UN WATER

Report

The United Nations World Water Development Report 2018

NATURE-BASED SOLUTIONS FOR WATER



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Sustainable Development Goals

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The United Nations World Water Development Report 2018

NATURE-BASED SOLUTIONS FOR WATER

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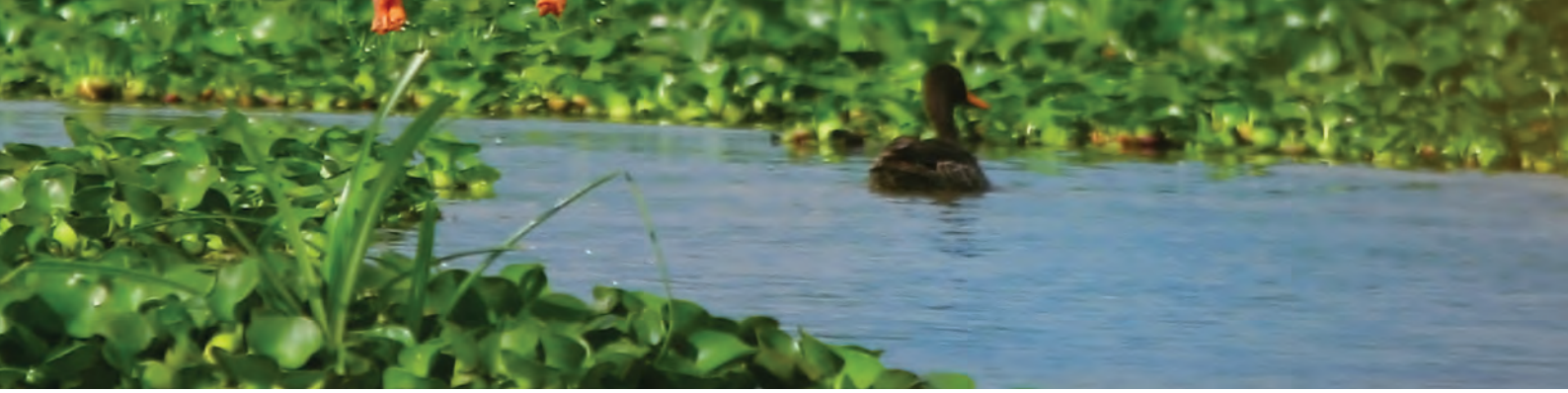
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FOREWORD

by Audrey Azoulay, Director-General of UNESCO

We need new solutions to managing water resources to offset the rising challenges to water security from population growth and climate change. This report proposes an innovative response that has, in fact, been around for thousands of years: nature-based solutions.

Today, more than ever, we must work with nature, instead of against it. Demand for water is set to increase in all sectors. The challenge we must all face is meeting this demand in a way that does not exacerbate negative impacts on ecosystems.

The stakes are high. Current trends suggest that around two thirds of forests and wetlands have been lost or degraded since the beginning of the 20th century. Soil is eroding and deteriorating in quality. Since the 1990s, water pollution has worsened in almost all rivers in Africa, Asia and Latin America.

These trends pose broader challenges from the increased risk of floods and droughts, which, in turn, has an impact on our ability to adapt to climate change. We know also that water scarcity can lead to civil unrest, mass migration, and even to conflict within and between countries.

Goal 6 of the 2030 Agenda for Sustainable Development recognises the importance of ensuring the availability and sustainable management of water and sanitation. Nature-based solutions are essential to meet this goal.

Their impact can be significant: from the small-scale water harvesting structures in Rajasthan, India that brought water back to 1,000 drought-stricken villages, to the revival of traditional 'hima' land management practices in Jordan's Zarqa River basin that yield higher quality spring water by not over-exploiting the soil.

These solutions can also contribute to other aspects of sustainable development: from ensuring food security and reducing disaster risk to building sustainable urban settlements and boosting decent work. Ensuring the sustainable use of the planet's resources is vital for ensuring long-term peace and prosperity.

This World Water Development Report does not argue that nature-based solutions are a panacea, but our conclusion is clear -- they are one of many important tools to shift to a more holistic approach to water management.

In this spirit, I want to thank the Government of Italy and the Umbria Region for supporting UNESCO's World Water Assessment Programme. Coordinated by WWAP, with help from the International Hydrological Programme, this report is the fruit of continued cooperation by members and partners of UN-Water. I wish to thank all those involved for their input and their commitment to promoting sustainable water security, which balances human needs with the future of our planet.



Audrey Azoulay

FOREWORD

by Gilbert F. Houngbo, Chair of UN-Water and President of the International Fund for Agricultural Development

More than 2 billion people lack access to safe drinking water and more than double that number lack access to safe sanitation. With a rapidly growing global population, demand for water is expected to increase by nearly one-third by 2050. In the face of accelerated consumption, increasing environmental degradation and the multi-faceted impacts of climate change, we clearly need new ways to manage competing demands on our precious freshwater resources.

The 2018 edition of the UN World Water Development Report (WWDR2018) suggests that solutions may be closer than we think.

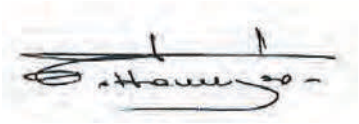
Since its first edition in 2003, the WWDR has presented the broad perspective of the UN system on water supply and sanitation issues. Each Report harmonizes up-to-date knowledge and science-based content with balanced policy messages. This year's Report, which marks 15 years of UN-Water's formal existence, looks both forwards and backwards.

For too long, the world has turned first to human-built, or "grey", infrastructure to improve water management. In so doing, it has often brushed aside traditional and Indigenous knowledge that embraces greener approaches. Three years into the 2030 Agenda for Sustainable Development, it is time for us to re-examine nature-based solutions (NBS) to help achieve water management objectives.

The WWDR2018 illustrates that working with nature, rather than against it, would enhance natural capital and support a resource-efficient and competitive circular economy. NBS can be cost-effective, and simultaneously provide environmental, social and economic benefits. These interwoven benefits, which are the essence of sustainable development, are central to achieving Agenda 2030.

This flagship publication represents UN-Water's most substantial contribution to the 'Nature for Water' campaign that will begin on 22 March 2018, World Water Day. As the new Chair of UN-Water, I would like to thank my colleagues for their invaluable contributions. I am also grateful to UNESCO and its World Water Assessment Programme for their critical role in production.

I am confident this Report will inspire discussions and spur actions at all relevant levels to move towards a more sustainable management of water resources.



Gilbert F. Houngbo

PREFACE

by Stefan Uhlenbrook, WWAP Coordinator
and Richard Connor, Editor-in-Chief

The need to ensure that adequate volumes of water of suitable quality are made available to support and maintain healthy ecosystems has long been established. But, nature also plays a unique and fundamental role in regulating different features of the water cycle, in which it can act as a regulator, a cleaner and/or a supplier of water. As such, maintaining healthy ecosystems directly leads to improved water security for all.

As the fifth in a series of annual, theme-oriented reports, the 2018 edition of the United Nations World Development Report (WWDR) focuses on opportunities to harness the natural processes that regulate various elements of the water cycle, which have become collectively known as nature-based solutions (NBS) for water. This is not merely a 'good idea' (which of course it is), but an essential step to ensuring the long-term sustainability of water resources and of the multitude of benefits that water provides; from food and energy security to human health and sustainable socio-economic development.

There are several different types of NBS for water, ranging in scale from the micro/personal (e.g. a dry toilet) to landscape-level applications that include conservation agriculture. There are NBS that are appropriate for urban settings (e.g. green walls, roof gardens and vegetated infiltration or drainage basins) as well as for rural environments which often make up the majority of a river basin's area.

Yet, despite recent advances in the uptake of NBS, water resource management remains heavily dependent on human-built ('grey') infrastructure. The idea is not necessarily to replace grey with green infrastructure, but to identify the most appropriate, cost-effective and sustainable balance between grey infrastructure and NBS considering multiple objectives and benefits.

Maximizing nature's potential in helping to achieve the three main water management objectives – enhancing water availability, improving water quality and reducing water-related risks – will require creating an enabling environment for change, including suitable legal and regulatory frameworks, appropriate financing mechanisms and social acceptance. We remain confident that, with the political will to do so, current obstacles, such as the lack of knowledge, capacity, data and information about NBS for water, can be effectively overcome.

As this report points out, there are a number of mechanisms that can be used to accelerate the uptake of NBS for water. Payment for environmental services schemes and green bonds have been shown to generate interesting returns on investment while lowering the need (and costs) for larger, often more expensive infrastructure required for water resources management and the delivery of water supply and sanitation services.

NBS for water are central to achieving the 2030 Agenda for Sustainable Development because they generate social, economic and environmental co-benefits, including in the fields of human health and livelihoods, food and energy security, sustainable economic growth, decent jobs, ecosystem rehabilitation and maintenance, and biodiversity. The substantial value of these co-benefits can tip investment decisions in favour of NBS.

Implementation of NBS involves the participation of many different stakeholder groups, thus encouraging consensus-building and helping to raise awareness about what NBS can truly offer to improve water security. We have endeavoured to produce a balanced, fact-based and neutral account of the current state of knowledge, covering the most recent developments pertaining to NBS for water, and the various benefits and opportunities they offer in terms of improving the sustainable water resources management. Although primarily targeted at national-level decision-makers and water resources managers, it is hoped that this report will also be of interest to the broader development community, as well as academics, professionals and anyone interested in building an equitable and sustainable water future with the support of NBS.

This latest edition of the WWDR is the result of a concerted effort between Chapter Lead Agencies FAO, UNDP, UN Environment, UNESCO-IHP, UNU-INWEH and WWAP, with complementary material on regional perspectives provided by UNECE, UNECLAC, UNESCAP, UNESCWA and UNESCO Multisectoral Regional Office in Abuja. The report also benefited from the inputs and contributions of several UN-Water members and partners, members of WWAP's Technical Advisory Committee, as well as from numerous scientists, professionals and NGOs who provided a wide range of relevant data and information.

On behalf of the WWAP Secretariat, we would like to extend our deepest appreciation to the afore-mentioned agencies, members and partners of UN-Water, and to the writers and other contributors for collectively producing this unique and authoritative report that will, hopefully, have multiple impacts worldwide. David Coates deserves specific recognition for having generously shared his knowledge and wisdom throughout the report's production process.

We are profoundly grateful to the Italian Government for funding the Programme and to the Regione Umbria for hosting the WWAP Secretariat in Villa La Colombella in Perugia. Their contributions have been instrumental to the production of the WWDR.

Our special thanks go to Audrey Azoulay, Director-General of UNESCO, for her vital support to WWAP and the production of the WWDR. The guidance of Gilbert F. Houngbo, President of the International Fund for Agricultural Development (IFAD), as Chair of UN-Water, has made this publication possible.

Last but not least, we extend our most sincere gratitude to all our colleagues at the WWAP Secretariat, whose names are listed in the acknowledgments. The report could not have been completed without their professionalism and dedication.



Stefan Uhlenbrook



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The Spanish version of the Report was made possible thanks to ANEAS (National Association of Water and Sanitation Utilities) of Mexico and its members. We also would like to acknowledge the UNESCO Field Offices in Almaty, Beijing, Brasília, Cairo and New Delhi for the translation of the Executive Summary of the WWDR 2018 into Russian, Chinese, Portuguese, Arabic and Hindi languages. Thanks to the valuable collaboration between the National Water Agency (ANA) and the UNESCO Office in Brazil, the Portuguese language has been included in the translation series.

EXECUTIVE SUMMARY



Wetland in South San Francisco Bay (USA)



Nature-based solutions (NBS) are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water. An NBS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. They can be applied at micro- (e.g. a dry toilet) or macro- (e.g. landscape) scales.

Attention to NBS has significantly increased in recent years. This is evidenced through the mainstreaming of NBS into a wide range of policy advances, including in water resources, food security and agriculture, biodiversity, environment, disaster risk reduction, urban settlements, and climate change. This welcome trend illustrates a growing convergence of interests around the recognition of the need for common objectives and the identification of mutually supporting actions – as illustrated best in the 2030 Agenda for Sustainable Development through its acknowledgment of the interdependency of its various Goals and targets.

Upscaling NBS will be central to achieving the 2030 Agenda for Sustainable Development. Sustainable water security will not be achieved through business-as-usual approaches. NBS work with nature instead of against it, and thereby provide an essential means to move beyond business-as-usual to escalate social, economic and hydrological efficiency gains in water resources management. NBS show particular promise in achieving progress towards sustainable food production, improved human settlements, access to water supply and sanitation services, and water-related disaster risk reduction. They can also help to respond to the impacts of climate change on water resources.

NBS support a *circular economy* that is restorative and regenerative by design and promotes greater resource productivity aiming to reduce waste and avoid pollution, including through reuse and recycling. NBS also support the concepts of *green growth* or the *green economy*, which promote sustainable natural resource use and harness natural processes to underpin economies. The application of NBS for water also generates social, economic and environmental co-benefits, including improved human health and livelihoods, sustainable economic growth, decent jobs, ecosystem rehabilitation and maintenance, and the protection and enhancement of biodiversity. The value of some of these co-benefits can be substantial and tip investment decisions in favour of NBS.

