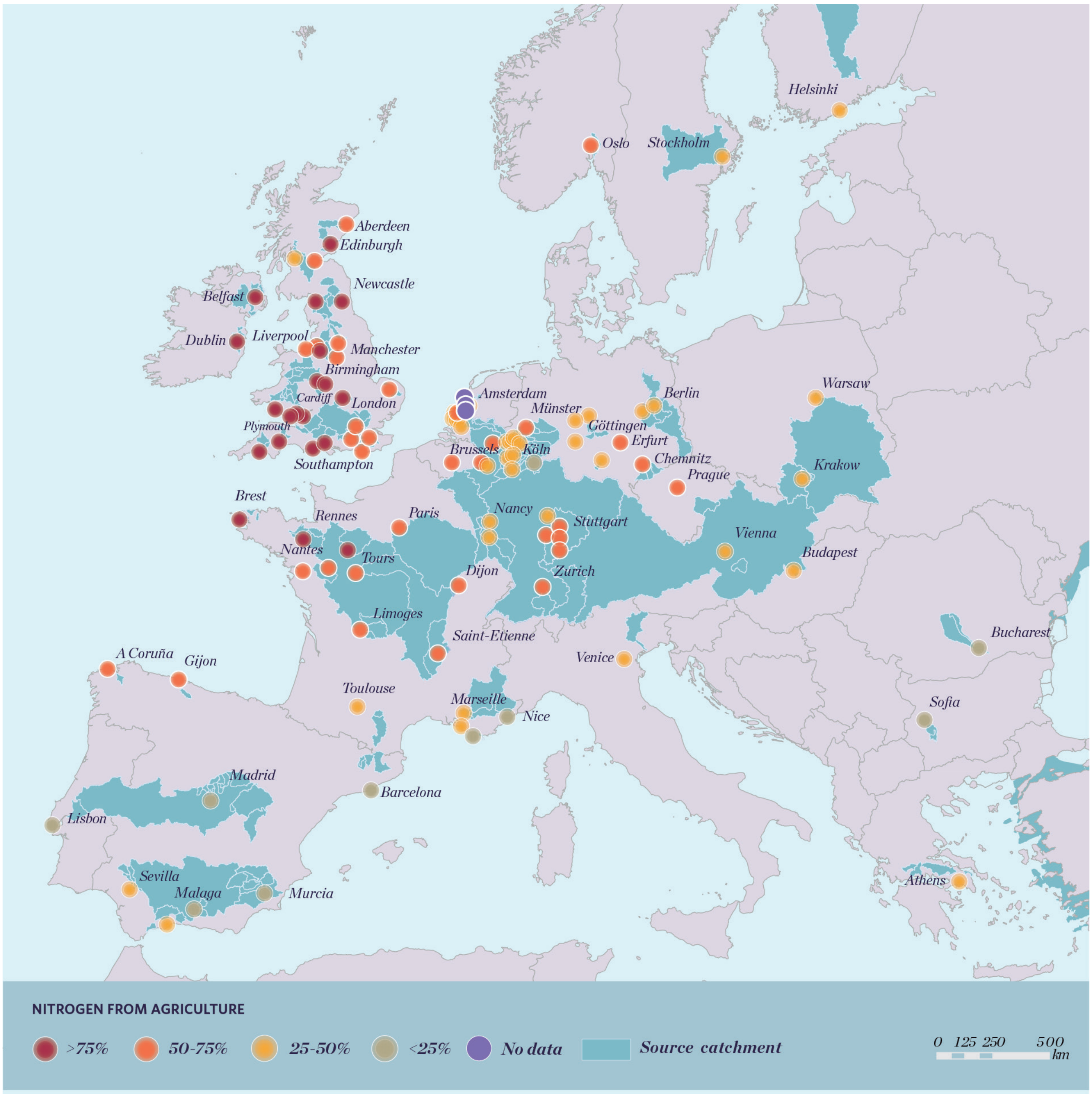


Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

Source: Authors' analysis based on data from Grizzetti et al. (2012)

FIGURE 4-8b

Percentage of nitrogen pollution attributable to agriculture

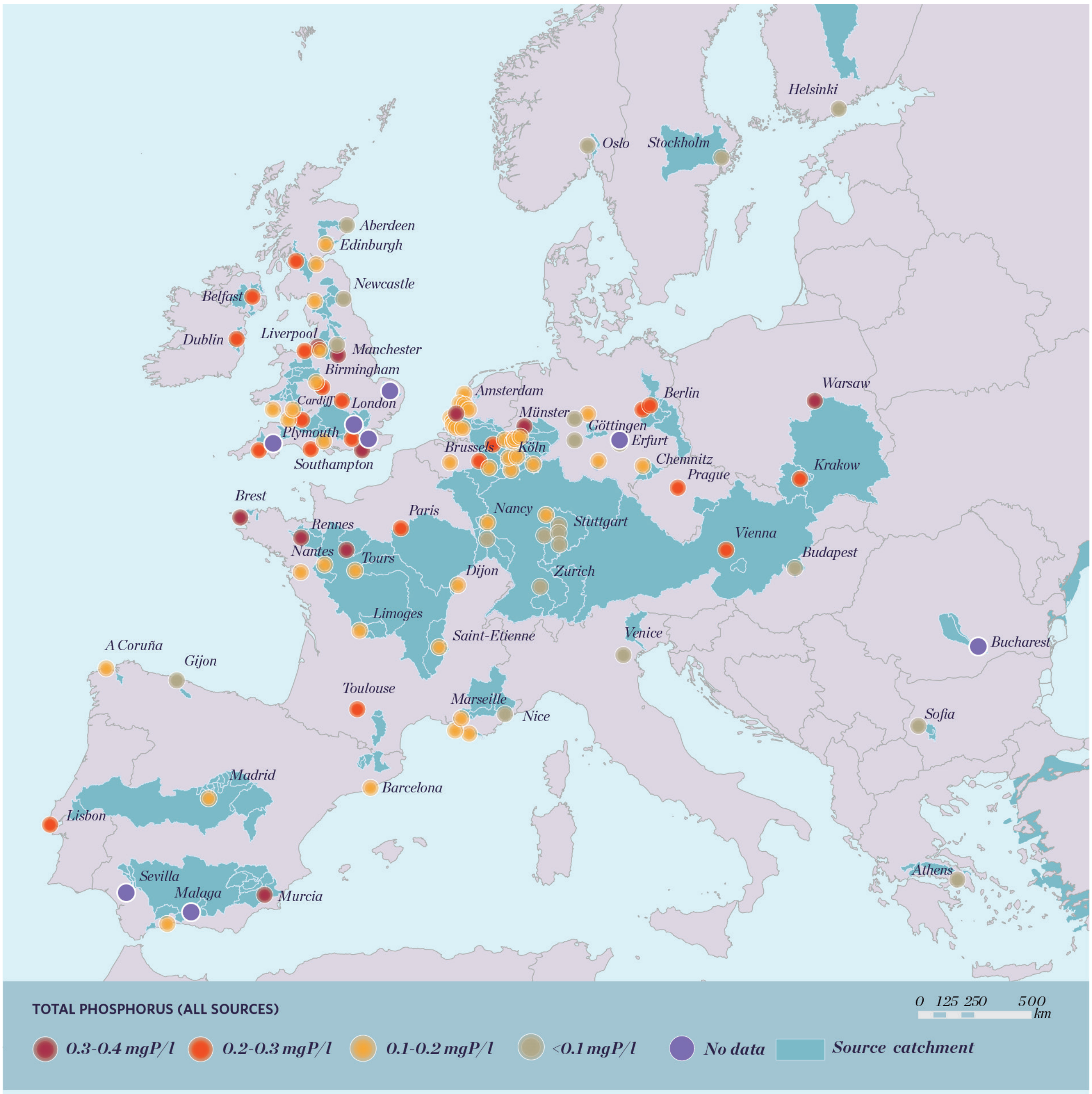


Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

Source: Authors' analysis based on data from Grizzetti et al. (2012)

FIGURE 4-9a

Estimate of instream total phosphorus concentration



Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

Source: Authors' analysis based on data from Grizzetti et al. (2012)

FIGURE 4-9b

Percentage of phosphorus pollution attributable to agriculture

Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

Source: Authors' analysis based on data from Grizzetti et al. (2012)

5. Harnessing nature to protect European surface water sources

We examined the potential for four nature-based solutions types to address diffuse pollution that affect the 109 cities analysed in this report. These include agricultural cover crops, riparian buffers, reforestation and forest protection.

Our analysis shows that nature-based solutions can be a feasible approach for supporting drinking water protection for many cities. Our analysis shows they have broad potential across the cities that we assessed, with 63 cities—representing 42 million people—demonstrating high feasibility potential for at least one NbS and pollutant type. While the costs of implementing NbS are difficult to estimate reliably at this scale (due to high variability), case study data suggest considerable differences in terms of costs according to NbS types, with the lowest costs associated with improved agricultural practices.

Planting of cover crops came out strongly as the NbS having the greatest potential to address sediment and nutrient pollution at the lowest cost. This is true for sediment pollution in particular, with 44 cities showing high feasibility potential for NbS implementation that would reduce sediment pollution. Forest protection could also be an important approach for reducing (avoiding) soil loss and protecting water quality for many of these cities: more than half of the cities in the sample have moderate to high feasibility potential for reducing sediment in waterways through forest protection.

Riparian buffers—while limited in their potential to improve overall catchment health as an individual strategy—are still an important NbS for protecting source catchments. Model results indicate that riparian buffers are limited in their ability to achieve pollution reduction at the catchment scale, where only nine cities are able to reach the 10 percent reduction target for annual sediment loads via investing in riparian buffers alone. However, at local scales, there is strong and convincing evidence that riparian buffers are highly effective at reducing sediment and nutrient pollution, with removal efficiencies greater than 70 percent for typical buffer widths (Lind et al., 2019). This suggests that, while riparian buffers alone are unlikely to achieve catchment-scale changes for most of the assessed cities, combining them with approaches that reduce pollution at source could be effective.

Cost savings for water providers can offset the costs of implementing nature-based solutions for catchment protection. This combined with the co-benefits that they generate means that nature-based solutions where they can deliver results at scale are a safe investment for cities and water service providers looking to boost the resilience of water supplies.

5.1. WHICH NATURE-BASED SOLUTIONS CAN HELP PROTECT SURFACE WATER SOURCES?

Four nature-based solutions for protecting surface waters were modelled in this report, including cover crops, riparian buffers, forest protection and reforestation. These were selected because of their broad applicability for these challenges and their proven performance.

TABLE 5-1
NbS for source water protection modelled in the report

NbS	*Description*
Cover crops	Planting of cover crops. These are an example of Agricultural BMP that can help limit sediment and nutrient runoff
Riparian buffers	Restoration of habitats natural habitat within a small strip on either side of a river or stream, to reduce erosion and improve water quality
Forest Protection	Purchase of land, land rental, fencing out cattle and funding for park guards to maintain watershed services
Reforestation	Restoration and planting of native trees, grasses and shrubs in critical areas to reduce erosion and related sediment transport

Source: Adapted from McDonald et al., 2014

We provide additional explanation on each of these categories of NbS below.

COVER CROPS: AN EXAMPLE OF AGRICULTURAL BMPs TO LIMIT SEDIMENT AND NUTRIENT RUNOFF

Agricultural best management practices (BMPs) are changes in agricultural land management to produce several positive environmental outcomes, including preventing or reducing agricultural non-point source pollution. These farming methods minimise risk to the environment without sacrificing economic productivity (Hilliard et al., 2002).

Three main methods can control diffuse water pollution at farm level. Pollutants can be tackled at source, during transport towards the water bodies and at the point where they are delivered to water bodies (IGER/ADAS, 2005). Pollution controls can be applied by the farmer at several stages: through planning and general farm measures, in-field, at the field margin or through riparian, in-stream measures (Vinten et al., 2005).

Many studies have shown that cover crops have been very successful at reducing sediment losses. Figures reported range from 7 to 87 percent, with an average reduction of 52 percent (Stevens and Quinton, 2009). A Finnish study demonstrated that planting cover in winter can reduce erosion by 10 to 40 percent and reduce nitrate leaching by 10 to 70 percent (Helsinki Commission, 2007).

Other agricultural BMPs can also significantly contribute. For example, contour farming is the practice of tilling sloped land along lines of consistent elevation to conserve rainwater and reduce soil losses from surface erosion. Conservation and management measures such as contouring have also had a significant impact on reducing soil loss (9.5 percent on average) in the EU during the last decade (Eurostat, 2018). These objectives are achieved by means of furrows, crop rows and wheel tracks across slopes, all of which act as reservoirs to catch and retain rainwater, thus permitting increased infiltration and more uniform distribution of water. The practice has proved effective to reduce fertiliser loss, power consumption and wear on machines, as well as to increase crop yields and reduce erosion. Contour farming can help absorb the impact of heavy rains, which in straight-line planting often wash away topsoil (Khot, 2018).

We can find many applications of agricultural BMPs in agriculture in Europe. Many such practices are funded through the agri-environmental measures included in the European Union Common Agricultural Policy. Alternatively, corporations have supported the adoption of such practices when they can significantly improve the quality of water downstream on which they depend economically. In France, for example, several mineral water companies have worked with farmers to reduce agricultural impacts on water. A historical example is the scheme by Nestle Water to protect the water catchment area for one of its brands, Vittel. Vittel developed the research programme Agriculture-Environnement-Vittel (AGREV) with the French National Agronomic Institute (INRA). It compensated farmers for changing their agricultural practices to reduce levels of nitrate and pesticide in the water downstream from the farms (Perrot-Maître, 2006; Illes et al., 2017; Hernandez & Benoit, 2011).

RIPARIAN BUFFERS

Riparian buffers restore natural habitat within a small strip on either side of a river or stream. Riparian buffers on agricultural land can play an important role in filtering runoff from the agricultural field, preventing sediment and nutrients from reaching the riparian area itself. Vegetated buffers within riparian zones are among the most well-studied and frequently used mitigation measures to reduce nitrogen, sediment and phosphorus losses to surface waters via runoff (Trémolet et al., 2019). They can help trap soil and flood water that is washed off bare fields. They prevent chemicals reaching waterways and maintain natural conditions within the water body. They can also provide valuable natural habitat for both riparian and terrestrial species, areas of carbon storage, and contributions towards services such as pest control and maintenance of a clean water supply. Stream buffers enhance habitat and biodiversity by providing terrestrial wildlife habitat and travel corridors, and food and habitat in aquatic ecosystems. Located at the interface between land and water, riparian and streamside areas provide permanent habitat for diverse organisms that require both aquatic and terrestrial habitats, including many species of fish and other instream organisms, amphibians, and terrestrial plants and animals. (Tompkins County Planning Department, n.d.).

Though riparian areas and stream buffers generally comprise a small proportion of the landscape, they provide a disproportionately high amount of habitat and ecosystem benefits, including by protecting water quality, stabilising streams, minimising flood damages and enhancing ecological diversity (Tompkins County Planning Department, n.d.).

Woodland buffer strips hold large promise in reducing sediment and nutrient delivery to rivers (Nisbet et al., 2011). Vegetated and woodland buffer areas can be placed in and around cropped fields and alongside watercourses to reduce nutrient and pesticide pollution and runoff. Buffer strips help to prevent pollutants from entering water by slowing the flow, depositing sediment and sediment-bound contaminants, intercepting them by vegetation, plant uptake and infiltration. The effectiveness of buffer strips in removing nutrients, pesticides and suspended solids is affected by the width of the strip, gradient of the drained field, soil type, and the variety and density of strip vegetation. A distinction can be made between 'edge-of-field' buffer strips, which are placed around fields and along watercourses, and 'in-field' buffer strips, positioned within cropped fields (Dabney et al., 2006).

In Europe, riparian buffers are commonly used in response to the Nitrates Directive's requirement to reduce diffuse pollution (EC, 2012). Most countries completely prohibit the application of fertilisers, plant protection products or tillage in buffer strips. Some EU countries also prohibit the grazing or cultivation of soil, whereas others allow limited agricultural use or require the harvesting of grass or the clearing of perennial crops within set time limits. Member States established mandatory standards for 'edge-of-field' buffer strips within the Good Agricultural and Environmental Conditions (GAEC) framework.[11]

Riparian buffers are deemed very effective at field level. The efficiency of nutrient removal depends on the width of the strips, with retention rates for sediment and total phosphorus as high as 98 to 99 percent for a width of 30 metres. Studies have shown that the effectiveness of well-maintained grass riparian buffers for sediment removal may be as high as 90 to 95 percent. For example, experiments with a grass buffer width of 8.53 metres have achieved 90 percent sediment reductions (Osmond et al., 2002). Efficiency and lifetime of buffer strips can be improved when the width is adjusted according to local conditions (Kronvang, et al., 2015b). Existing research supports their role to reduce sediment, especially particulate-bound phosphorus. However, existing studies show that their effectiveness for reducing dissolved phosphorus and nitrogen is more variable (Kronvang, et al., 2015a).

FOREST PROTECTION

Forest protection guards designated natural areas from development or other human land uses. This can be done through buying land outright or associated development rights or via the direct designation of land as protected by governments. Forest protection avoids the conversion of land, thereby avoiding future risk of increased sediment or nutrient transport, as opposed to reducing current pollutant levels. The realisation of such benefits depends upon the magnitude of forest loss risk: where the risk of forest loss is greater, there can be greater certainty that forest protection actually prevents elevated sediment and nutrients. In other words, forest protection is a viable strategy when such lands would otherwise be converted to agricultural or other landscape types.

While in recent years, forest cover is expanding in Europe as a whole, forest loss continues in parts of Europe, and the intensity of forest harvesting has intensified in others (FAO and UNEP, 2020; Buras and Menzel, 2019; Ceccherini et al., 2020). Additionally, the share of formally protected forest areas in Europe—particularly outside of western Europe—is among the lowest in the world, with only 5 percent of forest areas under some form of legal protection (FAO and UNEP, 2020). The protection of forest areas could not only support improved drinking water quality but also the resilience of these ecosystems in the face of future climate change, and it is directly aligned with the implementation of the EU Biodiversity Strategy's target to protect 30 percent of Europe's land territory by 2030.

11 Good agricultural and environmental conditions (GAEC) refers to a set of European Union standards aiming to achieve a sustainable agriculture.

REFORESTATION

Reforestation restores previously forested areas through either natural regeneration or tree planting. Reforestation reduces sediment and nutrient transport by stabilising soil. It also reduces nutrient transport by eliminating the deposition of manure and fertiliser to pastureland.

Restoration of arable land and managed grassland to forests reduces the level of nutrient inputs from fertilisers and organic amendments and increases the net capturing of nitrogen from the ground via tree nutrient uptake and removal in harvested biomass. This decreases nutrient leaching to groundwater and surface water on a local/regional scale (Rosenqvist, 2007). Moreover, phosphorus load decreases with an end to fertiliser use, tree uptake, and reduced erosion and sediment delivery to forests. Nutrient uptake is greater for more productive forest types and systems such as conifers and short rotations, and it declines with age, which calls for regular harvesting to sustain high nutrient uptake and removal. Such regular harvesting is important especially in areas such as riparian buffers, where woodland is used to intercept nutrient delivery pathways. Woodlands can also reduce faecal contamination, in contrast with intensively managed or grazed grasslands.

Given that a change in land use from agriculture to forestry replaces the annual cultivation/harvesting cycle with much longer forest cycles and involves less frequent soil disturbance, woodland creation increases on-site carbon sequestration (with implications for global GHG emissions), soil organic carbon/nitrogen stocks, and on-site soil fertility and quality (Mathers et al., 2010). Woodland creation helps reduce soil erosion and sediment delivery, increases soil infiltration, and reduces rapid surface runoff and downstream flood risk.

5.2 POTENTIAL IMPACT OF NBS ON SELECTED CITIES' WATER SOURCES

Using a global dataset developed previously by TNC (McDonald & Shemie, 2014; McDonald, 2016), we estimated the potential for nature-based solutions to reduce or avoid sediment and nutrient pollution if applied at scale in the catchments for selected cities. Using spatially distributed models of sediment and phosphorus loading, this data set incorporates multiple scenarios intended to approximate implementation of the four representative NbS types identified above (cover crops, forest protection, reforestation of pastureland and riparian buffers).

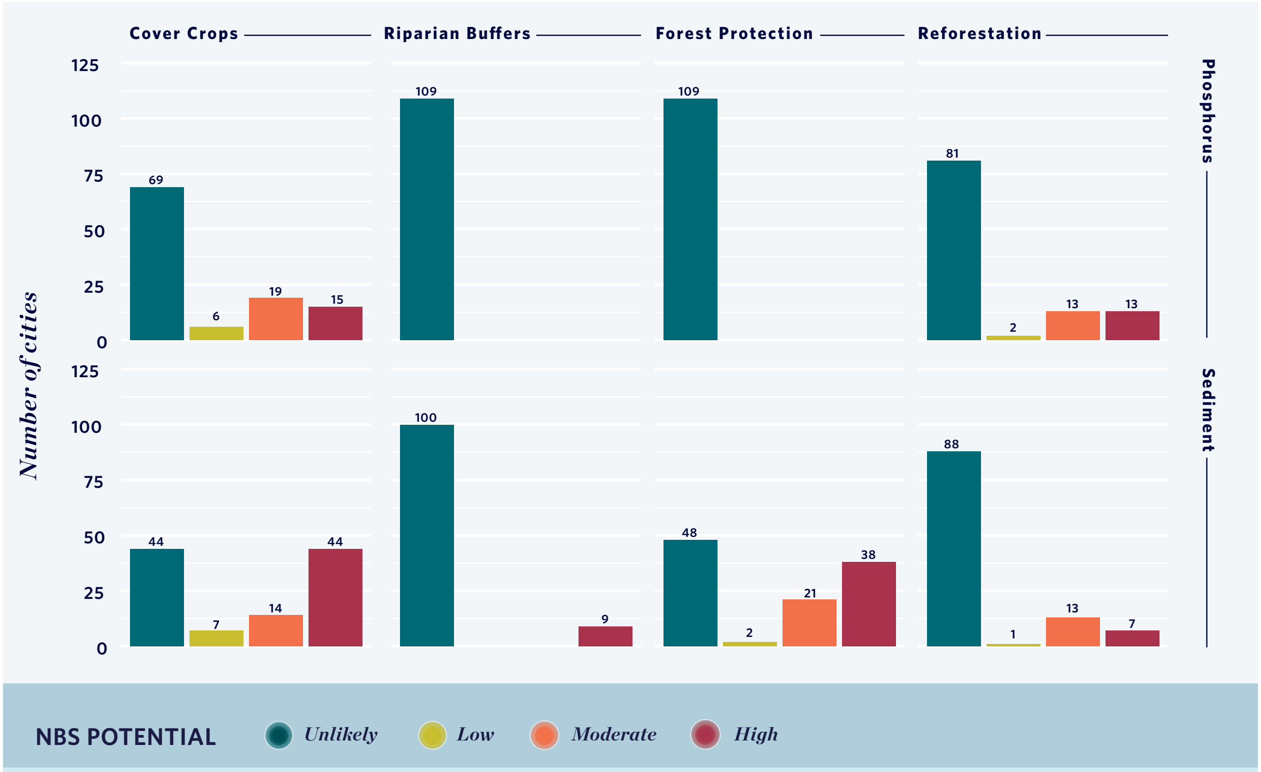
The models generate a simplified assessment of nature-based solutions' potential to generate a minimum level of pollution reduction. To determine the NbS potential for a given catchment and pollutant type, the models estimate the minimum implementation area (in hectares) needed to reduce diffuse pollution by 10 percent—for annual loads of either sediment or phosphorus. The selection of a 10 percent reduction threshold does not suggest the necessary mitigation threshold for any particular location. Rather, we use it as a minimum threshold for observable pollution reduction impacts. It is further important to note that these models consider each NbS type separately, whereas in practice NbS types are often employed conjunctively using multiple strategies (Trémolet et al., 2019). So, while model results may indicate that an individual NbS type cannot achieve the 10 percent reduction target, it is possible that a combination of NbS strategies, such as riparian buffers and other agricultural BMPs, could achieve such a reduction.

Model outputs were developed for phosphorus only. Previous work identified that nitrogen loading highly correlated with phosphorus loading, such that phosphorus loading is interpreted as indicative of nutrient loading overall (both phosphorus and nitrogen) (McDonald & Shemie, 2014). Additional details about our methodology, including important notes about assumptions and limitations, are provided in Annex B.

To compare across cities, we use a composite categorical ranking (from unlikely to high) to reflect the extent to which different NbS categories have the potential to significantly reduce pollution by pollutant type. Figure 5-1 presents the results of this analysis. It shows the number of cities that could benefit from the four NbS under review for phosphorus and sediment. While not prescriptive of specific NbS for any given city, the results indicate the scope of opportunity for different NbS and pollutants.

FIGURE 5-1

Comparison of NbS potential across different NbS and pollutant types



Source: Authors' analysis based on collected dataset

Figure 5.1. shows that out of the four NbS reviewed, planting cover crops has the greatest potential to mitigate sediment and nutrient (phosphorus) pollution for the larger number of selected cities. This is true for sediment pollution in particular, with 44 cities showing high feasibility potential for NbS implementation that would reduce sediment pollution. This further suggests that approaches that consider a broad suite of agricultural best management practices—in addition to cover crops—could have high potential for reducing both sediment and nutrient pollution.

Forest protection could also be an important approach for reducing (avoiding) soil loss and protecting water quality for many of these cities. More than half of the cities in the sample have moderate to high feasibility potential for reducing sediment in waterways through forest protection. While additional information is needed to understand what this would look like in practice—for example, whether forest lands are publicly or privately managed—the presence of forests within these cities' catchments strongly suggests the importance of forest protection as NbS for water quality.

Reforestation of previously forested land could also mitigate sediment and nutrient pollution. Restoration of these areas—including riparian corridors next to croplands—might mitigate sediment and nutrient pollution in assessed catchment areas. Forty of the selected cities indicate moderate to high potential for either forest restoration or riparian restoration. While the scope of these NbS types appears more limited than agricultural best management practices and forest protection, these could be important strategies for a subset of cities—or, more importantly, these strategies could effectively complement other NbS strategies. Restoration of these areas also could support other European initiatives and commitments, including that of the EU 2030 Biodiversity Strategy (European Commission, 2020).

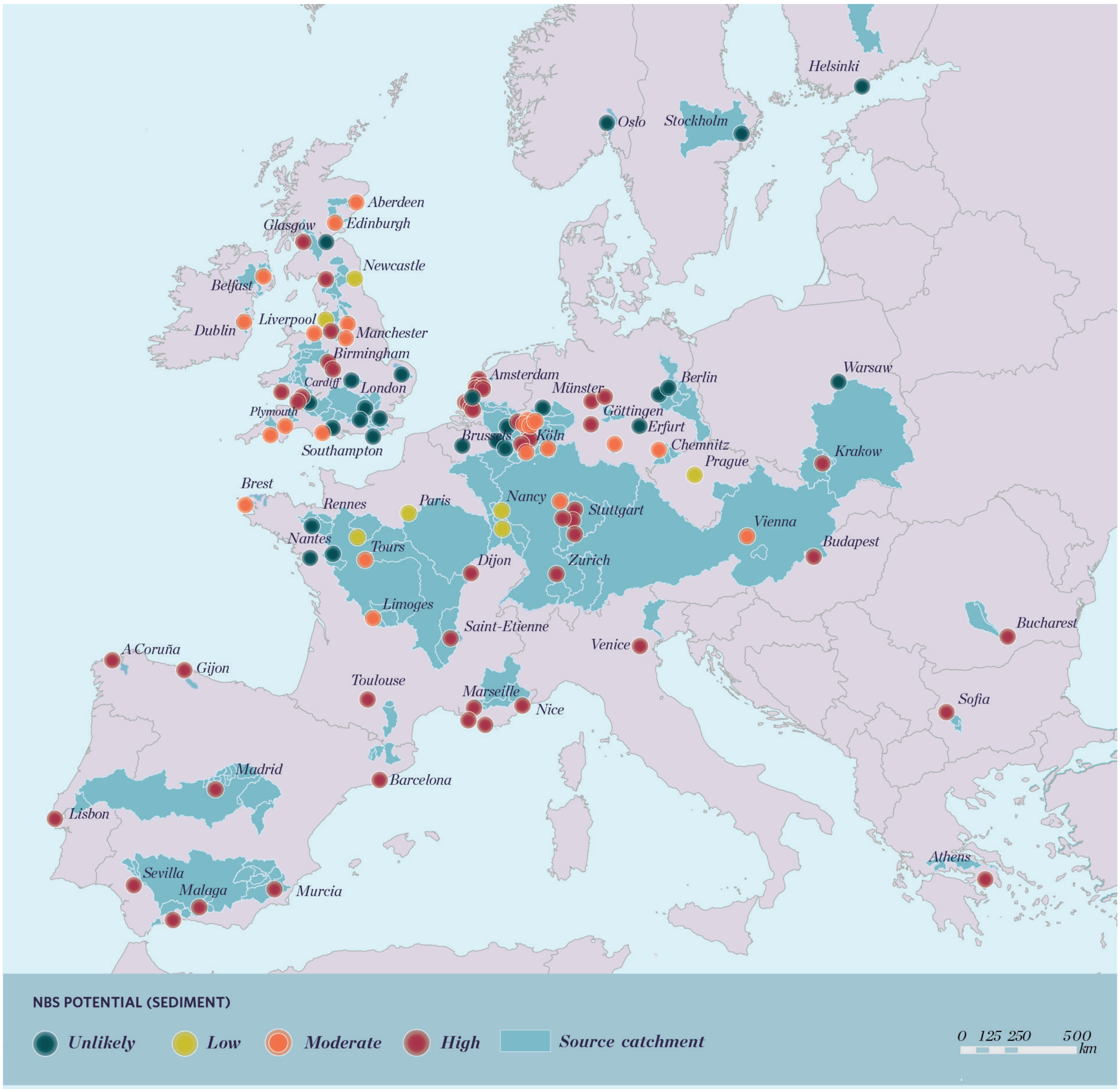
Riparian buffers—while limited in their potential to improve overall catchment health as an individual strategy—are still an important NbS for protecting source catchments. Model results indicate that riparian buffers are limited in their ability to achieve pollution reduction at the catchment scale, where only 9 cities are able to reach the 10 percent reduction target for annual sediment loads via investing in riparian buffers alone. However, at local scales, there is strong and convincing evidence that riparian buffers are highly effective at reducing sediment and nutrient pollution, with removal efficiencies greater than 70 percent for typical buffer widths (Lind et al., 2019). This suggests that, while riparian buffers alone are unlikely to achieve catchment-scale changes for most of the assessed cities, combining them with approaches that reduce pollution at source could be effective.