However, despite a long history of and growing experience with, the application of NBS, there are still many cases where water resources policy and management ignore NBS options – even where they are obvious and proven to be efficient. For example, despite rapidly growing investments in NBS, the evidence suggests that this is still well below 1% of total investment in water resources management infrastructure.

The world's water: Demand, availability, quality and extreme events

The global demand for water has been increasing at a rate of about 1% per year as a function of population growth, economic development and changing consumption patterns, among other factors, and it will continue to grow significantly over the next two decades. Industrial and domestic demand for water will increase much faster than agricultural demand, although agriculture will remain the largest overall user. The vast majority of the growing demand for water will occur in countries with developing or emerging economies.

At the same time, the global water cycle is intensifying due to climate change, with wetter regions generally becoming wetter and drier regions becoming even drier. At present, an estimated 3.6 billion people (nearly half the global population) live in areas that are potentially water-scarce at least one month per year, and this population could increase to some 4.8–5.7 billion by 2050.

Since the 1990s, water pollution has worsened in almost all rivers in Africa, Asia and Latin America. The deterioration of water quality is expected to further escalate over the next decades and this will increase threats to human health, the environment and sustainable development. Globally, the most prevalent water quality challenge is nutrient loading, which, depending on the region, is often associated with pathogen loading. Hundreds of chemicals are also impacting on water quality. The greatest increases in exposure to pollutants are expected to occur in low- and lower-middle income countries, primarily because of higher population and economic growth and the lack of wastewater management systems.

The trends in water availability and quality are accompanied by projected changes in flood and drought risks. The number of people at risk from floods is projected to rise from 1.2 billion today to around 1.6 billion in 2050 (nearly 20% of the world's population). The population currently affected by land degradation/desertification and drought is estimated at 1.8 billion people, making this the most significant category of 'natural disaster' based on mortality and socio-economic impact relative to gross domestic product (GDP) per capita.

Ecosystem degradation

Ecosystem degradation is a leading cause of increasing water resources management challenges. Although about 30% of the global land remains forested, at least two thirds of this area are in a degraded state. The majority of the world's soil resources, notably on farmland, are in only fair, poor or very poor condition and the current outlook is for this situation to worsen, with serious negative impacts on water cycling through higher evaporation rates, lower soil water storage and increased surface runoff accompanied by increased erosion. Since the year 1900, an estimated 64–71% of the natural wetland area worldwide has been lost due to human activity. All these changes have had major negative impacts on hydrology, from local to regional and global scales.

There is evidence that such ecosystem change has over the course of history contributed to the demise of several ancient civilizations. A pertinent question nowadays is whether we can avoid the same fate. The answer to that question will depend at least partly on our ability to shift from working against nature to working with it – through, for example, better adoption of NBS.

The role of ecosystems in the water cycle

Ecological processes in a landscape influence the quality of water and the way it moves through a system, as well as soil formation, erosion, and sediment transport and deposition – all of which can exert major influences on hydrology. Although forests often receive the most attention when it comes to land cover and hydrology, grasslands and croplands also play important roles. Soils are critical in controlling the movement, storage and transformation of water. Biodiversity has a functional role in NBS whereby it underpins ecosystem processes and functions and, therefore, the delivery of ecosystem services.

Ecosystems have important influences on precipitation recycling from local to continental scales. Rather than being regarded as a 'consumer' of water, vegetation is perhaps more appropriately viewed as a water 'recycler'. Globally, up to 40% of terrestrial rainfall originates from upwind plant transpiration and other land evaporation, with this source accounting for most of the rainfall in some regions. Land use decisions in one place may therefore have significant consequences for water resources, people, the economy and the environment in distant locations – pointing to the limitations of the watershed (as opposed to the 'precipitationshed') as the basis for management.

Green infrastructure (for water) uses natural or semi-natural systems such as NBS to provide water resources management options with benefits that are equivalent or similar to conventional grey (built/physical) water infrastructure. In some situations, nature-based approaches can offer the main or only viable solution (for example, landscape restoration to combat land degradation and desertification), whereas for different purposes only a grey solution will work (for example supplying water to a household through pipes and taps). In most cases, however, green and grey infrastructure can and should work together. Some of the best examples of the deployment of NBS are where they improve the performance of grey infrastructure. The current situation, with ageing, inappropriate or insufficient grey infrastructure worldwide, creates opportunities for NBS as innovative solutions that embed perspectives of ecosystem services, enhanced resilience and livelihood considerations in water planning and management.

A key feature of NBS is that they tend to deliver groups of ecosystem services together – even if only one is being targeted by the intervention. Hence, NBS usually offer multiple water-related benefits and often help address water quantity, quality and risks simultaneously. Another key advantage of NBS is the way in which they contribute to building overall system resilience.

NBS for managing water availability

NBS mainly address water supply through managing precipitation, humidity, and water storage, infiltration and transmission, so that improvements are made in the location, timing and quantity of water available for human needs.

The option of building more reservoirs is increasingly limited by silting, decrease of available runoff, environmental concerns and restrictions, and the fact that in many developed countries the most cost-effective and viable sites have already been used. In many cases, more ecosystem-friendly forms of water storage, such as natural wetlands, improvements in soil moisture and more efficient recharge of groundwater, could be more sustainable and cost-effective than traditional grey infrastructure such as dams.

Agriculture will need to meet projected increases in food demand by improving its resource use efficiency while simultaneously reducing its external footprint, and water is central to this need. A cornerstone of recognized solutions is the 'sustainable ecological intensification' of food production, which enhances ecosystem services in agricultural landscapes, for example through improved soil and vegetation management. 'Conservation agriculture', which incorporates practices aimed at minimizing soil disturbance, maintaining soil cover and regularizing crop rotation, is a flagship example approach to sustainable production intensification. Agricultural systems that rehabilitate or conserve ecosystem services can be as productive as intensive, high-input systems, but with significantly reduced externalities. Although NBS offer significant gains in irrigation, the main opportunities to increase productivity are in rainfed systems that account for the bulk of current production and family farming (and hence provide the greatest livelihood and poverty reduction benefits). The theoretical gains that could be achievable at a global scale exceed the projected increases in global demand for water, thereby potentially reducing conflicts among competing uses.

NBS for addressing water availability in urban settlements are also of great importance, given that the majority of the world's population is now living in cities. Urban green infrastructure, including green buildings, is an emerging phenomenon that is establishing new benchmarks and technical standards that embrace many NBS. Business and industry are also increasingly promoting NBS to improve water security for their operations, prompted by a compelling business case.

NBS for managing water quality

Source water protection reduces water treatment costs for urban suppliers, and contributes to improved access to safe drinking water in rural communities. Forests, wetlands and grasslands, as well as soils and crops, when managed properly, play important roles in regulating water quality by reducing sediment loadings, capturing and retaining pollutants, and recycling nutrients. Where water becomes polluted, both constructed and natural ecosystems can help improve water quality.

Non-point (diffuse) source pollution from agriculture, notably nutrients, remains a critical problem worldwide, including in developed countries. It is also the one most amenable to NBS, as these can rehabilitate ecosystem services that enable soils to improve nutrient management, and hence lower fertilizer demand and reduce nutrient runoff and/or infiltration to groundwater.

Urban green infrastructure is increasingly being used to manage and reduce pollution from urban runoff. Examples include green walls, roof gardens and vegetated infiltration or drainage basins to support wastewater treatment and reduce stormwater runoff. Wetlands are also used within urban environments to mitigate the impact of polluted stormwater runoff and wastewater. Both natural and constructed wetlands also biodegrade or immobilize a range of emerging pollutants, including certain pharmaceuticals, and often perform better than grey solutions. For certain chemicals, they may offer the only solution.

There are limits to how NBS can perform. For example, NBS options for industrial wastewater treatment depend on the pollutant type and its loading. For many polluted water sources, grey-infrastructure solutions may continue to be needed. However, industrial applications of NBS, particularly constructed wetlands for industrial wastewater treatment, are growing.

NBS for managing water-related risks

Water-related risks and disasters, such as floods and droughts associated with an increasing temporal variability of water resources due to climate change, result in immense and growing human and economic losses globally. Around 30% of the global population is estimated to reside in areas and regions routinely impacted by either flood or drought events. Ecosystem degradation is the major cause of increasing water-related risks and extremes, and it reduces the ability to fully realize the potential of NBS.

Green infrastructure can perform significant risk reduction functions. Combining green and grey infrastructure approaches can lead to cost savings and greatly improved overall risk reduction.

NBS for flood management can involve water retention by managing infiltration and overland flow, and thereby the hydrological connectivity between system components and the conveyance of water through it, making space for water storage through, for example, floodplains. The concept of 'living with floods', which, among other things, includes a range of structural and non-structural approaches that help to 'be prepared' for a flood, can facilitate the application of relevant NBS to reduce flood losses and, most importantly, flood risk.

Droughts are not limited to dry areas, as is sometimes portrayed, but can also pose a disaster risk in regions that are normally not water-scarce. The mix of potential NBS for drought mitigation is essentially the same as those for water availability and aim to improve water storage capacity in landscapes, including soils and groundwater, to cushion against periods of extreme scarcity. Seasonal variability in rainfall creates opportunities for water storage in landscapes to provide water for both ecosystems and people over drier periods. The potential of natural water storage (particularly subsurface, in aquifers) for disaster risk reduction is far from being realized. Storage planning at river basin and regional scales should consider a portfolio of surface and subsurface storage options (and their combinations) to arrive at the best environmental and economic outcomes in the face of increasing water resources variability.

NBS for enhancing water security: Multiplying the benefits

NBS are able to enhance overall water security by improving water availability and water quality while simultaneously reducing water-related risks and generating additional social, economic and environmental co-benefits. They allow for the identification of win-win outcomes across sectors. For example, NBS in agriculture are becoming mainstream because they deliver increased sustainable agricultural productivity and profitability but also enhance overall system-wide benefits, such as improved water availability and reduced downstream pollution. Watershed restoration and protection has become increasingly important in the context of meeting multiple challenges in sustaining water supplies to rapidly growing cities and reducing risks in them. Urban green infrastructure can yield positive results in terms of water availability, water quality and flood and drought reduction. In the context of water and sanitation, constructed wetlands for wastewater treatment can be a cost-effective NBS that provides effluent of adequate quality for several non-potable uses, including irrigation, as well as offering additional benefits, including energy production.

Challenges and limitations

Challenges to upscaling NBS so that they reach their full and significant potential are somewhat generic across the sectors and at global, region-specific or place-based scales. There remains a historical inertia against NBS due to the continuing overwhelming dominance of grey infrastructure solutions in the current instruments of the Member States – from public policy to building codes and regulations. This dominance can also exist in civil engineering, market-based economic instruments, the expertise of service providers, and consequentially in the minds of policy makers and the general public. These and other factors collectively result in NBS often being perceived to be less efficient, or riskier, than built (grey) systems.

NBS often require cooperation among multiple institutions and stakeholders, something that can be difficult to achieve. Current institutional arrangements did not evolve with cooperation on NBS in mind. There is a lack of

awareness, communication and knowledge at all levels, from communities to regional planners and national policy makers, of what NBS can really offer. The situation can be compounded by a lack of understanding of how to integrate green and grey infrastructure at scale, and an overall lack of capacity to implement NBS in the context of water. Myths and/or uncertainty remain about the functioning of natural or green infrastructure, and about what ecosystem services mean in practical terms. It is also not entirely clear, at times, what constitutes a NBS. There is a lack of technical guidance, tools and approaches to determine the right mix of NBS and grey-infrastructure options. The hydrological functions of natural ecosystems, like wetlands and floodplains, are much less understood than those provided by grey infrastructure. Consequently, NBS are even more neglected in policy appraisal and in natural resource and development planning and management. This situation is partly compounded by insufficient research and development in NBS and particularly by the lack of impartial and robust assessments of current NBS experience, especially in terms of their hydrological performance, and cost–benefit analyses in comparison or conjunction with grey solutions.

There are limits to what ecosystems can achieve and these need much better identification. For example, 'tipping points', beyond which negative ecosystem change becomes irreversible, are well theorized but rarely quantified. It is therefore necessary to recognize the limited carrying capacity of ecosystems and determine the thresholds where any additional stresses (e.g. the addition of contaminants and toxic substances) will lead to irreversible damage to the ecosystem.

The high degree of variation in the impacts of ecosystems on hydrology (depending on ecosystem type or subtype, location and condition, climate and management) cautions to avoid generalized assumptions about NBS. For example, trees can increase or decrease groundwater recharge according to their type, density, location, size and age. Natural systems are dynamic and their roles and impacts change over time.