Overall, we see that nature-based solutions are a feasible approach for supporting drinking water protection for many cities across Europe. According to our analysis, NbS have broad potential across the assessed cities: 63 cities demonstrate high feasibility potential for at least one NbS and pollutant type, as shown on Figures 5-2 and 5-3. Cumulatively, these cities are home to 42 million people, who are on the one hand potential beneficiaries and on the other, potential sources of funding. In France alone, we identified 13 cities with high NbS potential which are home to more than 5 million people—over 90 percent of the population assessed within our city selection for that country. Given the approach for city selection, it is difficult to make broad statements regarding how these results might apply to NbS potential for other European cities. However, it is clear that NbS potential is broad and expansive across multiple countries, providing further support for the importance of mainstreaming NbS.

Riparian buffers are highly effective at reducing sediment and nutrient pollution, with removal efficiencies greater than ***70% for typical buffer widths***

FIGURE 5-2

Highest category of NbS potential to address soil loss

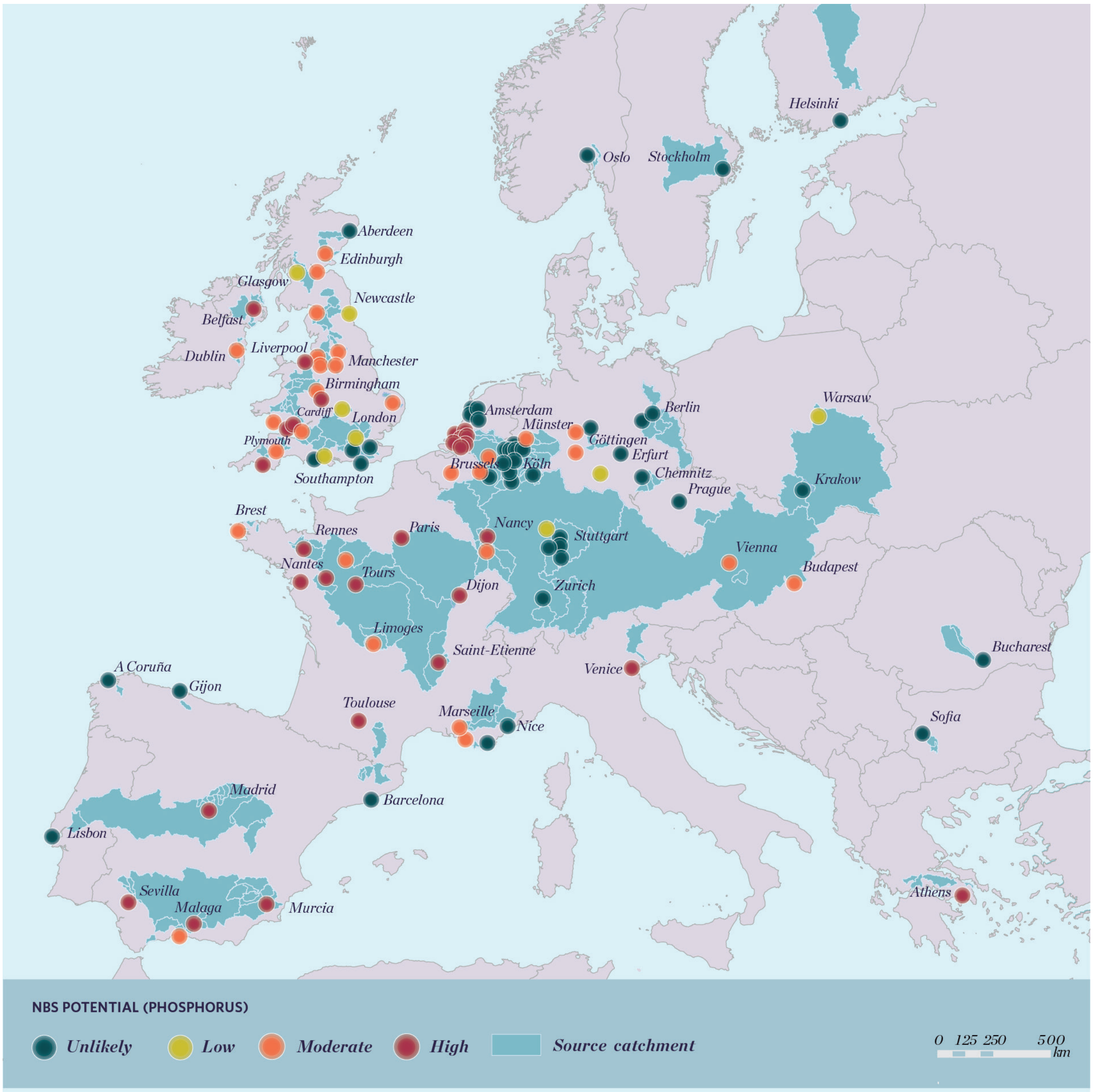


Note: The dots correspond to the 109 cities assessed for this report (see the full list in Annex C)

Authors' analysis based on collected dataset

FIGURE 5-3

Highest category of NbS potential to address phosphorus pollution



Note: The dots correspond to the 109 cities assessed for the report (see the full list in Annex C)

Source: Authors' analysis based on collected dataset

Our analysis for Manchester, for example, suggests that cover crops and forest protection have a high potential to alleviate sediment excess from soil loss in the catchments. For the same catchments, reforestation of areas that have been deforested or depleted could also play a significant role in reducing phosphorous excess and mitigating sediment pollution. In Madrid, cover crops also appear to have a high potential to reduce sediment pollution, as well as the amount of phosphorous in its waters. The protection of forested areas in the catchments (although limited in extension) also appears to have moderate potential to decrease sediment pollution in the city.

The results presented here provide an initial overall picture of nature-based solutions potential for the selected cities. They show that approaches that are limited in scope —either employing a single NbS solution or even using NbS approaches alone—are unlikely to fully protect drinking water supplies. A coordinated and strategic approach, in which several NbS types support multiple local and regional objectives, is likely to be the strongest way to advance the use of NbS across Europe. While the best course of action will vary by city, the prevalence of cities with moderate to high NbS potential makes a strong case for including NbS to protect urban drinking water supplies and restore the health of freshwater ecosystems.

It is important to emphasise the exploratory nature of these results. Given the significant uncertainties of underlying data, the results are most appropriately considered in aggregate—highlighting potential patterns and trends across the cities assessed. More efforts are needed to strategically target interventions as part of broader strategies. While we made an effort to account for the major determinants of pollution loading and calibrated models to other data sources on sediment and phosphorus loads, these results are not intended to suggest specific prescriptive actions for a given city or source catchment. This would require more robust and detailed examination of local conditions, as well as an account of costs and benefits from implementing those approaches at the local level.

5.3. POTENTIAL COSTS OF IMPLEMENTING NBS FOR SOURCE WATER PROTECTION

There are considerable differences in terms of the costs associated with different nature-based solutions, with the lowest costs associated with cover crops. Using data from documented programs in the UK and Ireland, we estimated total implementation costs for the four modelled NbS types—including capital expenses, operations and maintenance (O&M), financing and potential opportunity costs (see Annex B for more details on the methodology).

Review of the data collected from the UK and Ireland reveals that the costs of NbS implementation may vary by orders of magnitude, as shown on Table 5-2.

TABLE 5-2
Estimated implementation costs for NbS types modelled in this report

NbS Type	*Minimum cost (€/ha/yr)*	*Maximum cost (€/ha/yr)*
Cover Crops	2	13
Riparian Buffers	25	41
Forest Protection	199	239
Reforestation	374	641

Costs are presented as annualised figures under 30-year financing with a discount rate of 3.5 percent.
Source: Ecologic and The Nature Conservancy (2019).

Based on this empirical data, it appears that the implementation of cover crops is likely to have the lowest implementation costs. With comparatively low capital and opportunity costs, improved agricultural practices can be a more cost-effective approach to sediment and nutrient pollution reduction.

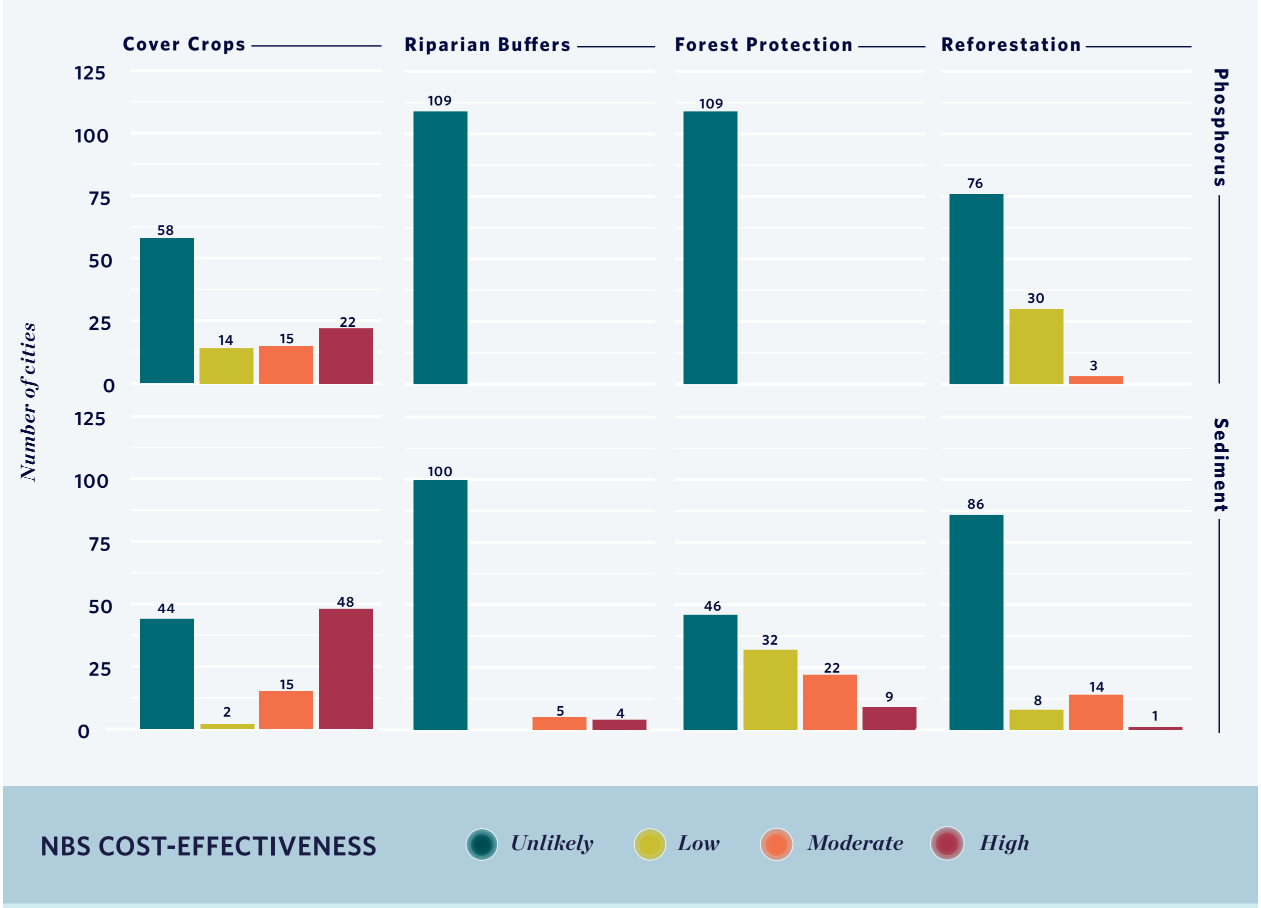
Reforestation is costly in comparison, with high initial costs for land preparation and planting, as well as potentially significant opportunity costs given that land is removed from agricultural production.

Comprehensive and reliable data sets for nature-based solutions costs are critically lacking at present, however. While the data used for this analysis are not necessarily representative of costs throughout Europe, they do provide an entry point for looking at the potential implications of the cost-effectiveness of different NbS types for source catchment protection.

Figure 5-4 presents data on implementation costs by nature-based solutions and pollutant type for the cities in our sample. For a given city and NbS and pollutant type, total costs are estimated using the average implementation area needed to achieve a 10 percent pollutant reduction. These area values are then combined with the cost values from Table 5-2 and population data in order to estimate annual per capita costs of NbS implementation. These values are interpreted to represent cost-effectiveness—whereby higher cost effectiveness is exhibited by cities with lower per capita costs of implementation.