An often overstated assumption about NBS is that they are 'cost-effective', whereas this should be established during an assessment, including consideration of co-benefits. While some small-scale NBS applications can be low- or no-cost, some applications, particularly at scale, can require large investments. Ecosystem restoration costs, for example, can vary widely from a few hundred to several millions of US dollars per hectare. Site-specific knowledge on the field deployment of NBS is essential yet often inadequate. Now that attention to NBS has increased, NBS practitioners need to greatly increase knowledge to support decision making and avoid overstating NBS performance if this new impetus is not to be squandered.

Responses – Creating the enabling conditions for accelerating the uptake of NBS

The required responses to these challenges essentially involve creating enabling conditions for NBS to be considered equitably alongside other options for water resources management.

Leveraging financing

NBS do not necessarily require additional financial resources but usually involve redirecting and making more effective use of existing financing. Investments in green infrastructure are being mobilized thanks to the increasing recognition of the potential of ecosystem services to provide system-wide solutions that make investments more sustainable and cost-effective over time. Assessments of the returns on investments in NBS often do not factor in these positive externalities, just as those for grey infrastructure often do not take all negative environmental and social externalities into account.

Payment for environmental services schemes provide monetary and non-monetary incentives to upstream communities, farmers and private land owners to protect, restore and conserve natural ecosystems and to adopt sustainable agricultural and other land use practices. These actions generate benefits to downstream water users in the form of water regulation, flood control, and erosion and sediment control, among others, thus ensuring a constant, high-quality water supply, and helping reduce water treatment and equipment maintenance costs.

The emerging 'green bond' market shows promising potential for mobilizing NBS financing and, notably, demonstrates that NBS can perform well when assessed against rigorous standardized investment performance criteria. The private sector can also be further stimulated and guided to advance NBS in the areas in which it operates. Building in-house expertise and awareness of the effectiveness of NBS will facilitate this.

Transforming agricultural policy represents a significant pathway for financing the further uptake of NBS. This requires overcoming the fact that the vast majority of agricultural subsidies, and probably the majority of public funding and almost all private sector investment in agricultural research and development, support the intensification of conventional agricultural, which increases water insecurity. Mainstreaming the concept of sustainable ecological intensification of agricultural production, which essentially involves deploying NBS (e.g. improved soil and landscape management techniques), is not only the recognized way forward in order to achieve food security, but would also be a major advance in NBS financing for water.

Assessing co-benefits of NBS (through a more holistic cost–benefit analysis) is an essential step in achieving efficient investments and tapping into financial resources across multiple sectors. All benefits, not just a narrow set of hydrological outcomes, need to be factored into an assessment of investment options. This requires a detailed systematic approach, but evidence shows it will lead to significant improvements in decision making and overall system performance.

Creating an enabling regulatory and legal environment

The vast majority of current regulatory and legal environments for water management were developed largely with grey-infrastructure approaches in mind. Consequently, it can often be challenging to retrofit NBS into this framework. However, rather than expecting drastic changes in regulatory regimes, much can be achieved by promoting NBS more effectively through existing frameworks. In places where enabling legislation does not yet exist, identifying where and how NBS can support existing planning approaches at different levels can be a useful first step in this process.

National legislation to facilitate the implementation of NBS at the local level is particularly crucial. A small but growing number of countries have adopted regulatory frameworks promoting NBS at the national level. In Peru, for example, a national legal framework was adopted to regulate and monitor investment in green infrastructure. Regional frameworks can also stimulate change. The European Union, for instance, has significantly increased opportunities for NBS deployment through the harmonization of its legislation and policies regarding agriculture, water resources and the environment.

At the global level, NBS offer Member States a means to respond to and use the various multilateral environmental agreements (especially the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, the Ramsar Convention on Wetlands, the Sendai Framework on Disaster Risk Reduction, agreed frameworks for food security and the Paris Agreement on Climate Change), while also addressing economic and social imperatives. An overarching framework for promoting NBS is the 2030 Agenda for Sustainable Development with its Sustainable Development Goals (SDGs).

Improving cross-sectoral collaboration

NBS can require much greater levels of cross-sectoral and institutional collaboration than grey-infrastructure approaches, particularly when applied at landscape scale. However, this can also open opportunities to bring those groups together under a common approach or agenda.

In many countries, the policy landscape remains highly fragmented. Better harmonization of policies across economic, environmental and social agendas is a general requirement in its own right. NBS are not only a beneficiary of such harmonization but also a means to achieve it, because of their ability to deliver multiple, and often significant, co-benefits beyond just hydrological outcomes. Clear mandates from the highest policy level can significantly accelerate NBS uptake and foster improved intersectoral cooperation.

Improving the knowledge base

Improving the knowledge base on NBS, including in some cases through more rigorous science, is an essential overarching requirement. Established evidence helps convince decision makers of the viability of NBS. For example, a frequently raised concern is that NBS take a long time to achieve their impact, implying that grey infrastructure is quicker. However, the evidence shows that this is not necessarily the case and timescales to deliver benefits can compare favourably to those of grey-infrastructure solutions.

Traditional or local-community knowledge of ecosystem functioning and the nature–society interaction can be a significant asset. Improvements need to be made in the incorporation of this knowledge into assessments and decision making.

A priority response is the development and implementation of common criteria against which both NBS and other options for water resources management can be assessed. Common general criteria for an assessment of water resources management options (e.g. green versus grey solutions) can be developed on a case-by-case basis. The full inclusion of all hydrological benefits, other co-benefits and the entire range of the costs and benefits of ecosystem services (for any option) is a key requirement. This in turn will require consensus building across the various relevant stakeholder groups.

The potential contribution of NBS for water management to achieving the 2030 Agenda for Sustainable Development

NBS offer high potential to contribute to the achievement of most of the targets of SDG 6 (on water). Areas in which this contribution translates into particularly striking positive direct impacts on other SDGs are with regards to water security for underpinning sustainable agriculture (SDG 2, notably Target 2.4), healthy lives (SDG 3), building resilient (water-related) infrastructure (SDG 9), sustainable urban settlements (SDG 11) and disaster risk reduction (SDG 11 and, as related to climate change, SDG 13).

The co-benefits of NBS are particularly significant in relation to the ecosystem/environment-related SDGs, including the reduction of land use pressures on coastal areas and the

oceans (SDG 14) and the protection of ecosystems and biodiversity (SDG 15). Some other areas where the co-benefits of NBS deliver particularly high rewards in terms of achieving the SDGs include other aspects of agriculture; energy; inclusive and sustainable economic growth; full and productive employment and decent work for all; making cities and human settlements inclusive, safe, resilient and sustainable; ensuring sustainable consumption and production patterns; and combating climate change and its impacts.

Moving forward

Increased deployment of NBS is central to meeting the key contemporary water resources management challenges of sustaining and improving water availability and quality, while reducing water-related risks. Without a more rapid uptake of NBS, water security will continue to decline, and probably rapidly so. NBS offer a vital means to move beyond business-as-usual. However, the necessity and opportunities for increased deployment of NBS remain underappreciated.

World Water Development Reports have consistently argued for transformational change in how water is managed. The inadequate recognition of ecosystems' roles in water management reinforces the need for transformational change, and increased uptake of NBS provides a means to achieve it. This transformational change can no longer just be aspirational – the shift needs to rapidly accelerate and, more importantly, translate into fully operationalized policy, with improved action at site level. The objective needs to be to minimize costs and risks, and maximize system returns and robustness, while providing optimal 'fit-for-use' performance. A role of policy should be to enable the right site-level decisions to be taken in these regards. We have made a good, if somewhat belated, start in this process but there is a long way yet to go.

Coda

As humankind charts its course through the Anthropocene, and tries to avoid the tragedies of the past, adopting NBS is not only necessary for improving water management outcomes and achieving water security, it is also critical for ensuring the delivery of co-benefits that are essential to all aspects of sustainable development. Although NBS are not a panacea, they will play an essential role in building a better, brighter, safer and more equitable future for all.



PROLOGUE

THE STATE OF WATER RESOURCES IN THE CONTEXT OF NATURE-BASED SOLUTIONS



WWAP | David Coates and Richard Connor

With contributions from: International Institute for Applied Systems Analysis (IIASA)

The mangrove forest in Phang-Nga Bay (Thailand)



Current trends in the state of water resources are largely as assessed and identified in previous World Water Development Reports. The world continues to face multiple and complex water challenges that are expected to intensify in the future. This Prologue expands on two aspects of these water resources challenges of particular relevance to nature-based solutions (NBS). Firstly, it includes a global-level assessment of the current status and trends in water demand and availability, extreme water-related events and water quality, recognizing that the sustainable management of food, energy and water are deeply interconnected and that these linkages need to be assessed. Secondly, it describes how the impacts of ecosystem change on water resources clearly show the need to include ecosystems in this food–energy–water nexus.

Water demand

Global water use has increased by a factor of six over the past 100 years (Wada et al., 2016) and continues to grow steadily at a rate of about 1% per year (AQUASTAT, n.d.). Water use is expected to continue increasing at the global level, as a function of population growth, economic development and changing consumption patterns, among other factors.

The world population is expected to increase from 7.7 billion in 2017 to between 9.4 and 10.2 billion by 2050, with two thirds of the population living in cities. More than half of this anticipated growth is expected to occur in Africa (+1.3 billion), with Asia (+0.75 billion) expected to be the second largest contributor to future population growth (UNDESA, 2017). Over the same period (2017–2050), global gross domestic product (GDP) is expected to increase by a factor of 2.5 (OECD, n.d.), although with large differences among and within countries. Global demand for agricultural and energy production (mainly food and electricity), both of which are water-intensive, is expected to increase by roughly 60% and 80% respectively by 2025 (Alexandratos and Bruinsma, 2012; OECD, 2012). At the same time, the

> Global water demand will continue to grow significantly over the next two decades

global water cycle is intensifying due to global warming, with wetter regions generally becoming wetter and drier regions becoming even drier (IPCC, 2014). These aspects of global change illustrate the need for swift planning and execution of strategic, reasonable and effective management and countermeasures against deteriorating water security[1] (Burek et al., 2016).

Contemporary global water demand has been estimated at about 4,600 km³ per year and projected to increase by 20%–30% to between 5,500 and 6,000 km³ per year by 2050 (Burek et al., 2016). However, *"estimations at the global scale are complicated because of limited available observational data and the interactions of a combination of important environmental, social, economic, and political factors, such as global climate change, population growth, land use change, globalization and economic development, technological innovations, political stability and the extent of international cooperation. Because of these interconnections, local water management has global impacts, and global developments have local impacts."* (Wada et al., 2016, p. 176).

Agriculture accounts for about 70% of global water withdrawals, the vast majority of which are used for irrigation. Yet global estimates for annual irrigation water demand are fraught with uncertainty. This is not merely due to a lack of monitoring and reporting on water used for irrigation, but also to the inherently erratic nature of the practice itself. The amounts of water used for irrigation at any given time will vary with crop type and their various growing seasons, and also depend on cropping practices and variability in local soil and climatic conditions, not to mention any changes in the land area equipped for irrigation. The efficiency of different irrigation techniques will also have a direct impact on overall water use. This is what makes projecting future water demand for irrigation so difficult. For example, whereas Burek et al. (2016) have projected increases in global crop irrigation water requirements for 2050 to be somewhere between 23% and 42% above the level in 2010, the Food and Agriculture Organization of the United Nations (FAO, 2011a) estimated a 5.5% increase in water withdrawals for irrigation from 2008 to 2050. Citing anticipated increases in irrigation water efficiency, the Organisation for Economic Co-operation and Development (OECD, 2012) predicted a slight decrease in water use for irrigation through the period 2000–2050.

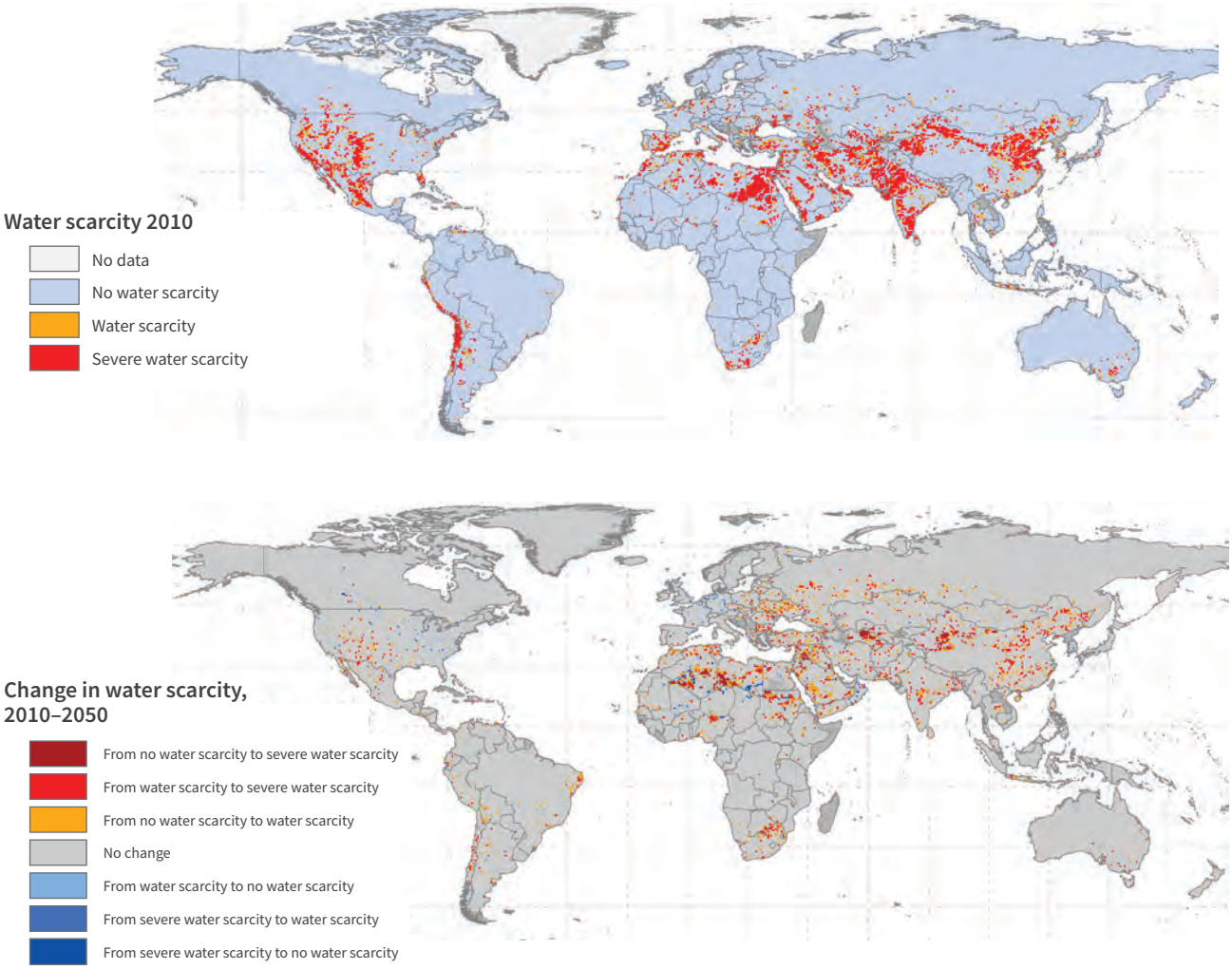
Regardless of any increase in water demand for agriculture, meeting the estimated 60% increase in food demand will require the expansion of arable land under business-as-usual. Under prevailing management practices, intensification of production involves increased mechanical disturbance of soil and inputs of agrochemicals, energy and water. These drivers associated with food systems account for 70% of the predicted loss of terrestrial biodiversity by 2050 (Leadley et al., 2014). However, these impacts, including requirements for more land and water, can largely be avoided if further intensification of agricultural production is based on ecological intensification that involves improving ecosystem services to reduce external inputs (FAO, 2011b).

Water use by industry, which account for roughly 20% of global withdrawals, is dominated by energy production, which is responsible for approximately 75%, with the remaining 25% of industrial water withdrawals being used for manufacturing (WWAP, 2014). Projections by Burek et al. (2016) suggest the overall water demand from industry will increase across all the regions of the world, with the exception of Northern America and Western and Southern Europe. Industrial demand could increase with up to eight times (in relative terms) in regions such as Western, Middle, Eastern and Southern Africa, where industries currently account for a very small proportion of total water use. Industrial demand should also increase significantly (up to two and a half times) in Southern, Central and Eastern Asia (Burek et al., 2016). According to the OECD (2012), water demand for manufacturing is projected to increase by 400% over the period 2000–2050. Global water withdrawals for energy production have been projected to rise by one-fifth over the period 2010–2035, whereas water consumption would increase by 85% driven by the shift towards more efficient power plants with more advanced cooling systems (that reduce water withdrawals but increase consumption) and increased production of biofuels (IEA, 2012). Chaturvedi et al. (2013) suggest that restricting bioenergy production to non-irrigated marginal or abandoned cropland might alleviate negative impacts on food production and prices, water use, and biodiversity.

Domestic water use, which roughly accounts for the remaining 10% of global water withdrawals, is expected to increase significantly over the 2010–2050 period in nearly all regions of the world, with the exception of Western Europe where it remains constant. In relative terms, the greatest increases in domestic demand should occur in African and Asian sub-regions where it could more than triple, and it could more than double in Central and South America (Burek et al., 2016). This anticipated growth can be primarily attributed to an anticipated increase in water supply services in urban settlements.

[1] Water security is defined as "*the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*" (UN-Water, 2013).

Figure 1 **Physical water scarcity in 2010 (upper figure) and projected change in water scarcity* by 2050 (lower figure) based on the *middle-of-the-road* scenario****



*Regions are considered water scarce when total annual withdrawals for human use are between 20 and 40% of the total available renewable surface water resources, and severely water scarce when withdrawals exceed 40%.

**The scenarios used for this modelling exercise are based on 'water extended shared socio-economic pathways'. The *middle-of-the-road* scenario assumes world development is progressing along past trends and paradigms, such that social, economic, and technological trends do not shift markedly from historical patterns (i.e. business-as-usual).

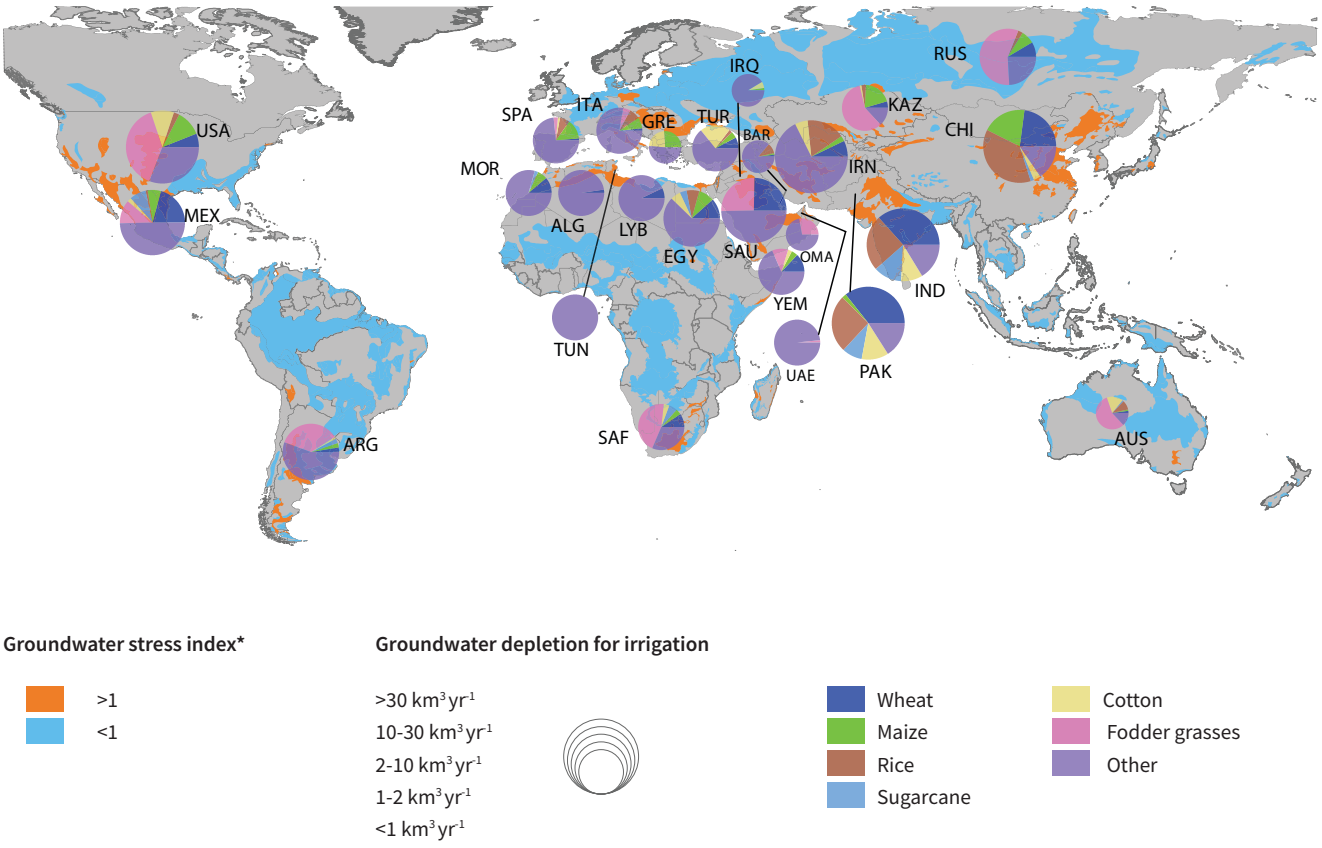
Source: Burek et al. (2016, fig. 4–39, p. 65).

In summary, global water demand will continue to grow significantly over the next two decades. Industrial and domestic demand for water will likely grow much faster than agricultural demand, although agriculture will remain the largest overall user. Rosegrant et al. (2002) forecasted that for the 'first time in world history' absolute growth in non-agricultural demand for water will exceed growth in agricultural demand, resulting in a fall in agriculture's share of total water consumption in developing countries from 86% in 1995 to 76% in 2025. These projections highlight the importance of addressing water challenges facing agriculture where agricultural demand for water, and competition for it, are both set to increase. The agricultural development options adopted will be the most critical factor in determining the future for water security in agriculture and other sectors.

Water availability

Available surface water resources at continent level should remain relatively constant as opposed to the development of population, GDP or water demand. At the sub-regional level, any change would be small, ranging from -5 to +5%, due to climate change effects, but changes can be much more pronounced at the country level (Burek et al., 2016). Many countries are already undergoing pervasive water scarcity conditions and will likely have to cope with lower surface water resources availability in the 2050s (Figure 1). At present, almost all countries in a belt around 10 to 40 degrees north, from Mexico to China and to Southern Europe are affected by water scarcity, together with Australia, Western South America and Southern Africa in the Southern

Figure 2 Crop-specific contribution to groundwater depletion worldwide in 2010



*The groundwater stress index is the calculated ratio of the *groundwater footprint* (defined more formally as GF = $A[C/(R-E)]$, where C, R and E are respectively the area-averaged annual abstraction of groundwater, recharge rate, and the groundwater contribution to environmental streamflow; and A is the areal extent of any region of interest where C, R and E can be defined) to the aquifer area (A_A). GF/A_A > 1 indicates areas where unsustainable groundwater consumption could affect groundwater availability and groundwater-dependent surface water and ecosystems.

Note: The pie charts show fractions of groundwater depletion for irrigation (GWD) of major crops by country, and their sizes indicate total GWD volume. The background map shows groundwater stress index (corresponding to overexploitation when larger than one) of major aquifers. Some countries have overexploited aquifers but no pie chart is shown because groundwater use is not primarily related to irrigation. Areas shaded grey represent zones with no major groundwater-dependent crop production.