FIGURE 5-4

Cost effectiveness for NbS and pollutant type based on annualised per capita implementation costs



Source: Authors' analysis based on collected data

The analysis suggests that taking account of cost-effectiveness criteria further emphasises the comparatively greater potential of agricultural BMPs for source catchment protection. Similar to considerations of implementation extent (area) alone, we observe that the application of NbS would be highly cost-effective in more than half of cities, particularly for sediment reduction, which alone accounts for 48 cities. In other words, whether NbS feasibility is considered in terms of area of implementation or per-capita costs, the general pattern of NbS potential for cover crops remains. The correspondence of these results suggests greater confidence in the potential for cover crops (and Agricultural BMPs in general) to support source catchment protection.

In contrast, where consideration of implementation area alone suggested forest protection as another strategy with good potential, cost considerations suggest a more cautious outlook. If the assumptions around comparatively higher costs hold true, forest protection may remain a viable approach for a smaller subset of cities. Thus, even though sediment reduction may be possible through forest protection, a strong focus on cost considerations would argue for giving priority to other approaches, with a particular focus on agricultural BMPs. However, full consideration of the co-benefits associated with forest protection (in terms of carbon sequestration and biodiversity) would probably tilt the balance and support their adoption as well.

5.4 POTENTIAL COST SAVINGS AND BENEFITS FROM NBS FOR SOURCE WATER PROTECTION

Cost savings for water providers can offset the costs of implementing nature-based solutions for catchment protection. Reductions in nonpoint pollution can lead to lower operations and maintenance (O&M) costs, including reduced material and energy inputs for water treatment plants. The Nature Conservancy previously estimated that a 10 percent reduction in sediment could on average result in a 2.6 percent reduction in O&M costs for water service providers (McDonald & Shemie, 2014). A study by the US Forest Service identified cost savings of a similar order of magnitude, where reducing sediment in the water by 1 percent was found to lower water treatment costs by 0.19 percent (Warziniack et al., 2017).

Besides lowering O&M costs, NbS can save capital costs. New York City is one frequently cited example where avoided capital costs have resulted in considerable savings. The city's water supply comes from three watersheds, 75 percent of which is forested area. Most of it is privately owned and managed. New York City invested in a working forests pollution prevention program in addition to its existing agricultural best management practices program, collaborating with landowners to reduce nonpoint source pollution at its source. This program provided an alternative to building a US$8 billion to US$10 billion treatment plant (Abell et al., 2017). Since its inception, the Watershed Protection Program has grown and evolved to respond and adapt to new challenges. A recent review of the programme published by the National Academies of Sciences, Engineering, and Medicine (2020) assessed its progress over these last two decades.

Examples of significant cost savings associated with nature-based solutions adoption can also be found throughout Europe (Trémolet et al., 2019), with some key examples summarised below.

BOX 5-1

Examples of cost savings associated with NbS for source water protection in France and the UK

EAU DE PARIS

Eau de Paris is the public water service provider for 3 million consumers in the city of Paris, France's capital. Since 2008, Eau de Paris has supported farmers with financial assistance programs that help them reduce fertiliser and pesticide use and adopt organic farming practices. Five of its staff disseminate good agricultural practices. The company has helped develop market opportunities for farmers' products, including in school canteens managed by the City of Paris. Eau de Paris has also purchased land where there is a specific risk of contamination, acquiring 574 hectares by 2018. Eau de Paris leases the land to farmers for one symbolic euro. In exchange, farmers engage in agricultural practices protecting water quality, including organic farming and grass-fed cattle rearing. Since early 2020, Eau de Paris has secured the authorisation from the European Commission to make direct "payments for ecological services" to the farmers that it works with. This was not previously allowed as it was considered to be a public subsidy: the rule change was considered a major breakthrough that could pave the way for replication in other cities.

EAU DU GRAND LYON

Eau du Grand Lyon, a Veolia subsidiary, provides and distributes water in the Grand Lyon, the metropolitan area surrounding France's third largest city, under contract with the municipality. It is actively protecting 375 hectares around water fields in the heart of the city. Based on ex-post calculation, they found that this "green infrastructure" (wellfields with source protection) is more cost-effective than building a water filtration plant—and generates biodiversity benefits. Total annualised costs associated with a typical coagulation and filtration plant would be EUR 52 million to EUR 74 million per year, compared to the annualised costs of the existing green infrastructure (EUR 32 million per year). The company has achieved significant savings on operating costs: EUR 0.04 per cubic metre for green infrastructure as opposed to EUR 0.15–0.25 per cubic metre for a typical plant.

WESSEX WATER

The water company Wessex Water in the UK adopted a catchment-based approach in 2005 to address high nitrate concentration linked to agriculture in its catchment. Instead of building more water treatment plants, the company engages farmers to protect water at source, including for 15 groundwater sources at risk from nitrates, one groundwater source threatened by pesticides and five reservoirs at risk from a combination of pesticides and nutrients. Wessex Water catchment advisers engage with landowners and farmers in the catchment to raise awareness, provide agronomic advice and develop agricultural management plans (for soil, manure, fertiliser and crop protection). The company estimates that the cost of this approach is one-sixth of a conventional treatment alternative and has a significantly lower carbon footprint.

Source: Trémolet et al., 2019

In addition to potential financial benefits for water providers and users, these interventions would generate significant co-benefits in terms of freshwater biodiversity (particularly where land development is a significant driver of species decline), carbon sequestration and avoided carbon emissions (where investments in grey infrastructure and associated energy consumption can be avoided). They also generate amenity value and positive impacts on health and well-being.

Whereas these co-benefits could not be estimated for this study at such a broad European scale, decisions to invest in NbS at the local level would need to take them into account. This would also enable mobilising different sources of funding for their implementation—for example, the sale of biodiversity offsets or carbon credits, or agricultural subsidies aimed at providing incentives to adopt agricultural BMPs.

6. Key findings and recommendations

6.1. SUMMARY OF KEY FINDINGS

The report has shown that European cities are dependent on the health of the catchments they rely on for their water supplies. Many such catchments have been substantially developed: for nearly two thirds of the cities reviewed in this report, more than half of their catchment areas has been converted to artificial or agricultural land.

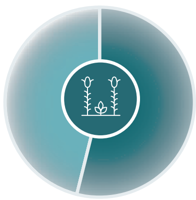
Such alteration decreases the ability of these catchments to provide beneficial ecosystem services for city water supplies. For more than one third of assessed cities, soil loss rates are considered high when compared to other European catchments.

Land activities are also a significant driver of nutrient pollution for selected cities' source catchment areas: for 40 percent of the cities in the sample, agriculture accounts for more than half of nitrogen and phosphorus pollution.

Nature-based solutions can clearly play a significant role to address water quality challenges, but this is not the case for all NbS, nor do they apply everywhere. We found that NbS have broad potential across the cities selected to tackle diffuse pollution—with 63 cities (home to 42 million people) demonstrating high potential for at least one NbS and one pollution type. To remove phosphorus, the analysis identified that planting cover crops holds moderate to high potential for 34 cities and that reforestation does so for 26 cities. With respect to sediment, a greater number of cities would stand to benefit, and from a broader range of NbS: 58 cities would see a significant reduction in sediment load from the adoption of cover crops, whilst 59 would benefit from forest protection, 20 from reforestation and nine from riparian restoration.

For methodological reasons, the analysis considered each NbS in isolation from the others. In practice, however, these measures would typically be implemented as part of a combined package aimed at delivering overall improvements, thereby increasing their overall effectiveness. Where source catchment protection can reduce pollution impacts, drinking water supply and freshwater species both stand to benefit. Identifying these synergies—and recognising the multiple values of catchment protection—can further support the case for nature-based solutions as a preferred option.

To remove phosphorus:



Planting cover crops holds moderate to high potential for

34 cities

Reforestation does so for

26 cities

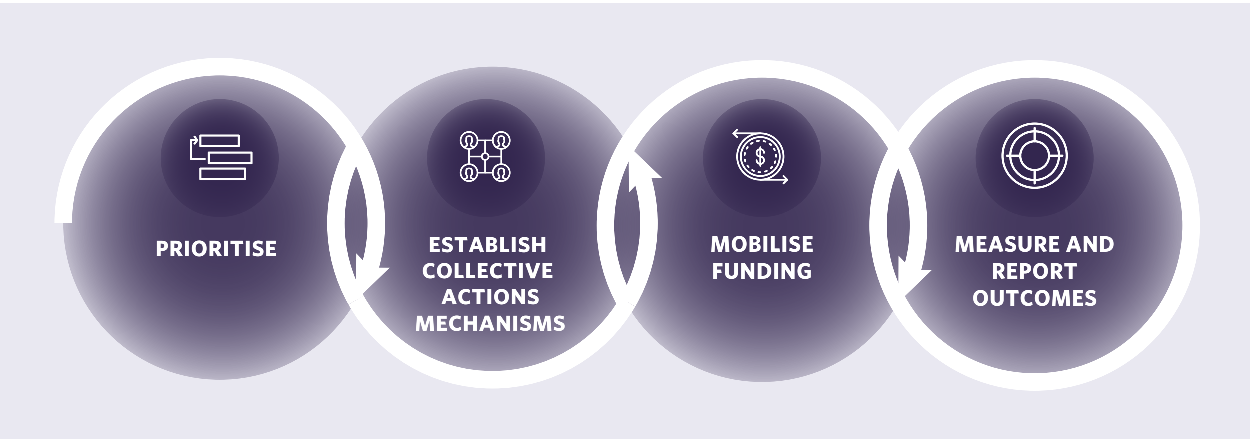
While exploratory in nature, these findings emphasise the broad applicability of NbS for clean water across Europe. For the cities identified as holding high potential for NbS implementation at scale, more detailed analysis is needed to confirm such potential and plan specific investment programmes. The identification of investment options must be done in an iterative manner, to help cities confirm potential before conducting further analysis. To that end, TNC is in the process of developing several tools, including an app (WaterProof) for estimating the return on investment (ROI) on catchment-scale investments for different NbS types which could be used by multiple actors looking to prioritise investments (see next section on Recommendations). To conduct further prioritisation, it will be necessary to develop a much stronger information basis, particularly on effectiveness and costs associated with different types of NbS. This also calls for clearer typologies of NbS and the associated development of standards so that it becomes gradually easier to compare the costs of NbS across geographies. Doing so is complicated by the fact that NbS are usually part of a comprehensive package of green and grey measures—so there are inherent limits on our ability to estimate unit costs of NbS for high-level cost-effectiveness assessments. But work in this area should be supported: building an information base for NbS will help decision makers more commonly adopt NbS as part of their water sector investment programmes.

6.2. RECOMMENDATIONS: ACCELERATING NBS ADOPTION TO TACKLE DIFFUSE POLLUTION

To deliver maximum impact on water security, nature-based solutions need to be implemented at scale, targeting the areas where greatest results can be generated. The coming seven years (from 2021 to 2027) present a unique opportunity in Europe to demonstrate how NbS can deliver substantial improvements to tackle diffuse pollution. This calls for a number of key steps to be adopted, including to prioritise where nature-based solutions can have the greatest impact, establish collective action mechanisms to enable coordinated implementation, mobilise funding and monitor outcomes, as shown in Figure 6-1. The recommendations presented here build upon and complement those that were set out for a broader set of water security challenges and NbS in the companion report (Trémolet et al., 2019).

FIGURE 6-1

Accelerating investments in NbS for tackling diffuse pollution in Europe



Prioritise

NbS work better to address diffuse pollution when certain conditions are in place. The present report identified physical factors that determine where investing in NbS at scale could deliver significant reductions in diffuse pollution. The underlying methodology can be used in different geographies to further identify priority areas in greater detail. It could be expanded to include a more expansive list of NbS—and possibly explore a greater set of water security, climate adaptation and biodiversity challenges. Additional prioritisation criteria need to be taken into account, such as conducive regulatory frameworks, social acceptability, alignment with local development plans and available land for NbS implementation.

Establish Collective Action Mechanisms

Water governance is typically complex as it touches on multiple sectors that all draw on—and compete for—water resources. Even though River Basin Districts are in place throughout the European Union, they operate at a scale that is usually too large to enable local actors to tackle specific diffuse pollution challenges. More localised, action-orientated collective action mechanisms, such as Water Funds (see Box 6-1) can help accelerate implementation and should be established where potential for applying NbS at scale has been identified. These can act as governance and funding platforms to mobilise funding against a prioritised investment programme, which could combine nature-based solutions and grey infrastructure (only where necessary) to tackle diffuse pollution. To be effective, these platforms need to operate with clear outcome targets and report on this basis.

Mobilise Funding

So far, NbS in Europe have mostly been funded through farming subsidies associated with the Common Agricultural Policy (CAP). Many other funding sources can be tapped, and this has already been the case in a number of places. For example, proceeds from water and sanitation tariffs, flood levies, land stewardship schemes, local taxes, corporate social responsibility or crowd-funding schemes have been mobilised but in a disjointed manner. In addition, more innovative sources, such as carbon or biodiversity credits, could generate substantial funding for NbS to improve water quality but have so far remained limited. In the context of the European Green Deal and COVID-19 recovery plans, substantial public funding will be allocated to such interventions: it will be essential for such funding to be effective that it is provided to collective action mechanisms with long-term planning in place to ensure that investments are sustained over time.

Measure and Report on Outcomes

Despite substantial investments in the past, diffuse pollution from nutrients and sediment has remained high, and its impacts will worsen with climate change. Establishing collective action mechanisms with clear outcome targets will create accountability and enable better tracking of the effectiveness of NbS (and associated measures) on environmental outcomes.

BOX 6-1
Water Funds: examples of collective action mechanisms to tackle diffuse pollution

Water Funds are financial and governance mechanisms that coordinate public, private and civil society actors to contribute to water security through nature-based solutions. Water Funds are adapted to the local context and they promote long-term systemic change. Their creation is based on scientific evidence to identify whether and how NbS can contribute to water security in their area of intervention. Water Funds operate under different financing and governance models with the following common features:

- Develop a shared vision that translates into actions to achieve water security;
- Bring together different actors who, through collective action, promote the political will necessary to achieve meaningful and positive impacts;
- Influence local water governance and decision-making processes;
- Drive the launch of natural infrastructure projects and other innovations in the target catchments;
- Mobilise diverse funding and financing sources (both public and private).