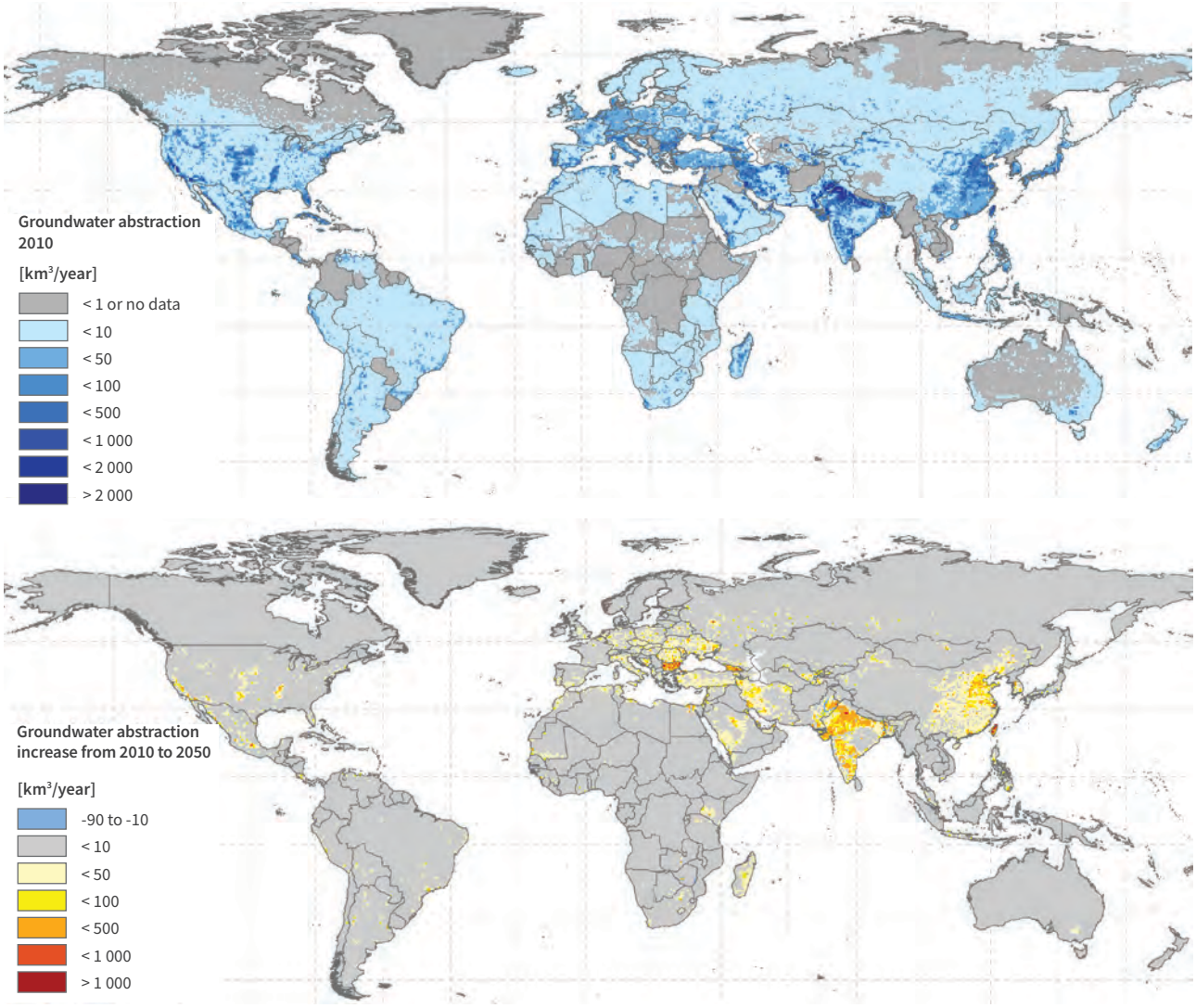
Source: Dalin et al. (2017, fig. 1, pp. 700–704). © 2017 Reprinted by permission from Macmillan Publishers Ltd.

Hemisphere (Veldkamp et al., 2017). Throughout the early-mid 2010s, about 1.9 billion people (27% of the global population) lived in potential severely water-scarce areas and in 2050 this could increase to some 2.7–3.2 billion. However, if monthly variability is taken into account, 3.6 billion people worldwide (nearly half the global population) are already living in potential water-scarce areas at least one month per year and this could increase to some 4.8–5.7 billion in 2050. About 73% of the affected people live in Asia (69% by 2050). Factoring in adaptive capacity, 3.6–4.6 billion people (43–47%) will be under water stress in the 2050s with 91–96% living in Asia, mainly Southern and Eastern, and 4–9% in Africa, mainly in the north (Burek et al., 2016).

Groundwater use globally, mainly for agriculture, amounts to 800 km³ per year in the 2010s, with India, the United States of America (USA), China, Iran and Pakistan (in descending order) accounting for 67% of total abstractions worldwide (Burek et al., 2016). Water withdrawals for irrigation have been identified as the primary driver of groundwater depletion worldwide (Figure 2). A large surge in groundwater abstractions amounting to 1,100 km³ per year has been predicted to occur by the 2050s, corresponding to a 39% increase over current levels (Figure 3).

The importance of current water availability challenges can only be fully understood by comparing water withdrawal to their maximum sustainable levels. At about 4,600 km³ per year, current global withdrawals are already near maximum sustainable levels (Gleick and Palaniappan, 2010; Hoekstra and Mekonnen, 2012) and, as noted in previous World Water Development Reports, global figures mask more severe challenges at regional and local scales. A third of the world biggest groundwater systems are already in distress (Richey

Figure 3 Groundwater abstractions in 2010 (upper figure) and increases in groundwater abstraction by 2050 above 2010 levels (lower figure) based on the *middle-of-the-road* scenario*



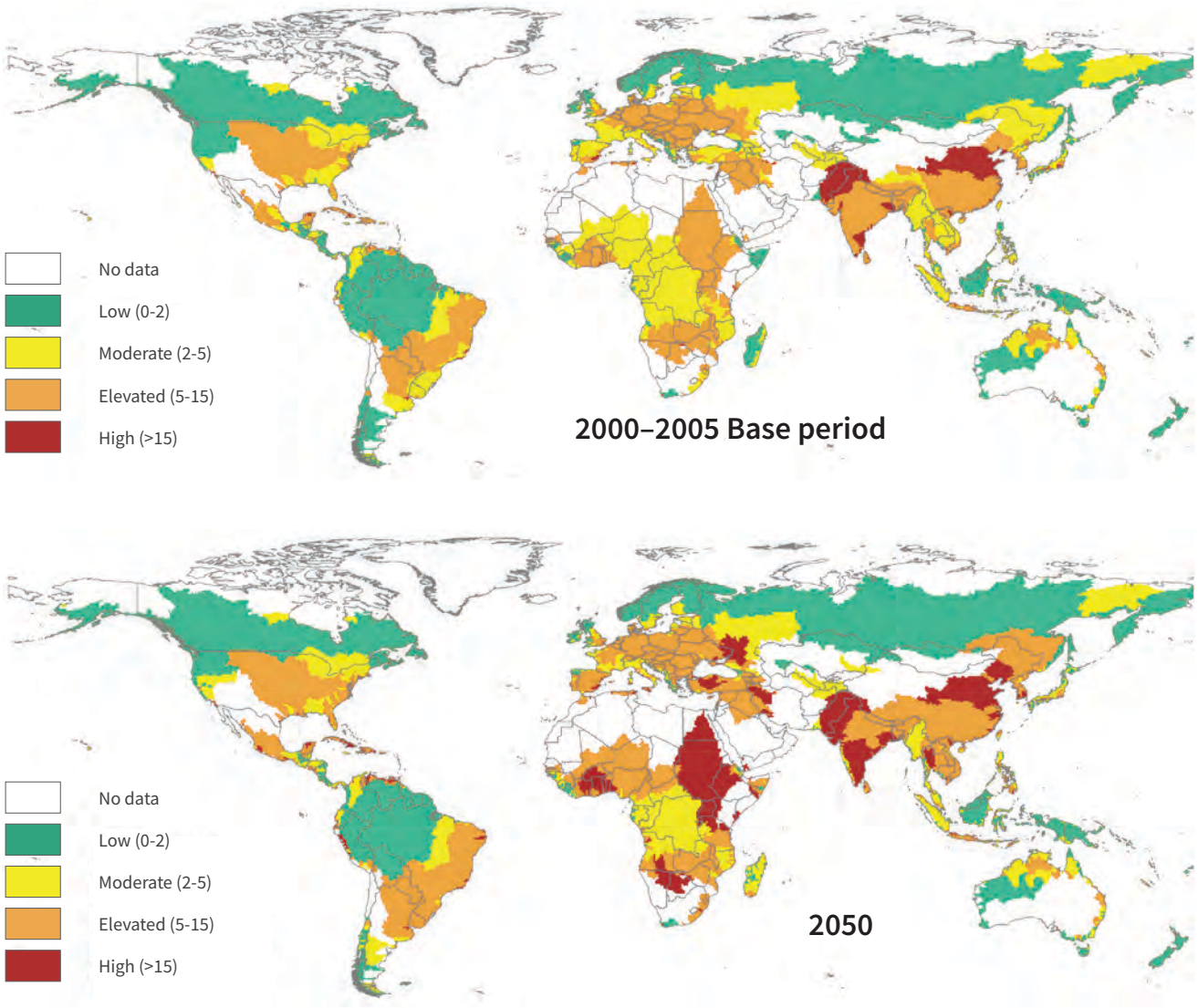
*The scenarios used for this modelling exercise are based on 'water extended shared socio-economic pathways'. The *middle-of-the-road* scenario assumes world development is progressing along past trends and paradigms, such that social, economic and technological trends do not shift markedly from historical patterns (i.e. business-as-usual).

Source: Burek et al. (2016, fig. 4–29, p. 55).

et al., 2015). The above-mentioned groundwater trends also assume increasing withdrawals from non-renewable (fossil) groundwater – indisputably an unsustainable path.

There is high competition for marginal, degraded and abandoned cropland for food production, urban expansion and restoration of natural ecosystems, negating the suggestion that these lands offer a reasonable alternative for irrigated bioenergy production (SCBD, 2014). Furthermore, improving the efficiency of irrigation water use may actually lead to an overall intensification of water depletion at basin level through increases in the total evaporation from crops and reductions in return flows (Huffaker, 2008). Water efficiency gains in irrigation should therefore be accompanied by regulatory measures on water allocations and/or irrigation areas (Ward and Pulido-Velazquez, 2008). The Comprehensive Assessment of Water Management in Agriculture (2007) already noted that the scope for the expansion of irrigation worldwide is limited, with some regional exceptions, and that attention needs to shift away from surface water allocations to improving rain-fed agriculture. The option of building more reservoirs is increasingly limited by silting, available runoff, environmental concerns and restrictions, and the fact that most cost-effective and viable sites in developed countries have been identified and used. In certain areas, more

Figure 4 **Water quality risk indices for major river basins during the base period (2000–2005) compared to 2050 (nitrogen index under the CSIRO*-*medium-scenario***)**



*Commonwealth Scientific and Industrial Research Organization

**This scenario takes account of a drier future (as projected by the CSIRO climate change model) and a medium level of socio-economic growth.

Source: Veolia/IFPRI (2015, fig. 3, p. 9).

ecosystem-friendly forms of water storage, such as natural wetlands, soil moisture and more efficient recharge of groundwater could be more sustainable and cost-effective than traditional infrastructure such as dams (OECD, 2016).

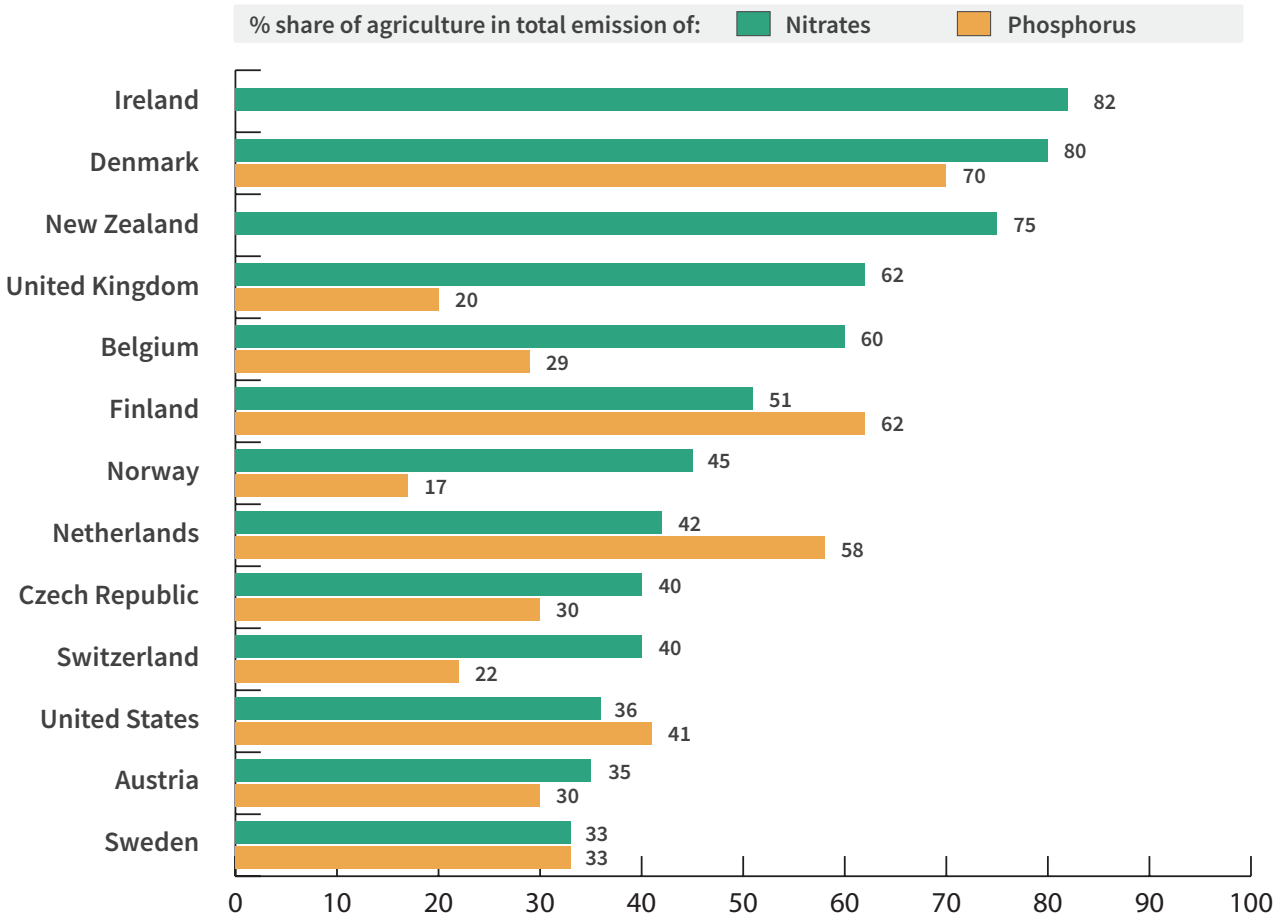
Water quality

The main areas that are subject to water quality threats are largely correlated to population densities and areas of economic growth, with the future scenarios determined largely by the same factors (Figure 4). Since the 1990s, water pollution has worsened in almost all rivers in Africa, Asia and Latin America (UNEP, 2016a). The deterioration of water quality is expected to escalate over the next decades and this will increase threats to human health, the environment and sustainable development (Veolia/IFPRI, 2015).

An estimated 80% of all industrial and municipal wastewater are released to the environment without any prior treatment, resulting in a growing deterioration of overall water quality with detrimental impacts on human health and ecosystems (WWAP, 2017).

Globally, the most prevalent water quality challenge is nutrient loading, which depending on the region is often associated with pathogen loading (UNEP, 2016a). The relative contribution of nutrients from point source wastewater versus diffuse sources varies by region. Despite

Figure 5 Percentage share of agriculture in total emissions of nitrates and phosphorus in OECD countries, 2000–2009



Note: Countries are ranked in descending order of highest share of nitrates in surface water.

For nitrates, the figures presented correspond to the year 2000 for Austria, the Czech Republic, New Zealand, Norway, Switzerland and the USA; 2002 for Denmark; 2004 for Finland and Ireland; 2005 for Belgium (Wallonia); 2008 for the United Kingdom (UK); and 2009 for the Netherlands and Sweden.

For phosphorus, the figures presented correspond to the year 2000 for Austria, the Czech Republic, Norway, Switzerland and the USA; 2002 for Denmark; 2004 for Finland; 2005 for Belgium (Wallonia); and 2009 for the Netherlands, Sweden and the UK.

Source: OECD (2013, fig. 9.1, p. 122).

decades of regulation and large investments to reduce point source water pollution in developed countries, water quality challenges endure as a result of under-regulated diffuse sources of pollution. Managing diffuse runoff of excess nutrients from agriculture, including into groundwater, is regarded as the most prevalent water quality-related challenge globally (UNEP, 2016a; OECD, 2017). Agriculture remains the predominant source of reactive nitrogen discharged into the environment and a significant source of phosphorus (Figure 5). Economic development alone is not a solution to this problem. Almost 15% of groundwater monitoring stations in Europe recorded that the standard for nitrates established by the World Health Organization (WHO) were exceeded in drinking water, and monitoring stations recorded that approximately 30% of rivers and 40% of lakes were eutrophic or hypertrophic in 2008–2011 (EC, 2013a).

Hundreds of chemicals, in addition to nutrients, are also implicated in impacting water quality. Agricultural intensification has already increased chemical use worldwide to approximately two million tonnes per year with herbicides accounting for 47.5%, insecticides for 29.5%, fungicides for 17.5% and others for 5.5% (De et al., 2014). The impacts of this trend are largely unquantified and there are serious data gaps: for example, Bünemann et al. (2006) found no data available for the effects on soil biota, among first non-target organisms exposed, for 325 of 380 active constituents of pesticides registered for use in Australia. A recent report of the Special Rapporteur on the right to food (UNGA, 2017) draws attention to the urgency of improved pesticide use policies. Contaminants of emerging concern are continually evolving and increasing, and often detected at concentrations higher

> Globally, the most prevalent water quality challenge is nutrient loading

than expected (Sauvé and Desrosiers, 2014). Examples include pharmaceuticals, hormones, industrial chemicals, personal care products, flame retardants, detergents, perfluorinated compounds, caffeine, fragrances, cyanotoxins, nanomaterials and anti-microbial cleaning agents and their transformation products. Impacts on people and biodiversity will be mainly delivered via water and are largely unknown (WWAP, 2017).

Climate change will affect water quality in various ways. For example, changes in spatial and temporal patterns and variability of precipitation affect surface water flows and hence dilution effects, while increases in temperature cause higher evaporation from open surfaces and soils, and increased transpiration by vegetation potentially reduce water availability (Hipsey and Arheimer, 2013). Dissolved oxygen will deplete faster because of higher water temperatures and it can be expected that higher contents of pollutants will flow into water bodies following extreme rain events (IPCC, 2014).

The greatest increases in exposure to pollutants are expected to occur in low- and lower-middle income countries, primarily because of higher population and economic growth in these countries, especially those in Africa (UNEP, 2016a), and the lack of wastewater management systems (WWAP, 2017). Given the transboundary nature of most river basins, regional cooperation will be critical to addressing projected water quality challenges.

Extreme events

The trends in water availability are accompanied by projected changes in flood and drought risks. One particular concern is that the increasing flood risk occurs in some traditionally water-scarce areas (e.g. in Chile, China and India, as well as the Middle East and North Africa) where local coping strategies for flood events are likely to be poorly developed. Economic losses due to water-related hazards have risen greatly over the past decades. Since 1992, floods, droughts and storms have affected 4.2 billion people (95% of all people affected by all disasters), causing US$1.3 trillion of damage – 63% of all disaster-related damage worldwide (UNESCAP/UNISDR, 2012).

According to the OECD, *"the number of people at risk from floods is projected to rise from 1.2 billion today to around 1.6 billion in 2050 (nearly 20% of the world's population) and the economic value of assets at risk is expected to be around US$45 trillion by 2050, a growth of over 340% from 2010"* (OECD, 2012, p. 209). Floods have accounted for 47% of all weather-related disasters since 1995, affecting a total of 2.3 billion people. The number of floods rose to an average of 171 per year over the period 2005–2014, up from an annual average of 127 in the previous decade (CRED/UNISDR, 2015). Examples of costs of flooding include 39 and 11% of GDP in the People's Democratic Republic of Korea and Yemen, respectively (CRED/UNISDR, 2015).

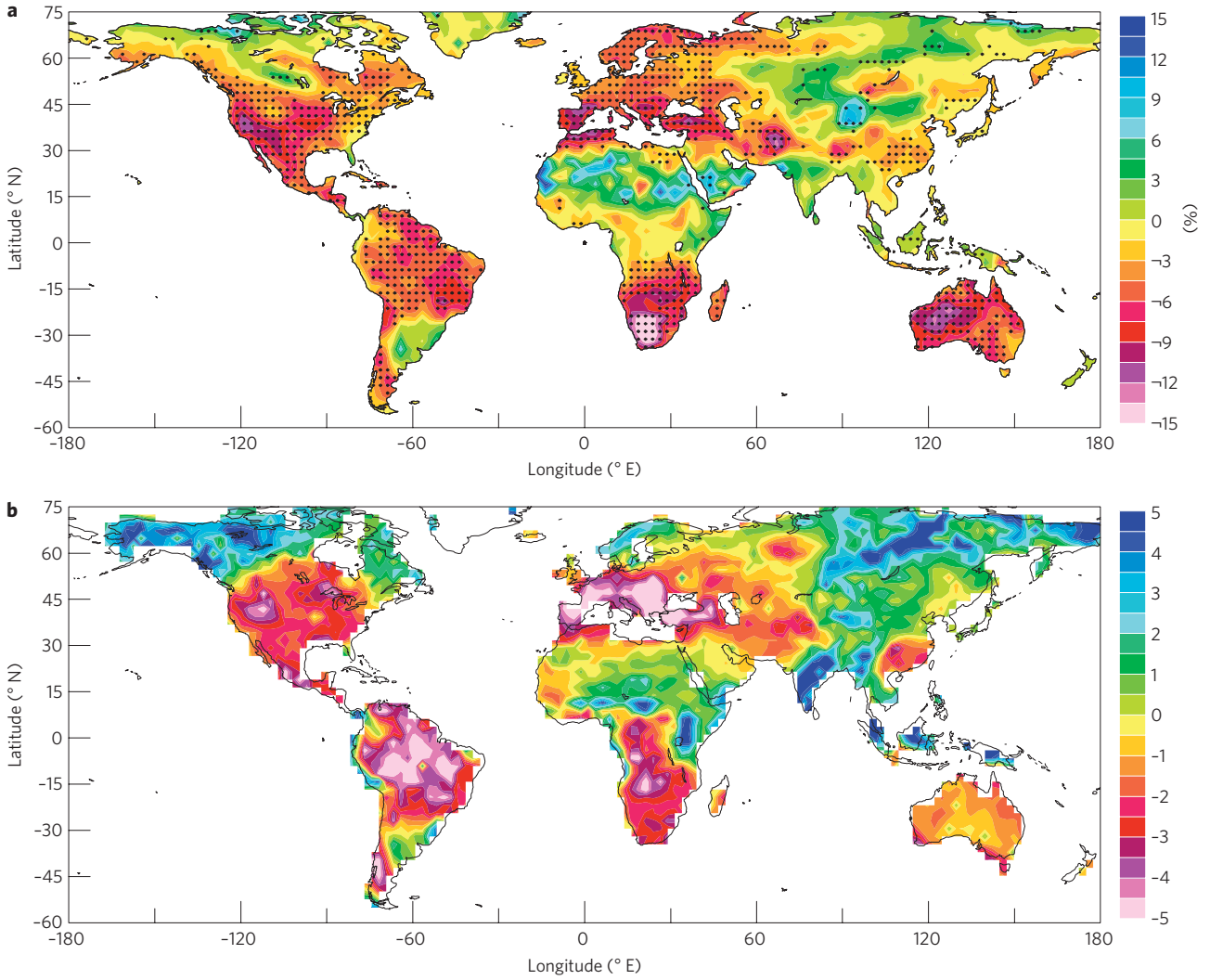
The population currently affected by land degradation/desertification and drought is estimated at 1.8 billion people, making this the most significant category of 'natural disaster' based on mortality and socio-economic impact relative to GDP per capita (Low, 2013). Drought is also a chronic, long-term problem compared to the short-term impacts of flooding, and droughts are arguably the greatest single threat from climate change. Changes in future rainfall patterns will alter drought occurrence, and consequently, soil moisture availability for vegetation in many parts of the world (Figure 6). The predicted longer duration and severity of droughts can be alleviated by more water storage, which requires upscaling of infrastructure investments that can have significant trade-offs for society and the environment. Therefore, water storage in the environment ('green infrastructure') must be part of location-specific solutions. The impacts of droughts will be worsened by the increasing withdrawals in response to the increasing water demand.

Trends in ecosystem change that affect water resources

All major terrestrial, and most coastal, ecosystem types or biomes influence water availability, quality and risks (see Chapter 1). Trends in the extent and condition of these ecosystems are, therefore, particularly relevant to this report because they indicate the extent to which ecosystem conservation and/or restoration can contribute to meeting water resources management challenges.

About 30% of the global land area is forested, but at least 65% of this area is already in a degraded state (FAO, 2010). However, the rate of net forest area loss has been cut by over 50% in the past 25 years and in some regions planting is off-setting the loss of natural forest (FAO, 2016). Grasslands are among the most extensive biomes in the world and, when croplands and areas with trees but dominated by grass are included, their area exceeds that of forests. Grasslands naturally occur in regions where the climatic conditions are either too dry or too cold for other vegetation types such as forests, but large areas of forests and wetlands have also been converted into grasslands, especially for livestock grazing or the production of crops. Likewise, vast areas of natural grasslands have been 'improved' (i.e. altered for livestock grazing). Trends in area and condition are therefore more difficult to quantify.

Figure 6 **Predicted future changes in the mean soil moisture content in the top 10 cm layer in percentage change* from 1980–1999 (upper figure) to 2080–2099 (lower figure)**



*Based on multi-model ensemble predictions simulated by 11 Coupled Model Intercomparison Project Phase 5 (CMIP5) models under the representative concentration pathways (RCP) 4.5 emissions scenario.

Source: Dai (2013, fig. 2, p. 53). © 2013 Reprinted by permission from Macmillan Publishers Ltd.

Wetlands (including rivers and lakes) cover only 2.6% of land but play a disproportionately large role in hydrology per unit area. The best estimate of reported global loss of natural wetland area due to human activity averages between 54% and 57%, but loss may have been as high as 87% since 1700, with a 3.7 times faster rate of wetland loss during the twentieth and early twenty-first centuries, equating to a loss of 64–71% of wetlands extent since that existing in 1900 (Davidson, 2014). Losses have been larger and faster for inland than for coastal natural wetlands. Although the rate of wetland loss in Europe has slowed down, and in North America has remained low since the 1980s, the rate of loss has remained high in Asia, where large-scale and rapid conversion of coastal and inland natural wetlands is continuing. Some of these losses are off-set by the expansion of artificial or managed wetlands, principally reservoirs and rice paddies. The vast majority of reviews concluded that wetlands either increase or decrease a particular component of the water cycle (Bullock and Acreman, 2003). The extent of their loss, therefore, has significant implications for hydrology. However, different wetlands have different hydrological properties and quantifying the impact of this global change on water resources is challenging.