The first Water Fund was established in Quito in 2000 in response to growing water demands and concern over watershed degradation. The municipality of Quito, the water company of Quito and The Nature Conservancy helped create the Fund for the Protection of Water (FONAG). The goal was to mobilise critical watershed actors to exercise their civic responsibility on behalf of nature, especially related to water resources. The multi-stakeholder board—composed of public, private and NGO watershed actors—provides a mechanism for joint investment in watershed protection, including supporting the communities that live there. FONAG conducts source water protection through a variety of mechanisms. First, it works to protect and restore high Andean grasslands (páramos) and Andean forest in critical source areas of water for Quito, including those owned by local communities, private landowners and the Quito water company. FONAG also focuses on strengthening watershed alliances, environmental education and communication to bring additional watershed actors. Working with several academic institutions, FONAG has also established a rigorous hydrologic monitoring program to communicate and improve outcomes of investments. FONAG has an endowment of more than US$10 million and an annual budget of more than US$1.5 million. The largest source of funding (nearly 90 percent) comes from Quito's water company, which by a municipal ordinance is required to contribute 2 percent of the water company's annual budget. Since its inception, FONAG has worked to protect and/or restore more than 40,000 hectares of páramos and Andean forests through a variety of strategies, including working with more than 400 local families.

Another 40 Water Funds have since been established with support from The Nature Conservancy, including throughout South and North America as well as in Nairobi (Kenya) and Cape Town (South Africa). The establishment of a Water Fund is under preparation in Norfolk (Eastern England), with support from Norfolk County Council, Water Resources East (a regional water planning platform) and water utility Anglian Water.

In Europe as in other regions of the world, many of the existing collective action mechanisms to address nutrient and sediment pollution are led by water service providers, in collaboration with local and regional authorities, as well as the third sector. Some examples in Europe include Eau de Paris, Veolia, UK utilities such as Wessex Water, Anglian Water or United Utilities, and German utilities such as SWA Augsburg.

Source: Trémolet et al., 2019

European stakeholders need to play complementary roles to accelerate implementation. Recommendations are set out below for different types of actors and key areas of intervention. Although these are focused on the issue of tackling diffuse pollution, in line with the focus of this report, several recommendations could apply to other NbS to address other water security challenges.

PRIORITISE

- In the review of the second RBMP cycle (due in March 2022), EU institutions and national authorities should assess where NbS have been adopted to address diffuse pollution, analyse which NbS were used, at what cost, with which impact. This should cover but not be limited to NbS funded through CAP subsidies, to identify the scope for improving the design of the "eco-schemes" under the reformed CAP to deliver water quality outcomes.
- EU institutions should incorporate water quality objectives in the implementation of the EU Biodiversity Strategy, including for the designation of protected areas (which should include protected rivers) and definition of priorities for tree planting. Clear criteria should be defined so that reforestation and forest protection plans take full account of water availability and of the potential for these forests to contribute to reducing water pollution and reduce soil loss.
- In the new EU Adaptation Strategy, EU institutions should clarify the links among a hotter climate, soil loss and increased water pollution and recommend adaptation strategies that can simultaneously address these challenges where they are linked.
- Member States should ensure that NbS are prioritised in the preparation of the third RBMP (2022-2027), which are due to be finalised by the end of 2021.
- Water service providers that operate across multiple geographies (such as French leaders Veolia or Suez or regional companies in the United Kingdom, Portugal or Italy) should identify where, based on the priority cities identified in this report, they can invest resources to lead on the development of collective action mechanisms to facilitate investment in NbS for water security. This particularly applies to companies that have stated explicitly their willingness to act as change agents for the ecological transition (in purpose statements or other company-level declaration of objectives).
- Large-scale water users that operate in multiple locations (such as food and beverage companies or industrial users) and have defined water stewardship objectives should identify locations where they have an interest (and the opportunity) to act as water stewards and support NbS to tackle diffuse pollution.
- Associations of land-owners, farmers and forest managers should work with their members to help them identify where investing in nature-based solutions can generate greatest results and assist them to join collective action mechanisms to accelerate implementation.

ESTABLISH COLLECTIVE ACTION MECHANISMS

- EU institutions, city networks and other parties should identify and disseminate cases where collective action mechanisms have been established throughout Europe, with a focus on assessing the drivers for their establishment, evaluating governance mechanisms and potential for replication.
- EU institutions, national authorities and RBDs should support the creation of dedicated collective action mechanisms to tackle diffuse pollution and encourage that they be explicitly considered in the third RBMPs.

- MS should establish regulatory and planning frameworks that incentivise city authorities and their water service providers to take the lead in setting up collective action mechanisms, to channel greater resources to investing in NbS in a coordinated and targeted manner and incentivise performance based on environmental outcomes rather than the implementation of end-of-pipe grey infrastructure solutions (and associated outputs).
- Cities and/or water service providers should lead on the establishment of collective action mechanisms to tackle diffuse pollution and address other water security challenges in their upstream catchment. Such a role would need to be legitimised and adequately remunerated through regulatory regimes that recognise the value of such services. Water service providers are held to strict licensing standards at present in terms of pollution controls that often tie them to end-of-pipe approaches. Instead, they could benefit from helping other actors across the catchment to address diffuse pollution and deliver positive environmental outcomes. Few other actors would have the mandate, the legitimacy, the level of professionalism and, most importantly, access to the financial resources that would allow them to take the lead for setting up effective collective action mechanisms.
- All potential implementers of NbS (including farmers and forest managers) should be supported to join collective action mechanisms, so that they can partake in prioritised plans for NbS implementation, coordinated funding streams and joint monitoring.
- EU institutions and city networks should encourage cities to join the EU Green City Accord and ensure that they include water stewardship beyond their boundaries as a key plank of their engagements under this framework.
- EU institutions and city networks could launch innovation prizes and awards, to encourage the best experience and practice in this area to come forward, be rewarded or be provided with technical support and additional human and financial resources (in the case of an ex-ante prize).

MOBILISE FUNDING

- EU institutions, MS and other interested actors should fund research to compile comparable and robust data on the effectiveness, costs and associated co-benefits of NbS to tackle diffuse pollution. This would enable integrating NbS in green-grey investment plans on a more routine basis, as a key limiting factor tends to be the lack of reliable cost-effectiveness data.
- EU institutions should encourage MS to dedicate significant sums to tackling diffuse water pollution as part of their National Recovery and Resilience Plans.
- MS should allocate funding under third RBMP cycle to coordinated initiatives to tackle diffuse pollution (preferably with collective action mechanisms in place).
- EU institutions and MS should pro-actively support schemes that enable channelling Payments for Ecosystem Services from downstream users towards actors in charge of implementing NbS in the upstream catchment. In 2020, Eau de Paris was granted permission by the European Union to financially support farmers in its upstream catchment. This sets a precedent that will facilitate the adoption of similar schemes in other locations.

- Cities and water service providers should establish Payments for Ecosystem Services schemes to remunerate parties in upstream catchments that implement NbS in a targeted manner to deliver maximum impact, generating environmental benefits and traceable cost reductions for water supply services.
- Funders and financiers operating across Europe can use the report findings to target their resources (including for project preparation and intermediation) on cities and surrounding catchments that are most affected by diffuse pollution challenges and where NbS have the greatest potential to deliver results.
- Intermediaries (such as NGOs, banks or consultancies) can support key actors with the preparation of NbS investments at scale to tackle well-defined problems and with the establishment of collective action mechanisms.
- Where possible, repayable financing should be mobilised to bring forward benefits from the adoption of NbS to tackle diffuse pollution at scale. This should particularly be considered when there are substantial up-front costs, particularly those associated with reforestation or forest protection or other types of NbS associated with significant up-front investments.
- The EU Taxonomy can provide a guide to investors as to which NbS for water security can be considered as sustainable investments.

MEASURE AND REPORT ON OUTCOMES

- For any EU funds disbursed for tackling diffuse pollution (via the CAP, Structural Funds or the Recovery and Resilience Facility), EU institutions and MS should ensure that strong monitoring frameworks are in place to track pressures and progress in a transparent manner with prioritised measures and environmental outcomes. Consider funding moratoria where those are not in place.
- Regulators (either at national, regional or city level) should reformulate water service providers' contractual or regulatory obligations to enable them to work outside their service areas towards joined-up outcomes with other actors, rather than towards limited outputs.
- Performance indicators for collective action mechanisms should be defined as collective outcomes (for example, to reduce sediment or nutrient load in a water body by x amount), with clear mechanisms for tracking the contribution of each party to this collective achievement.
- Reporting on outcomes and in-depth evaluation of what works (and what does not work as well) will enable generating and sharing lessons. Mechanisms for rapidly reflecting learning into implementation should be established to accelerate and improve implementation.

Annex A
Case Studies

Manchester, UK

OVERVIEW

Number of catchments

2

Catchment landuse

WATER RISK

Quality

- Moderate soil loss (0.2 t/ha/yr)
- Low nitrogen pollution (<2 mgN/l)
- Moderate phosphorus pollution (0.1-0.2 mgP/l)

Quantity

- Low water depletion risk (<5%)

NATURE-BASED SOLUTIONS

Cover Crops

- High sediment reduction potential

Riparian Buffers

- Unlikely scope

Forest protection

- Low water depletion risk (<5%)

Reforestation

- Moderate sediment reduction potential
- Moderate phosphorus reduction potential

WHERE DOES THE CITY GETS ITS WATERS FROM?

Greater Manchester is a metropolitan county and combined authority area in North West England with a total population of 2.8 million—the third largest metropolitan area in England after Greater London and the West Midlands. Greater Manchester's waters come from four river catchments: the Irwell, Upper Mersey, Lower Mersey and Douglas.

This case study gives an overview of the larger metropolitan area of Greater Manchester and its wider catchment, looking at interconnected water challenges and green infrastructure initiatives related to water security issues. In terms of the scientific analysis of water sources and risks to assess the potential of the use of NbS, the study looks at water sources serving the city of Manchester only.

Manchester city is one of the metropolitan boroughs of and the principal city in Greater Manchester, home to about 530,000 people. Water is sourced from the Thirlmere reservoir and brought to the city via the 160-kilometre Thirlmere Aqueduct. An additional main source of water is the Haweswater Reservoir, linked to the urban area via a 90-kilometre aqueduct. Both Thirlmere (part of the North West river basin district) and Haweswater (part of Solway Tweed river basin district) reservoirs are located in the Lake District area, a mountainous national park in the region of Cumbria declared a Unesco World Heritage site in 2017.

The 1973 Water Act mandated the aggregation of locally owned water and sanitation service providers and transfer of a range of water-related responsibilities to regional water authorities.[12] As a result of this legislative change, ownership of the reservoirs and of the aqueduct (as well as the area surrounding the reservoirs) was transferred to the North West Water Authority. Following privatisation of water service providers in England and Wales in 1989, North West Water became the owner of these assets. In 1995, the company became United Utilities, one of the largest water utilities in the UK, with the merger of North West Water and NORWEB.[13] Today, the group manages the regulated water and wastewater network in North West England, including in Greater Manchester, Cumbria, Cheshire, Lancashire and Merseyside, with a combined population of nearly seven million.

12 As a result, 200 public water suppliers and almost 1,400 public sewerage authorities were consolidated into 10 regional water authorities with boundaries based mainly upon river catchments. Private water companies continued to serve approximately 25 percent of the population. Regional water authorities were established to carry out integrated river basin management (IRBM) activities and provide water and sanitation services in the region (World Bank, 2005).

13 NORWEB was a British electricity supply and distribution company. After the merger, the electricity supply arm was sold off in 2000.

HOW DOES WATER POLLUTION AFFECT THE CITY?

According to the latest River Basin Management Plans (RBMPs)—prepared by the Environmental Agency every six years to meet Water Framework Directive's obligations—the basins that serve Greater Manchester are characterised by a high risk of both sediment and nutrient pollution.

In the North West river basin district (RBD), where the Thirlmere reservoir is located, pollution affects 18 percent of water bodies. In this river basin, changes in land management have increased the amount of sediment that is being washed off the land, carrying phosphorus into the waters, which in turn can cause eutrophication. Land management issues are exacerbated by increasingly intense rainfall, causing pollutants to enter into water systems in the upscale catchments or across catchments. Furthermore, historic land management and degradation of peatlands affects both water colouration and other issues. Loss or changes to surfaces in an urban context, coupled with the impact of a changing climate, also increase water security risks and vulnerability.

Nitrates from fertilisers have built up in groundwater in the RBD over decades and will take a long time to reduce. Sedimentation from erosion, forestry practices, saturated and compacted fields, and livestock trampling on riverbanks has affected river ecology in the area. Other impacts include contamination from animal faeces and livestock slurry being washed off the land, as well as pesticides from farming, forestry, golf courses and parks. These contaminants pose a particular threat to drinking water.

Physical modifications are also affecting 50 percent of water bodies in this river basin district. People have made many physical changes to rivers, lakes and estuaries—for example, flood defences and weirs, and changes to the size and shape of natural river channels for land drainage and navigation. These modifications alter natural flow levels and cause excessive build-up of sediment in surface water bodies and the loss of habitats and recreational uses. The Thirlmere reservoir has historically experienced turbidity during storms. In 2015, for instance, the reservoir was so badly affected by flood runoff that United Utilities had serious trouble dealing with high levels of turbidity in the reservoir, forcing it to put the reservoir out of service for a period of time.

This case study focuses on two main pressures on water quality: sediment from soil loss and phosphorus from excess fertiliser use. For the city of Manchester, a continental-scale model of net soil erosion developed for the EU confirms that the level of excess phosphorus in the catchment is high, potentially increasing the risks of nutrient-related water quality impacts. Sediment pollution from soil erosion into streams also represents a comparatively moderate risk for the city's water resources.

WHAT NBS ARE BEING ADOPTED TO ADDRESS WATER POLLUTION, AND WHAT MORE COULD BE DONE?

Local institutions, including the Greater Manchester Combined Authority (GMCA, made up of the 10 Greater Manchester councils and the mayor) and United Utilities for some time have been considering and investing in nature-based solutions to address the challenges they face. They have initiated a number of projects that highlight the role that NbS can play to tackle water quality issues in the region.

Following the 2015 turbidity incident in the Thirlmere reservoir, United Utilities has planned to invest GBP 5 million in a programme of tree planting and land stabilisation around the catchment, to reduce potential runoff from future floods in its current investment period, 2020 to 2025. This will improve water quality by

reducing the amount of soil and debris washing into the reservoir.

Another example is Natural Course, an EU LIFE Integrated Project led by the Environmental Agency in collaboration with the GMCA, United Utilities and other organisations such as Natural England and the Rivers Trust. This EUR 20 million project started in 2015 and will run until 2025. The overall strategy is to work in a more integrated way to address the barriers preventing the region from achieving Water Framework Directive "good" status in the North West of England. Through Natural Course, the organisations are working together to tackle diffuse pollution from urban and rural sources and flood risk management challenges in the area. The geographical focus for Greater Manchester is the densely populated Irwell catchment, which also provides water to Greater Manchester and is classified as "heavily modified" with poor or, at best, moderate ecological status.

The Natural Course project has so far produced a better understanding of the governance of the water sector across Greater Manchester in a complex urban environment with a rapidly evolving political agenda. Bringing together the Natural Course project, the GMCA, Natural Capital Group and the Urban Pioneer Work Programmes to support the integrated delivery of a natural capital agenda is a great example of the value of the project. Another example is the adoption of an evidence-based approach to integrated catchment planning, resulting in the Catchment Based Approach (CaBA) delivery plans, tools and data sharing, and solutions to long-standing physical barriers, delivered by the Rivers Trust.

Greater Manchester is also the first city-region in the UK to have developed a Natural Capital Investment Plan. The plan aims to encourage investment in the natural environment to secure financial and social returns (including water quality). The plan has three key parts: defining a pipeline of potential project types which need investment; establishing financial models to facilitate private sector investment and the role of public sector; and formulating recommendations to put the plan into practice over the next five years. Among project types identified as having the highest and most predictable revenue streams were catchment-scale initiatives for water quality, forest management and new woodland creation, and outcomes-based payment models for agribusiness. To mobilise financing, carbon and habitat banking initiatives are being considered, and a number of initiatives have looked at local NbS for flood management and wider up-river basin interventions which would start to address some of the water quality impacts affecting the area.

A key challenge for the region remains drawing an aggregate estimated potential of the impact of NbS at scale, given the size and the geographical and governance complexity of the area. Using the methodology described in Annex B, we examined the potential for NbS to reduce water pollution due to excess phosphorus and soil erosion, focusing on where a 10 percent reduction, at least, is achievable. Our analysis for Manchester suggests that cover crops and forest protection have a high potential to mitigate sediment excess from soil loss in the catchments. The reforestation of areas that have been deforested or depleted could also play a significant role in reducing phosphorus excess and in decreasing sediment pollution.

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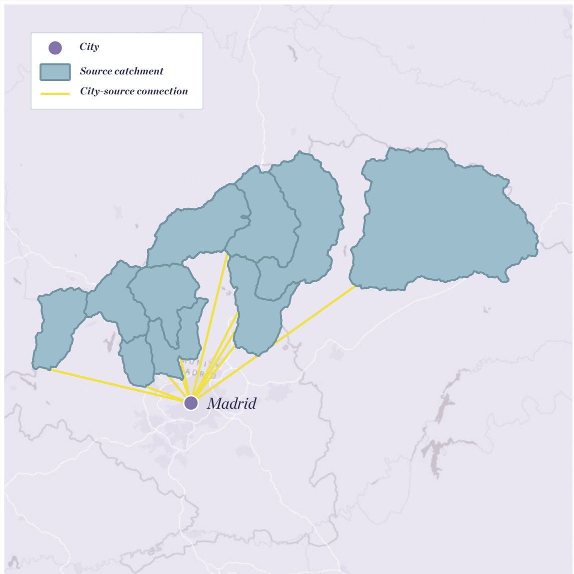
Madrid, Spain



OVERVIEW

Number of catchments

11

Catchment landuse

WATER RISK

Quality

- Moderate soil loss
- High excess phosphorus

Quantity

- Moderate stress (dry-year)

NATURE-BASED SOLUTIONS

Agricultural Best Practices

- High sediment reduction potential
- Moderate phosphorus reduction potential

Ripiarian restoration

Unlikely scope

Forest protection

- Moderate sediment reduction potential

Reforestation

Unlikely scope

WHERE DOES THE CITY GETS ITS WATERS FROM?

Water for the city of Madrid and its entire region comes from more than 11 surface water diversions in an area that spans 550,000 hectares—nearly ten-fold greater than the urban area itself. One of the main sources of water for the city and its region is the river Lozoya, in the Sierra del Guadarrama, in the mountains surrounding Madrid. The River Lozoya accounts for nearly 50 percent of the total water supply for the metropolitan area of Madrid. It has been significantly modified, with the construction of a series of reservoirs which take up roughly 50 percent of the river's length. The El Atazar reservoir is the most important for the Community of Madrid, accounting for almost 30 percent of the total volume of water impounded to supply the Community (Canal de Isabel II, 2019).

Canal de Isabel II is the company that delivers water supplies to the city of Madrid and surrounding areas. It is owned by the Community of Madrid. The name derives from a canal built in 1851, under the order of the reigning queen at the time, Isabel II. This public work project consisted of creating a series of reservoirs in the Lozoya River northwest of Madrid to bring water to the city. Over time, it expanded to the rest of the region. Canal de Isabel II now serves the 6.5 million people in the Madrid area and manages 13 reservoirs, 78 wells, 34 large water tanks and 294 small tanks, 14 treatment plants and 157 sewage treatment plants. Most of the company's catchment areas are located in the surroundings of the Sierra de Guadarrama National Park and other natural spaces of the Natura 2000 Network.

The city of Madrid and the entire region falls in the Tagus River Basin District and is managed by The Tagus River Basin Authority *(Confederación Hidrológica del Tajo)*. The Tagus River Basin is an international basin district shared by Spain and Portugal.

HOW DOES WATER POLLUTION AFFECT THE CITY?

Data provided by the European Environment Agency for the basin as a whole shows that only 30 percent of surface water bodies reach good ecological status in the Tagus RBD. A total of 40 percent of rivers and almost 60 percent of lakes in the basin are not in good ecological status, due to point source pollution (affecting 67 percent of water bodies) and diffuse pollution (affecting 30 percent). Other important pressures in the basin are excess abstraction and hydromorphological effects. However, the territory of the Community of Madrid is located at the head of the basin, where water bodies are significantly better conserved than the rest of the Tagus basin.

The most common problem preventing the achievement of good chemical status is the impact of pollution from

diffuse sources. In many areas, these exceed the limits set out by the WFD concerning the protection of waters against pollution caused by nitrates from agricultural sources. The nitrogen and phosphorus content of wastewater in Madrid, although in compliance with wastewater treatment regulations, prevents it from achieving the objectives set forth in the Water Framework Directive in downstream rivers. To avoid this, Canal de Isabel II has been focusing on repairing and maintaining its water infrastructure. For several years it has been working on investments to expand and improve its treatment plants. As part of its 2018-2030 Strategic Plan, these efforts are aimed at achieving the objectives of the WFD, especially with regard to eliminating nutrients such as phosphorus and nitrogen.

Given the different land use influences in the catchment areas around Madrid, surface waters are exposed to a wide range of contaminants. The number of studies assessing the contamination patterns in the watershed and associated risks are limited (Rico et al., 2019). The impact of pesticides has not been evaluated in the upper areas of the catchments, including Madrid. Studies targeting the identification of priority contaminants at a basin level, including pesticides, point source chemicals (such as pharmaceuticals) and other potentially hazardous substances, such as metals, are unavailable.

For the city and region of Madrid, the model developed for this study suggests that the level of excess phosphorus in the catchment is high, potentially increasing the risks of nutrient-related water quality impacts. Additionally, sediment pollution from soil erosion into streams represents a comparatively moderate risk for the city's water resources.

WHAT NBS ARE BEING ADOPTED TO ADDRESS WATER POLLUTION, AND WHAT MORE COULD BE DONE?

Despite focusing mainly on repairing and maintaining its grey infrastructure, Canal de Isabel II has also traditionally worked for the protection of the water catchments. This activity has included reforesting the basins of the reservoirs and limiting uses that are incompatible with maintaining water quality, such as recreation or motor navigation in the reservoirs and livestock farming. Banks and riverbeds are also cleaned to improve the quality of water bodies.

Since 2002, the reservoirs managed by the Canal de Isabel II have had management plans that protect them from activities that could worsen water quality. In 2020, these plans are still under review to adapt them to more demanding criteria related to sustainability and biodiversity in their basins. In addition, the company´s 2018-2030 Strategic Plan includes specific actions to strengthen protections. Specifically, it is working to better understand the dynamics of the reservoirs, study the catchment areas and develop mathematical models of the evolution of their behaviour. The Strategic Plan included provisions to protect the city´s water basins, reservoirs and aquifers to maintain and improve the quality of their water resources. Furthermore, it aims to involve society and local administration in its protection plans.

Going beyond these specific interventions, our analysis for Madrid suggests that cover crops have a high potential to mitigate sediment excess from soil loss in the catchments, as well as to reduce the amount of phosphorus in its waters. Protecting the forested areas in the catchments (although limited in extension) would also have a moderate potential in reducing sediment pollution.

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Annex B
Detailed Methodology

This annex presents the methodology used for conducting the analysis underlining the report for:

- Selecting cities and identifying relevant water sources;
- Characterising catchment threats in terms of water depletion and pollution; and
- Estimating NbS potential for tackling diffuse pollution at catchment level.

B.1. SELECTING CITIES AND IDENTIFYING RELEVANT WATER SOURCES

B.1.1. City selection

This report focuses on European cities with appreciable reliance on surface water sources. This is considered to exist where more than 25 percent of the city's total annual water supply comes from surface water sources. We considered surface water sources to be primarily composed of rivers (including bank filtration withdrawals), lakes and reservoirs.

For our analyses of European cities, we compiled a novel data set comprising 109 cities, which enables a comparative perspective within Europe and among a subset of cities. This subset was selected through an iterative process: we first identified cities for which surface water sources account for at least 25 percent of total average annual drinking water supply and where surface water sources may be at risk of contamination from anthropogenic pressures—particularly where high nutrient loads and sediment are attributed to landscape degradation. We also considered ease of access to information, as well as the need to have a mix of cities in terms of size and national representation, focusing in particular on cities in France, Germany, The Netherlands, Spain and the United Kingdom. Previous research conducted for (Trémolet et al., 2019) had already indicated significant potential for the adoption of NbS in those countries.

Data on water sources had previously been collected for 36 cities across 23 European countries for the purpose of an earlier analysis (McDonald & Shemie, 2014). To augment this dataset, we identified a target of 100 additional cities focusing primarily on the five European countries mentioned previously. We focused here primarily on medium to large cities (greater than 100,000 people) as the emphasis was placed on identifying areas where NbS could generate impact at scale. The underlying assumption is also that larger cities are likely to have access to greater financial resources to support NbS implementation.

In total, we identified water sources for 109 cities across 20 European countries, as presented in Table B-1. This dataset is not representative for other cities or countries in Europe, however, due to the selection method.

TABLE B-1
Number of cities in the dataset per country

Country	*City count*	*City names*
Austria	1	Vienna
Belgium	1	Brussels
Bulgaria	1	Sofia
Czechia	1	Prague
Finland	1	Helsinki
France	17	Aix-en-Provence, Angers, Brest, Dijon, Le Mans, Limoges, Marseille, Metz, Nancy, Nantes, Nice, Paris, Rennes, Saint-Etienne, Toulon, Toulouse, Tours
Germany	26	Aachen, Berlin, Bochum, Bonn, Braunschweig, Chemnitz, Dortmund, Duisburg, Erfurt, Essen, Gelsenkirchen, Göttingen, Halle (Saale), Heidelberg, Heilbronn, Hildesheim, Köln, Münster, Pforzheim, Potsdam, Recklinghausen, Remscheid, Reutlingen, Siegen, Stuttgart, Wuppertal
Greece	1	Athens
Hungary	1	Budapest
Ireland	1	Dublin
Italy	1	Venice
Netherlands	14	Alkmaar, Amsterdam, Delft, Den Haag, Dordrecht, Haarlem, Haarlemmer-meer, Leiden, Maastricht, Rotterdam, Venlo, Westland, Zaanstad, Zoetermeer
Norway	1	Oslo
Poland	2	Warsaw, Kraków
Portugal	1	Lisbon
Romania	1	Bucharest
Spain	8	A Coruña, Barcelona, Gijón, Granada, Madrid, Málaga, Murcia, Sevilla
Sweden	1	Stockholm
Switzerland	1	Zurich
United Kingdom	28	Aberdeen, Belfast, Birmingham, Bolton, Bournemouth, Bristol, Cardiff, Carlisle, Crawley, Dundee, Eastbourne, Edinburgh, Exeter, Glasgow, Leeds, Liverpool, London, Maidstone, Manchester, Newcastle, Newport, Northampton, Norwich, Plymouth, Sheffield, Southampton, Swansea, Wolverhampton

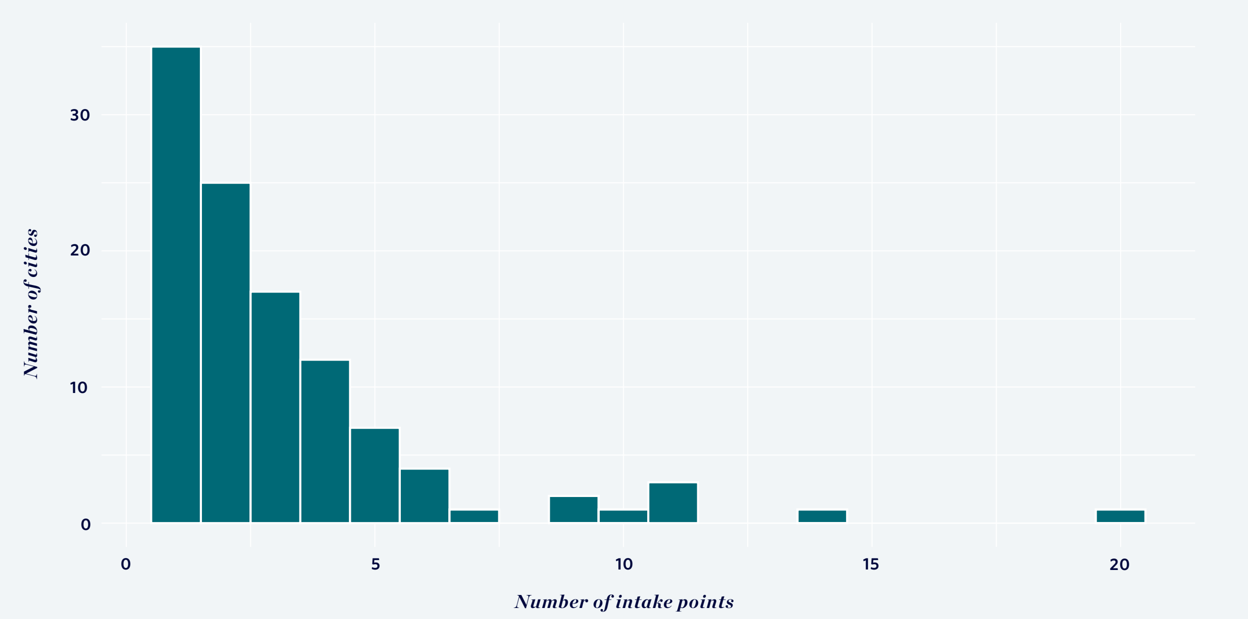
B.1.2. City water source data collection

The information we collected for these cities included the locations of major surface water withdrawals and the types of surface water sources in use. Currently, there is no centralised database with information on water sources for European cities. We conducted desk-based research to collect data for more than 100 identified cities. Data collected include coordinates of all known withdrawal points; water source type; name; diversion volume; water supplier name; and references for all data sources consulted.