Direct human-induced land use and land use change (LULUC) have major impacts on hydrology from local to regional and global scales (see Chapter 1, Section 1.3.3). There is compelling evidence that trends in LULUC have impacted basin-scale water balances, for example in the upper Mississippi River Basin (Schilling and Libra, 2003; Zhang and Schilling, 2006) or in the middle reaches of the Yellow River Basin (Sun et al., 2006; Zhang et al., 2015). In addition to affecting the water balance dynamics within a catchment, LULUC can also affect precipitation and runoff patterns in other catchments, due to the vegetation's role as 'water recycler' and the effects of atmospheric circulation.

Human activities that lead to hydrological changes in grasslands are now widespread (Gibson, 2009). Overgrazing, soil degradation and surface compaction are leading to higher evaporation rates, lower soil water storage and increased surface runoff, all of which are considered detrimental to the water-provisioning services of grasslands, including water quality (McIntyre and Marshall, 2010), and the attenuation of flood and drought risks (Jackson et al., 2008). Significant impacts are increasingly manifest when grassland management is associated with regular burning, which tends to increase water use through vegetation regrowth, and thus reduce water yield (Sakalauskas et al., 2001). Soil compaction and the associated reductions of infiltration capacity caused by grazing are increasingly documented in the literature (Bilotta et al., 2010). About 7.5% of grassland worldwide has been degraded because of overgrazing alone (Conant, 2012).

The most extensive knowledge regarding the current status of, and trends in, ecosystem change and impacts on water resources exists in the domain of soils, or land degradation. The soil–vegetation layer is the most critical interface between water, ecosystems and human needs (see Chapter 1, Section 1.3.2). The 2015 assessment of the *Status of the World's Soil Resources*, undertaken by the Intergovernmental Technical Panel on Soils (FAO/ITPS, 2015a), concluded that the majority of the world's soil resources are in fair, poor or very poor condition and the current outlook is for this situation to worsen. Table 1 presents a global summary of the condition and trend for the top-ten threats to soils. The most significant threats to the natural capital of soil at the global scale are soil erosion, loss of soil organic carbon, nutrient imbalance and loss of biodiversity, and these are strongly interdependent (as are the other functions impacted by most other threats) and impact water resources.

Land degradation is linked with impaired ecosystem services and low water productivity (Bossio et al., 2008), including in irrigated systems (Uphoff et al., 2011). Soil erosion from croplands carries away 25–40 billion tonnes of topsoil every year, significantly reducing crop yields and the soil's ability to regulate water, carbon and nutrients, and transporting 23–42 million tonnes of nitrogen and 15–26 million tonnes of phosphorus off land, with major negative effects on water quality (FAO/ITPS, 2015a). The global loss of the soil organic carbon pool since 1850 is estimated at about 66 ± 12 billion tonnes; a significant contribution to the increased concentration of greenhouse gases in the atmosphere, but also a major factor undermining crop water availability (FAO/ITPS, 2015b). Soil salinity and sodicity are becoming a significant problem worldwide in both irrigated and non-irrigated areas, taking an estimated 0.3–1.5 million ha of farmland out of production each year and decreasing the production potential of another 20–46 million ha (FAO/ITPS, 2015a). An estimated 60 million ha of irrigated land (or 20% of the total) is affected by soil salinity (Squires and Glenn, 2011).

> About 30% of the global land area is forested, but at least 65% of this area is already in a degraded state

There is ample evidence that ecosystem change has increased risks and vulnerability and in many cases is the primary factor setting risk levels (Renaud et al., 2013). Land use change, soil degradation and erosion, and wetlands loss are all implicated in increasing disaster risk (Wisner et al., 2012). There is a vicious spiral between climate change impacts, ecosystem degradation and increased risk of climate-related disasters (Munang et al., 2013). Reversing the trend in ecosystem degradation is a key policy response for climate-proofing food security (FAO, 2013a). It is well established that intact coastal wetlands, including mangroves, can protect coastal communities from extreme weather events (and sea level rise) and their loss increases risk and vulnerability. Although increasing sediment loads are a problem for water quality worldwide, natural levels of sediment transport downstream can become interrupted when sediments become trapped behind dams, undermining sediment flows required to sustain the integrity of coastal wetlands. In the Mississippi Delta, for example, the loss of wetlands and their related storm and flood protection services, due to reduced sediment inputs from dam construction and operation upstream, was a primary factor contributing to the severity of the impacts of Hurricane Katrina in 2005 (Batker et al., 2010). Many major urban settlements and most megacities are located in deltas with similar, if not higher, levels of risk through similar (mis-)management approaches to land and water. The question is not whether most of these will be similarly impacted – but when.

Table 1 Global condition and trend for soil threats excluding Antarctica

Threat to soil function	Condition and trend				
	Very poor	Poor	Fair	Good	Very good
Soil erosion	↙NENA	↙A ↙LAC ↙SSA	↗E ↗NA ↗SP		
Organic carbon change		↓↑A ↓↑E ↙LAC ↙NENA ↙SSA	↗NA ↓↑SP		
Nutrient imbalance		↙A ↓↑E ↙LAC ↙SSA ↙NA	↙SP	↓↑NENA	
Salinization and sodification		↓↑A ↙E ↙LAC	↙NENA ↓↑SSA	↗NA ↓↑SP	
Soil sealing and land take	↙NENA	↙A ↙E	↓↑LAC ↙NA	=SSA ↙SP	
Loss of soil biodiversity		↙NENA ↙LAC	↓↑A ↙E ↙SSA	↓↑NA ↓↑SP	
Contamination	↙NENA	↙A ↙E	↓↑LAC	↙SSA ↗NA ↗SP	
Acidification		↙A ↓↑E ↗SSA ↙NA	↓↑LAC ↙SP	↓↑NENA	
Compaction		↙A ↙LAC ↙NENA	↓↑E ↓↑NA ↓↑SP	=SSA	
Waterlogging			↙A ↓↑E =LAC	↓↑NENA =SSA ↓↑NA ↓↑SP	

Stable = Variable ↓↑ Improving ↗ Deteriorating ↙

Note: NA: North America; E: Europe; NENA: Near East and North Africa; LAC: Latin America and the Caribbean; SSA: Sub-Saharan Africa; SP: Southwest Pacific; and A: Asia.

Source: FAO/ITPS (2015b, table 8, p. 67).

1 NATURE-BASED SOLUTIONS (NBS) AND WATER



WWAP | David Coates and Richard Connor

With contributions from: Giuseppe Arduino (UNESCO-IHP) and Kai Schwaerzel (UNU-FLORES)[2]

Mangrove reforestation



1.1 Introduction

Nature-based solutions (NBS) are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water. The defining feature of an NBS is, therefore, not whether an ecosystem used is 'natural' but whether natural processes are being proactively managed to achieve a water-related objective. An NBS uses ecosystem services to contribute to a water management outcome. An NBS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. They can be applied at micro- (e.g. a dry toilet) or macro- (e.g. landscape) scales.

In this report, nature-based approaches are articulated as 'solutions' to flag their current, and potential, contribution to solving or overcoming the major contemporary water management problems or challenges – a key focus of the *World Water Development Report* series. However, they can also have utility where no critical local water problem or challenge exists, for example by delivering improved co-benefits of water resources management or simply as an aesthetic choice, even where gains in productivity are marginal.

Recognition of the role of ecosystems and the concept and application of NBS in water management are certainly not new. The role of ecosystems has been entrenched in modern hydrological sciences for decades. NBS terminology emerged probably around 2002 (Cohen-Shacham et al., 2016), but the application of natural processes to manage water probably spans millennia. Previous editions of the *World Water Development Report* series have only briefly touched on NBS (usually using alternative terminology). However, there has been rapidly increasing attention to NBS in both policy forums and the technical literature, partly in response to the view that their potential is underestimated.

[2] The views expressed in this chapter are those of the author(s). Their inclusion does not imply endorsement by the United Nations University.

The 2030 Agenda for Sustainable Development, with its Sustainable Development Goals (SDGs), has reflected this in the adoption of Target 6.6 (*"By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes"*) to support the achievement of SDG 6 (*"Ensure availability and sustainable management of water and sanitation for all"*), including with regards to its other targets on drinking water, sanitation, water quality, water use efficiency and integrated water resources management (IWRM). In response, the 2018 edition of the *World Water Development Report* is devoted to NBS and pays particular attention to their role in contributing to this agenda.

There are important lessons from ancient history that help frame the context of this report. The precarious nature of the relationship between ecosystems, hydrology and human well-being is evidenced, for example, by the collapses of the early 'great river civilizations' of the Tigris-Euphrates, the Nile, the Indus-Ganges and the Yellow River (Ito, 1997) that were initiated by hydrological changes and reductions in rainfall of up to 30% in a tract of the globe extending from Europe to the Indus River (Cullen et al., 2000; Weiss and Bradley, 2001). In some cases, desertification initiated by hydro-meteorological changes may have been accelerated by changes in land use, including overgrazing by livestock, as migratory populations sought more favourable agricultural conditions (Weiss et al., 1993). A similar history can be traced back to the Maya Civilization (250–950 AD) of Central America (Peterson and Haug, 2005). Certainly, over the past two to three millennia, wherever humankind has altered landscapes, chiefly for agriculture, degradation of the natural capital base has ensued and invariably led to a loss in the productive capacity of the land, often leading to desertification and abandonment (Montgomery, 2007). Parallels can be drawn to today. A growing body of evidence (as discussed in the Prologue) suggests that, as humankind began to chart its course through the Anthropocene, fundamental shifts in the state and functioning of the Earth systems started to exceed the range of variability experienced in the Holocene (Steffen et al., 2015).

1.2 Compatible concepts, tools, approaches and terminology

There are a number of other concepts, tools, approaches or terminology in use among various stakeholder groups or forums that are the same as, similar to or compatible with NBS. All of these aim to balance a more technocratic, built-infrastructure approach that has tended to dominate water resources management, by recognizing the contribution that ecosystems can make. *Ecohydrology* is an integrative science that focuses on the interaction between hydrology and biota (Box 1.1). The *ecosystem approach* is a conceptual framework for resolving ecosystem issues, adopted by the Convention on Biological Diversity (CBD, 1992) and compatible with the *wise use of wetlands* concept of the Ramsar Convention on Wetlands (1971). *Ecosystem-based management* and *ecosystem-based adaptation* or *mitigation* involve the conservation, sustainable management and restoration of ecosystems. *Environmental flows* describe the quantities, quality and patterns of water flows required to sustain freshwater and estuarine ecosystems and the ecosystem services they provide. *Eco-*, *phyto-* and *bio-remediation* are concepts that use ecosystem restoration to reinstate a diverse system of plant communities in a particular ecosystem so that its buffering or remediation capacities are enhanced. Other concepts, tools and approaches partly related to NBS include *ecological restoration*, *ecological engineering*, *forest landscape restoration*, *green or natural infrastructure*, *ecosystem-based disaster risk reduction (DRR)* and *climate adaptation ecosystem services* (Cohen-Shacham et al., 2016).

NBS support a *circular economy* that promotes greater resource productivity aiming to reduce waste and avoid pollution, including through reuse and recycling, and is restorative and regenerative by design, in contrast to a linear economy which is a 'take, make, dispose' model of production. NBS also support the concepts of *green growth* or *green economy*, which promote sustainable natural resource use and harness natural processes to underpin economies.

NBS recognize ecosystems as *natural capital*, or the stock of renewable and non-renewable natural resources (e.g. plants, animals, air, water, soils and minerals) that combine to yield a flow of benefits to people (adapted from Jansson et al., 1994; Atkinson and Pearce, 1995). The *Natural Capital Protocol*[3] is being increasingly recognized by a wide range of stakeholders, including business, and supports the use of NBS by highlighting the flow of benefits that can be derived from using nature. Through a robust and structured process, the framework helps organize, identify, measure and value impacts and dependencies on natural capital and can catalyse investment in NBS.

NBS are also consistent with, if not essential to, numerous religious, cultural or totemic beliefs that emphasize conceptions about nature rather than management decisions driven by a technocratic approach. NBS reflect a global paradigm adopted by secular and spiritual leaders that generally state that to trespass natures' boundaries is a sin (or equivalent). For example, values found in most religions, including Islam, Buddhism, Zoroastrianism, Judaism and Christianity, advocate equity between man and nature and appropriate use instead of over-use and purification after use (Taylor, 2005). Likewise, *Mother Earth* or *Mother Nature* are common metaphorical expressions for the Earth and its biosphere as the giver and sustainer of life. Such concepts can be locally, nationally or regionally important and can trump science and technology-driven approaches. Since this report argues that NBS should also be based on sound science and economics, they offer a bridge between these traditional and modern paradigms. Among other things, this can make religious, cultural and totemic leaders powerful allies in the deployment of NBS.