Given the highly fragmented nature of the data and limited public access to the data, researchers employed multiple approaches across a diverse set of information sources to compile the dataset, including through enquiries with a number of networks (including the C40 Cities Climate Leadership Group, the 100 Resilient Cities Network, water utility networks), targeted surveys, web searches and direct contacts with individual water provider representatives. This search resulted in the collection of data on 303 unique surface water withdrawal locations (intake points) for the 109 cities noted previously (see Figure B-1).

FIGURE B-1

Number of surface water intake points for 109 selected cities



Source: From data collected by Ecologic and The Nature Conservancy (2019)

It is important to note that collected water source information did not include data on groundwater sources due in large measure to the paucity of available data. Accordingly, results within this report present an incomplete picture relative to the overall water supply for a given city. As noted previously, we made efforts to identify cities with 'appreciable reliance' on surface water sources. The threshold employed (25 percent) suggests that, for some cities, the condition of and NbS potential for groundwater and other water sources could be of significant importance to overall water supply. Future analyses at more localised scales should address this data gap.

B.1.3. Catchment delineation

To identify upstream contributing areas, we used surface water withdrawal location information (intake points) for each surface water source obtained. With these intake points, we determined the boundaries of upstream contributing areas by employing the HydroBASINS sub-basin delineation dataset (Lehner & Grill, 2013). Importantly, this delineation approach corresponds directly with the dataset used for assessing NbS potential. For each sub-basin within this dataset, there is an associated delineation of all combined upstream contributing sub-basins (that is, the upstream catchment). We used this feature to identify the catchment area for each water intake point that was associated with a specific HydroBASINS identifier (level 12). Each of these HydroBASINS delineations was then determined to represent the catchment delineation for a given intake point (where each intake point is associated with one catchment).

For many cities, the recorded intake point coordinates represented coarse approximations of actual water withdrawal intake points. In some cases, water intake coordinates were approximated using named locations or subjective evaluation using satellite imagery. Accordingly, we employed an adjustment procedure in order to associate (snap) each water intake coordinate to a respective sub-basin.

We employed a search radius (0.1 degrees) to identify possible sub-basin delineations for each water intake point. Within this pool of possible delineations, we then identified the sub-basin with the largest upstream contributing area (catchment). Therefore, we assumed that, given approximately equivalent distances, surface water withdrawal intake points are more likely to be located within catchments with greater total surface area (surface area being a proxy for total water availability for nearby catchments).

Given the scale of level 12 HydroBASINS sub-basin units (median area of 13,515 hectares), intake points near each other may be associated with the same delineated catchment area. While we documented 303 unique intake points, these intakes were subsequently associated with 209 unique catchments. With the exception of land cover analyses (see B.2.2 Land use/land cover), we included these duplicate catchments for all catchment-level analyses, likening these to nested catchments.

B.2. CHARACTERISING CATCHMENT THREATS IN TERMS OF WATER DEPLETION AND POLLUTION

B.2.1. Water depletion

To characterise water availability for a given catchment, we used the water depletion measure developed by Brauman et al. (2016). Water depletion is defined as the ratio of consumptive use to renewable available water. Water depletion data were derived from the global hydrological model, WaterGAP3 (Brauman et al., 2016; Döll et al., 2001). WaterGAP3 estimates water availability (surface and groundwater) as well as human water demand at daily time scales for 143,653 sub-basins (at a cell resolution of 5 arc minute).

We employed water depletion categories using the criteria described previously (Brauman et al., 2016). Briefly, water depletion considers annual, seasonal and dry-year water availability and consumptive use. Annual water depletion is consumption-to-availability greater than 75 percent. Seasonal depletion is defined as consumption-to-availability greater than 75 percent for at least one month of the model period (1971-2000). Dry-year depletion is identified as seasonal depletion occurring for at least 10 percent of the model period.

We associated each water source location with the respective enclosing WaterGAP3 sub-basin. For each city, we then reported the water depletion category for the associated sub-basin.

B.2.2. Land use/land cover

Land cover statistics were derived from Corine Land Cover (CLC) data set for the year 2018 (Copernicus Land Monitoring Service, 2020). CLC data are classified using a hierarchical 3-level system of land cover categories where level 1 presents the broadest groupings. For the analysis here, land cover was assessed using level 1 classification categories (see Table B-2). For each city and level 1 category, we calculated area sums for the total aggregate catchment area. Where catchments overlap (nested), we used the dissolved catchment extent to avoid duplicative sums for overlapping areas. Area values were calculated as proportions (percent) relative to total catchment area.

TABLE B-2
Abbreviated land use category nomenclature in this report against the original CLC designations

CLC category	*Abbreviation*
Agricultural areas	Agriculture
Artificial surfaces	Artificial
Forests and semi-natural areas	Forest
Wetlands	Wetland
Water bodies	Water

We further grouped "Agricultural areas" and "Artificial surfaces" categories within a composite categorical designation of "Developed". These "Developed" areas represent the total aggregate spatial extent of human converted landscapes and provide an indication of the degree to which human activities have resulted in the conversion of natural landscape areas. Using the sum of agricultural and artificial areas, we calculated the proportion of total catchment area within this "Developed" category. As previously, these values were calculated for the total aggregate catchment area of each city and reported as proportions (percent) relative to total catchment area.

B.2.3. Soil loss

Estimates of annual soil loss were derived from modelled data on net soil erosion for European Union countries published by the European Soil Data Centre (ESDAC) (P. Borrelli et al., 2018; Pasquale Borrelli et al., 2017; Panagos et al., 2015).[14] The WaTEM/SEDEM estimates overland (sheet and rill) erosion from landscape sources using the Revised Universal Soil Loss Equation (RUSLE). These estimates of gross erosion are then coupled with a hydrologic routing model that accounts for overland transport capacity based on topography and land cover. We did this in order to estimate the fraction of soil that enters

14 The WaTEM/SEDEM model provides coverage for EU countries only. Cities within non-EU countries (Zurich and Oslo) are therefore excluded from this analysis.

the stream network. Outputs are calibrated against measured data for 24 catchments distributed across Europe. Model outputs are presented as the estimated mean annual soil loss (metric tonnes) for each grid cell (100m).

For our analysis, we calculated average soil loss across each catchment. In cases where a given city uses a single catchment, we directly reported these catchment-level means. Where a city relies on multiple catchments, we further calculated volume-weighted means across these multiple catchments. In the absence of reliable and comprehensive data on annual water withdrawals for each catchment, we used total annual water availability as a proxy for the relative importance of a catchment for a given city. The implicit assumption of this approach is that a city is more likely to have greater dependence on catchments with greater water availability. There is considerable uncertainty with this assumption, but we deemed this approach preferable over the application of simple unweighted means, given that catchments can differ significantly in their biophysical attributes, such as area, precipitation and runoff. Estimates of total annual water availability were derived from the WaterGAP3 model described previously.

Results were reported as categorical values ("Low", "Moderate" and "High" soil loss) for each city. In order to determine category breaks, we selected a random sample of 3,000 catchments within the European Union and calculated average soil loss across each catchment. We then calculated quartile breaks for this sample set to determine categorical values as noted in Table B-3.

TABLE B-3
Value ranges represented by the respective reported categorical values

Category	*Category breaks*	*Values (Megagrams/ ha/year)*
Low	First quartile (1Q)	< 0.02
Moderate	Interquartile range (2Q-3Q)	0.02 – 0.60
High	Fourth quartile (4Q)	> 0.60

B.2.4. Estimating nitrogen and phosphorus pollution

Estimates of nitrogen and phosphorus pollution within catchment areas were derived from the continental-scale Geospatial Regression Equation for European Nutrient losses (GREEN) model (Grizzetti et al., 2012, Grizzetti et al., 2020). This model was developed to assess nitrogen pollution at medium and large basin scales, including both point and non-point (diffuse) sources. In addition to estimating loads from these sources, the GREEN model also estimates overland and instream nutrient attenuation with the model calibrated against measured data for several large river basins in Europe. GREEN model outputs include estimates of nutrient load, nutrient concentration and proportion of nutrient load attributable to contributing sources.

GREEN model outputs are reported for sub-basin units using the CCM River and Catchment Database (Vogt & Foisneau, 2007). We first associated each surface water withdrawal point with a proximal CCM sub-basin.

Similar to the Catchment delineation process described previously (see Section B.1.3.), we employed a search radius (0.25 degrees or approximately 20 kilometres) to identify possible upstream contributing areas. For each withdrawal point, we then determined the sub-basin which presented high correspondence with the respective HydroBASINS sub-basin in terms of total area (less than 15 percent difference) while also minimising the search radius distance. The GREEN model outputs for these sub-basins were then associated with each respective withdrawal point and catchment area.

GREEN model data values for catchments were then aggregated to the city-level using the approach described previously for Soil loss (see Section B.2.3.). Category breaks, for both concentration and share from agriculture and for both nitrogen and phosphorus, were derived from those employed by the originating authors (Grizzetti et al., 2012). These category breaks do not represent any particular regulatory or environmental thresholds; rather, they were established relative to the observed distribution of modelled results across Europe.

While the GREEN model presents a robust approach for estimating nitrogen and phosphorus at large spatial scales, the model outputs necessarily entail assumptions and uncertainties. For example, estimates of concentration values depend not only on modelled loads but also estimated stream flow volumes. Additionally, there is uncertainty regarding the equivalence of CCM and HydroBASINS sub-basins. We made efforts to minimise error and disagreement, but it is possible that associated GREEN model catchment areas do not fully overlap with HydroBASINS delineated catchments—meaning that GREEN model values may not be representative of city source catchment areas in such instances.

B.3. ESTIMATING NBS POTENTIAL FOR ADDRESSING DIFFUSE POLLUTION AT CATCHMENT LEVEL

B.3.1. Global models of sediment and phosphorus

To assess the potential for implementing nature-based solutions towards source water protection, we used data developed previously for a global analysis (McDonald & Shemie, 2014) and subsequently adapted for use within a web-based tool (McDonald, 2016). McDonald & Shemie (2014) describe their approach in detail within the report methodology description, which we refer to below as the Urban Water Blueprint (UWB).

Briefly, the UWB dataset was derived from two sets of models: estimates of total annual load for sediment and phosphorus and estimates of sediment and phosphorus reduction resulting from NbS implementation.

Sediment load estimates were developed from a modified version of the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). This empirically derived equation comprises factors (variables) that account for some of the primary contributing components of erosion and sediment transport. Global data sources were used to estimate these factors. Importantly, land use/cover is an important determinant of annual sediment load, as represented by the cover and management (C) and support practice (P) factors within the USLE. McDonald & Shemie, 2014 applied C and P factors using global land cover data (GlobCover 2009) combined with factor

values derived from pre-existing models developed within the United States.[15] These estimates of gross soil loss were then used to estimate net erosion, accounting for both overland deposition and instream attenuation (McDonald, 2016). Overland sediment deposition (surface attenuation) was incorporated by adjusting estimates relative to reference stream loading values within the United States using log-log linear regression. Adjustments for instream attenuation were derived from average instream attenuation rates calculated for streams within the United States (in terms of reduction amount per linear stream distance). In both cases, these adjustments were applied globally to create a global dataset on sediment loading for all level-12 sub-basin delineated catchments within the HydroBASINS data product (Lehner & Grill, 2013).

We derived phosphorus load estimates using an export coefficient approach, whereby each land cover class was assumed to export a certain amount of available phosphorus. For cropland and pastureland, available phosphorus was estimated using global data on fertiliser and manure application rates. Export coefficients for cropland and pastureland were derived from continental-scale estimates of plant nutrient uptake efficiencies. For other land cover types, estimates of both available phosphorus and export coefficients were derived from the same pre-existing US models noted above for sediment. Using the same approach as that for sediment, phosphorus load estimates were then adjusted for both surface and instream attenuation.

There are notable differences between nutrient data from the European GREEN models (see Section B.2.4. Nitrogen and phosphorus pollution) and the UWB model. Importantly, the UWB model included estimates only for phosphorus, not nitrogen. UWB model authors observed that, given their modelling approach and spatial correlation, phosphorus and nitrogen loading were highly correlated and therefore estimates for phosphorus could also be considered indicative of nitrogen loading. Additionally, the UWB model included estimates only for diffuse land-based sources, whereas point sources (such as wastewater treatment) and other diffuse sources such as atmospheric deposition were not considered.

15 See McDonald & Shemie (2014) for descriptions and references for these models.

B.3.2. Sediment and phosphorus reduction from NbS

In addition to estimating annual loads for sediment and phosphorus, McDonald & Shemie (2014) also estimate the potential for NbS to reduce these loads. Briefly, four indicative NbS practices were considered within the current report using model results from McDonald & Shemie (2014): cover crops, riparian buffers, forest protection and reforestation. Table B-4 provides an overview of each of these models.

TABLE B-4

NbS for source water protection modelled in the report

NbS type	*What is included*	*Methodology details*
Cover crops	Implementation of cover crops on all agri-cultural areas	• Modeled as cover crop implementation only • Sediment and phosphorus reduction values calcula-ted as 72% and 77%, respectively, as derived from average values reported in scientific literature
Riparian buffers	Revegetation of cur-rent agricultural land immediately adjacent to streams	• Modeled as cover crop implementation only • Sediment and phosphorus reduction values calcula-ted as 72% and 77%, respectively, as derived from average values reported in scientific literature
Forest Protection	Protection of current forest areas within naturally forested ecoregions	• Expected increase in pollutant load as a product of the probability of forest loss times change in pollutant load if that loss occurs • Probability of forest loss was extrapolated from observed forest cover changes between • Sediment reduction (avoided) calculated as the change in CP factor from forest to agricultural land • Phosphorus reduction (avoided) calculated as the change in nutrient export from forest to agricul-tural land
Reforestation	Revegetation of current grassland/pastureland areas that are within naturally forested ecoregions	• Sediment reduction calculated as change in CP factor from grassland to forest • Phosphorus reduction calculated as change in nutrient export from grassland to forest

Source: Adapted from McDonald & Shemie (2014)

For each of the four modelled NbS practices and each of the two pollutant types, the cumulative load reduction was calculated for each catchment. From these cumulative values, one-parameter optimisation was performed to identify the minimum implementation extent (area) necessary in order to achieve a 10 percent reduction in either sediment or phosphorus. In this manner, the models attempt to estimate optimal scenarios for NbS implementation whereby implementation is first targeted to those catchment areas with the greatest pollution reduction potential per unit of implementation area. The arbitrary 10 percent reduction threshold was considered to represent a minimum reduction amount—the specific reduction goals for a given location may necessitate higher (or lower) reduction amounts.

B.3.3. Evaluating NbS potential

Data from UWB NbS models correspond to the scale of individual catchments, reporting the area (hectares) needed for achieving a 10 percent reduction in sediment or phosphorus for that catchment. In order to report these results at city level, we defined procedures for determining thresholds and aggregating values using an approach modified from McDonald & Shemie (2014). Given the number of variables and subjective considerations, there is notable complexity and subjectivity in determining an aggregation approach. The methodology described here represents our attempt to provide a high-level indication where NbS may be able to play a meaningful role in sediment or phosphorus reduction—where the details of how we defined 'meaningful' are described subsequently.

To determine NbS potential for a given city, we considered each of the eight NbS reduction scenarios separately for each source catchment (eight scenarios in total given the four NbS types and two pollutant types). We evaluated NbS potential using three criteria whereby we assessed categorical values in sequence from high to low (where a catchment meeting any 'high' criteria would be considered 'high', even if other criteria indicate different categorical values). The rationale for these criteria and respective category thresholds is presented in Table B-5.

TABLE B-5

Criteria used for assessing NbS potential from UWB model outputs

Criteria	*Rationale*	*Thresholds*	
Absolute implementation extent	Where implementation area is small, NbS potential is greater irrespective of other considera-tions	High	< 1,000 hectares
		Moderate	< 10,000 hectares
		Low	> 10,000 hectares
		Unlikely	10% reduction target not possible according to model estimates
Implementation extent relative to catchment area	Where implementation is small relative to total catchment area, the potential return is greater	High	Relative area in lowest tercile
		Moderate	Relative area in middle tercile
		Low	Relative area in highest tercile
		Unlikely	10% reduction target not possible according to model estimates
Implementation extent relative to total possible implementation area	Where implementation comprises a smaller proportion of possible implementation area, NbS implementation is likely to be more feasible	High	Relative area < 10%
		Moderate	Relative area < 30%
		Low	Relative area in highest tercile
		Unlikely	10% reduction target not possible according to model estimates

To aggregate these data to the city level, we considered these categorical values in concert with total available water supply across all source catchments for that city. Similar to the process above, we assessed categorical values sequentially from high to low, whereby a city-level categorical ranking of 'high' indicates that these catchments both (a) account for at least 25 percent of total available supply and (b) exhibit NbS ranking of 'high' for at least one of the criteria in Table B-5. In cases where a given NbS type did not account for at least 25 percent of available supply for any NbS ranking, the value of "unlikely" was applied.

B.3.4. Costs of NbS implementation

To estimate the costs of NbS implementation, we reviewed case studies to identify examples of empirical data on costs for the NbS types evaluated within the UWB model—focusing in particular on European examples. From these examples, we estimated total unit area costs of NbS implementation, financed over a 30-year period using a public sector discount rate of 3.5 percent in order to determine the annual equivalent cost for each NbS type expressed as the average present value per unit area per year (HM Treasury, 2018; Lago, 2009). An overview of methodology, estimated cost ranges and information sources is presented in Table B-6.

TABLE B-6

Overview of cost estimation approach and data sourcesfor the four modelled NbS types

NbS type	*Methodology*	*Cost range (€/ha/yr)*	*Source*
Cover crops	Estimated from data on actual reported costs for cover crop im-plementation in the UK	2 – 13	Cuttle et al., 2006
Riparian buffers	Estimated based on data from the US and UK including materials, design, installation, maintenance, and farmer incentive payments	25 – 41	Cuttle et al., 2006; Guhin & Hayes, 2015
Forest Protection	Estimated based on data from the Republic of Ireland for forest maintenance costs and landowner payments	199 – 239	Cuttle et al., 2006
Reforestation	Estimated based on data from the Republic of Ireland including ma-terials, design, installation, maintenance, and farmer incen-tive payments	374 – 641	Agriculture and Food Develop-ment Authority, n.d.; Fo-rest Service, 2012

Source: Adapted from McDonald & Shemie (2014)

For each NbS type, we selected the midpoint of identified cost ranges. To account for administrative costs, we further included a 50 percent cost increase based on unpublished data collected from 18 watershed conservation programs in Latin America, Africa and China (Kang et al., 2020). For each catchment, NbS type and pollutant type, we then calculated the total cost of NbS implementation in order to achieve the 10 percent reduction target. Additionally, we also calculated per capita costs relative to city population so we could compare cities of different sizes (Eurostat, 2019).

To aggregate data to the city level, we then calculated volume-weighted means of costs and per capita costs using the approach described previously in Section B.2.3 Soil loss. For a given city and NbS and pollutant type, total costs are estimated using the average implementation area needed to achieve a 10 percent pollutant reduction. These area values are then combined with the cost values from Table B-6 and population data in order to estimate annual per capita costs of NbS implementation. These mean cost values were then categorised based on observed tercile breaks (where the lowest tercile represents the highest "cost effectiveness" ranking and higher cost effectiveness is exhibited by cities with lower per capita costs of implementation).

Annex C

Potential of NbS to protect water sources for selected European cities

High · **Moderate** · **Low** · **Unlikely**

NBS POTENTIAL

City	Country	Sediment reduction: Cover Crops	Sediment reduction: Riparian Buffers	Sediment reduction: Forest Protection	Sediment reduction: Reforestation	Phosphorus reduction: Cover Crops	Phosphorus reduction: Riparian Buffers	Phosphorus reduction: Forest Protection	Phosphorus reduction: Reforestation
A Coruña	Spain	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Aachen	Germany	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Aberdeen	United Kingdom	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Aix-en-Provence	France	High	High	Moderate	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Alkmaar	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Amsterdam	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Angers	France	Unlikely	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Athens	Greece	High	Unlikely	High	Moderate	High	Unlikely	Unlikely	Unlikely
Barcelona	Spain	High	Unlikely	High	Moderate	Unlikely	Unlikely	Unlikely	Unlikely
Belfast	United Kingdom	Unlikely	Unlikely	Moderate	Moderate	Unlikely	Unlikely	Unlikely	High
Berlin	Germany	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Birmingham	United Kingdom	Unlikely	Unlikely	High	High	Unlikely	Unlikely	Unlikely	High
Bochum	Germany	Low	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Bolton	United Kingdom	Unlikely	Unlikely	Unlikely	Low	Unlikely	Unlikely	Unlikely	Moderate
Bonn	Germany	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Boumemouth	United Kingdom	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Braunschweig	Germany	Moderate	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Brest	France	Moderate	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Bristol	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Moderate
Brussels	Belgium	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Bucharest	Romania	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely

NBS POTENTIAL

City	Country	Sediment reduction: Cover Crops	Sediment reduction: Riparian Buffers	Sediment reduction: Forest Protection	Sediment reduction: Reforestation	Phosphorus reduction: Cover Crops	Phosphorus reduction: Riparian Buffers	Phosphorus reduction: Forest Protection	Phosphorus reduction: Reforestation
Budapest	Hungary	High	Unlikely	High	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Cardiff	United Kingdom	Unlikely	Unlikely	High	High	Unlikely	Unlikely	Unlikely	High
Carlisle	United Kingdom	High	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Moderate
Chemnitz	Germany	Moderate	Unlikely	Low	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Crawley	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Delft	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	High
Den Haag	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	High
Dijon	France	High	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Dordrecht	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	High
Dortmund	Germany	Low	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Dublin	Ireland	Unlikely	Unlikely	Moderate	Moderate	Unlikely	Unlikely	Unlikely	Moderate
Duisburg	Germany	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Dundee	United Kingdom	Moderate	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Eastbourne	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Edinburgh	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Moderate
Erfurt	Germany	Moderate	Unlikely	Moderate	Unlikely	Low	Unlikely	Unlikely	Unlikely
Essen	Germany	Low	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Exeter	United Kingdom	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Moderate
Gelsenkirchen	Germany	Moderate	Unlikely	Moderate	Unlikely	Low	Unlikely	Unlikely	Unlikely
Gijon	Spain	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Glasgow	United Kingdom	High	Unlikely	High	Moderate	Unlikely	Unlikely	Unlikely	Low
Göttingen	Germany	Moderate	Unlikely	High	Unlikely	Moderate	Unlikely	Unlikely	Unlikely

High | Moderate | Low | Unlikely

NBS POTENTIAL

City	Country	Sediment reduction: Cover Crops	Sediment reduction: Riparian Buffers	Sediment reduction: Forest Protection	Sediment reduction: Reforestation	Phosphorus reduction: Cover Crops	Phosphorus reduction: Riparian Buffers	Phosphorus reduction: Forest Protection	Phosphorus reduction: Reforestation
Granada	Spain	High	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Haarlem	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Haarlemmemeer	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Halle (Saale)	Germany	Unlikely	Unlikely	Moderate	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Heidelberg	Germany	Moderate	Unlikely	Unlikely	Unlikely	Low	Unlikely	Unlikely	Unlikely
Heilbronn	Germany	High	High	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Helsinki	Finland	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Hildesheim	Germany	Moderate	Unlikely	High	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Köln	Germany	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Krakow	Poland	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Le Mans	France	Low	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Leeds	United Kingdom	Moderate	Unlikely	Moderate	Moderate	Unlikely	Unlikely	Unlikely	Moderate
Leiden	Netherlands	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	High
Limoges	France	Moderate	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Moderate
Lisbon	Portugal	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Liverpool	United Kingdom	Unlikely	Unlikely	Moderate	Moderate	Unlikely	Unlikely	Unlikely	High
London	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Low	Unlikely	Unlikely	Unlikely
Maastricht	Netherlands	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Madrid	Spain	High	Unlikely	Moderate	Unlikely	High	Unlikely	Unlikely	Unlikely
Maidstone	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Malaga	Spain	High	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Manchester	United Kingdom	High	Unlikely	High	Moderate	Unlikely	Unlikely	Unlikely	Moderate

High | Moderate | Low | Unlikely

NBS POTENTIAL

City	Country	Sediment reduction: Cover Crops	Sediment reduction: Riparian Buffers	Sediment reduction: Forest Protection	Sediment reduction: Reforestation	Phosphorus reduction: Cover Crops	Phosphorus reduction: Riparian Buffers	Phosphorus reduction: Forest Protection	Phosphorus reduction: Reforestation
Marseille	France	High	High	Moderate	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Metz	France	Low	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Münster	Germany	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Moderate
Murcia	Spain	High	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Nancy	France	Unlikely	Unlikely	Low	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Nantes	France	Unlikely	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Newcastle	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Low
Newport	United Kingdom	Unlikely	Unlikely	High	High	Unlikely	Unlikely	Unlikely	High
Nice	France	High	High	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Northampton	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Low	Unlikely	Unlikely	Unlikely
Norwich	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Oslo	Norway	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Paris	France	Low	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Pforzheim	Germany	High	High	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Plymouth	United Kingdom	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	High
Potsdam	Germany	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Prague	Czechia	Low	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Recklinghausen	Germany	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Remscheid	Germany	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Rennes	France	Unlikely	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Reutlingen	Germany	High	High	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Rotterdam	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	High

High | Moderate | Low | Unlikely

NBS POTENTIAL

City	Country	Sediment reduction: Cover Crops	Sediment reduction: Riparian Buffers	Sediment reduction: Forest Protection	Sediment reduction: Reforestation	Phosphorus reduction: Cover Crops	Phosphorus reduction: Riparian Buffers	Phosphorus reduction: Forest Protection	Phosphorus reduction: Reforestation
Saint-Etienne	France	High	Unlikely	Moderate	Moderate	High	Unlikely	Unlikely	Unlikely
Sevilla	Spain	High	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Sheffield	United Kingdom	Unlikely	Unlikely	Moderate	Moderate	Unlikely	Unlikely	Unlikely	Moderate
Siegen	Germany	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Sofia	Bulgaria	High	Unlikely	High	Moderate	Unlikely	Unlikely	Unlikely	Unlikely
Southampton	United Kingdom	Unlikely	Unlikely	Unlikely	Unlikely	Low	Unlikely	Unlikely	Unlikely
Stockholm	Sweden	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Stuttgart	Germany	High	High	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Swansea	United Kingdom	Unlikely	Unlikely	High	High	Unlikely	Unlikely	Unlikely	Moderate
Toulon	France	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Toulouse	France	High	Unlikely	Moderate	Unlikely	High	Unlikely	Unlikely	Unlikely
Tours	France	Moderate	Unlikely	Unlikely	Unlikely	High	Unlikely	Unlikely	Unlikely
Venice	Italy	High	High	High	High	High	Unlikely	Unlikely	Unlikely
Venlo	Netherlands	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Vienna	Austria	Moderate	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	Unlikely
Warsaw	Poland	Unlikely	Unlikely	Unlikely	Unlikely	Low	Unlikely	Unlikely	Unlikely
Westland	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	High
Wolverhampton	United Kingdom	Unlikely	Unlikely	High	High	Unlikely	Unlikely	Unlikely	Moderate
Wuppertal	Germany	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Zaanstad	Netherlands	High	Unlikely	High	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Zoetermeer	Netherlands	Unlikely	Unlikely	Unlikely	Unlikely	Moderate	Unlikely	Unlikely	High
Zurich	Switzerland	High	High	High	High	Unlikely	Unlikely	Unlikely	Unlikely

Annex D
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