[3] More information on Natural Capital and the Natural Capital Protocol can be found at naturalcapitalcoalition.org/protocol/.

BOX 1.1

ECOHYDROLOGY

Ecohydrology is an integrative science that focuses on the interaction between hydrology and biota. It seeks to reinforce ecosystem services in modified landscapes to reduce anthropogenic impacts. Holistic approaches that manage hydrology and biota aim to achieve sustainability in both ecosystems and human populations and improve IWRM. Ecohydrology provides basic knowledge and applied tools for the achievement of the SDG 6 on water.

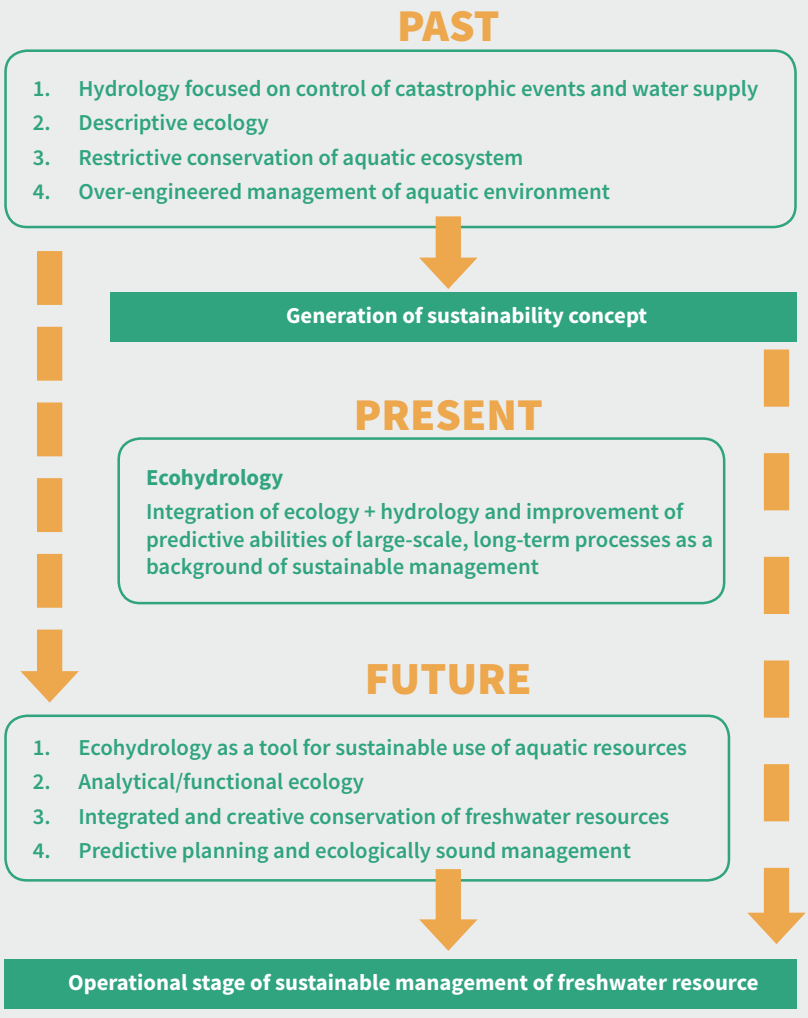
Ecohydrology promotes the integration of a catchment and its biota into a single entity and the use of ecosystem properties becomes a management tool within which ecohydrology can address fundamental aspects of water resources management. It provides a sound scientific basis for adopting a watershed as the basic planning unit. By incorporating the concept of improved ecosystem resilience as a management tool, ecohydrology strengthens the rationale for adopting a preventive and holistic approach to the watershed – as opposed to the reactive, sectoral and site-specific approach typical of present practices in water resources management. At the same time, ecohydrology stresses the importance of eco-technological measures as an integral component of water management, complementing standard engineering approaches (Zalewski, 2002). Furthermore, Mitsch and Jørgensen (2004) have developed the application of ecological engineering, e.g. the management of wetlands for water purification from excessive nutrient loads based on ecological theory and mathematical modelling.

Ecohydrology acts as an accelerating factor for the transition from descriptive ecology, restrictive conservation and over-engineered management of aquatic ecosystems to analytical/functional ecology and creative management and conservation of freshwaters (Zalewski et al., 1997).

Since 2011, UNESCO's International Hydrological Programme (UNESCO-IHP) has promoted the establishment of various demonstration sites around the world to apply systemic ecohydrology solutions in watersheds across all scales. A demonstration site applies ecohydrology in its objectives of dealing with issues such as pollutant and nutrient concentrations, water quality improvement, flood mitigation, loss of retention capacity of vegetation, etc. Hydrological and ecological processes are studied from molecular (microbial processes) to catchment scales in aquatic habitats like wetlands, marshes, mangroves and rivers from headwaters to plains and coastal zones, in order to find long-term solutions that integrate social components. The demonstration sites include the concept of enhanced ecosystem potential, through the application of ecohydrological strategies, to achieve sustainability of water-related ecosystems to improve IWRM. This is termed WBSRC (W-water, B-biodiversity, S-ecosystem services, R-resilience, C-culture or social dimension), containing the five elements that should be taken into consideration while trying to reinforce the carrying capacity of modified ecosystems.

Contributed by UNESCO-IHP.

Figure | Ecohydrology: Past, present, future



Source: Zalewski et al. (1997, fig. 2, p. 13).

NBS tend to be in harmony with *customary laws* and *traditional/local knowledge* that can be important locally. The *human rights-based approach* for water resources management and governance can also be consistent with NBS, especially if focusing on customary laws. Additional rights issues that need to be considered include the recognition of indigenous people's collective rights to the lands and territories, the natural resources that they have traditionally occupied and used, their right to development and the impacts of climate change adaptation and mitigation (the United Nations Declaration on the Rights of Indigenous Peoples).

1.3 How NBS work

1.3.1 The role of ecosystems in the water cycle

The physical, chemical and biological properties of ecosystems affect all the hydrological pathways in the water cycle (Figure 1.1). Biological processes in a landscape, and especially in soils, influence the quality of water as it moves through a system, as well as soil formation, erosion and sediment transport and deposition – all of which can exert major influences on hydrology. There are also large energy fluxes associated with this nature-driven cycle: for example, the latent heat involved with evaporation can exert a cooling effect and is a basis for NBS for regulating, for example, urban climates.

1.3.2 Major ecosystem components involved

All major terrestrial, and most coastal, ecosystem types or biomes influence water. The bulk of NBS applications, including in urban landscapes, essentially involve the management of vegetation, soils and/or wetlands (including rivers and lakes).

Vegetation

Plants cover about 72% of the global land mass (FAO/ITPS, 2015a). Plant stems and leaves intercept precipitation (rain or snow) or cloud moisture. Plants affect water availability and climate through transpiration functions and hence remove water from soils and sometimes groundwater. Plant roots contribute to soil structure and health and hence influence soil water storage/availability, infiltration and percolation to groundwater. In all but the driest or frozen landscapes, natural plant senescence builds up a critical layer of organic matter covering soil, regulating erosion and evaporation from land.

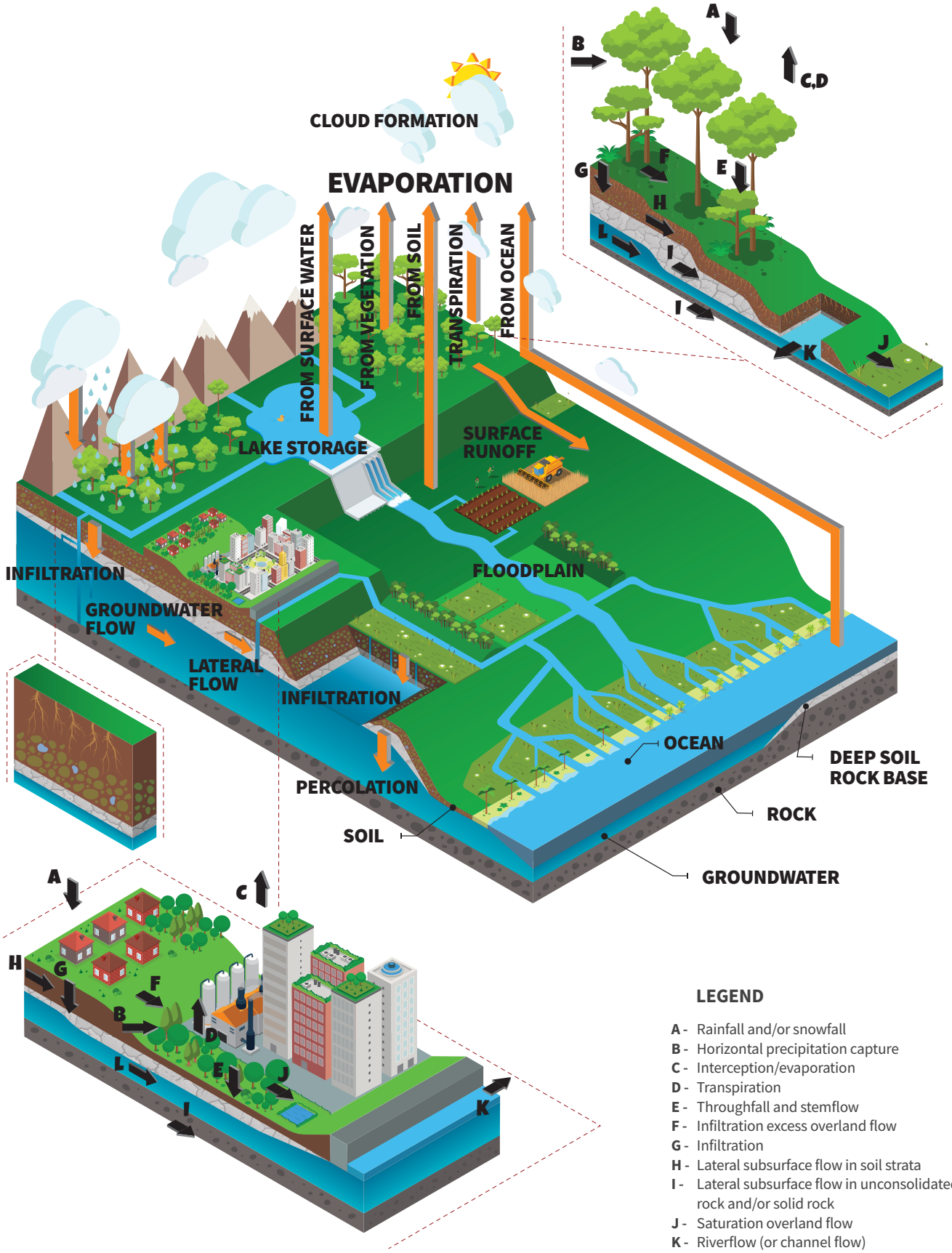
Landscapes tend to include a variety of vegetation cover categories, each of which can have different degrees of influence on the water cycle, which is also influenced by the management regime in place. Forests, for example, often receive the most attention regarding land cover and hydrology, but grasslands and croplands are also very important. Although forests are widely used successfully as restoration solutions, the restoration of grasslands and shrubs in the Loess Plateau in China have been found to bring greater improvements in soil moisture storage and soil conservation than reforestation in that location (Chen et al., 2010; Zhang et al., 2015). Natural grasslands also tend to produce high-quality water. However, in the case of manured grasslands (as in Western Europe and the USA, for example), elevated nitrogen and phosphorus loads in surface runoff form a major issue (Hahn et al., 2012). This calls for the adoption of a landscape approach to hydrology where land cover and management are the focus of attention and both are considered with regards to desired landscape performance. Above all, bare land (unless natural, as in deserts or the ice caps, for example) needs to be avoided since this is a significant contributor to soil/land degradation, including increased erosion and reduced water productivity (FAO/ITPS, 2015a).

Soils

Soils play a major, and often underestimated, role in the movement, storage and transformation of water. Soils involve complex living systems and their hydrobiological processes are closely linked to their ecological health. How much water infiltrates, evaporates from or percolates through land depends not only on vegetation and climate, but also on the geometry of the soil pore space, and therefore on soil structure. Moreover, the conditions at the soil surface (vegetation cover, soil structure, etc.) control the partitioning of rainfall into surface runoff and infiltration. In the root zone, infiltrated water is then partitioned between evaporation and transpiration on the one hand and deep percolation on the other. It is well known that changes in management and land cover affect the soil structure and hence modify these soil properties. For example, in an extreme case, soil sealing by roads and other infrastructure in cities completely undermines soil hydrology, resulting in the loss of infiltration and hence precipitation is diverted to overland flow, often contributing to flooding. In addition, the health of soils, and in particular their ability to support nutrient cycling, has a major influence on water quality, particularly in farming systems (FAO, 2011b).

The soil–vegetation system is the first receiver of the precipitation and energy that fall on land. The zone between the upper ranges of the groundwater table (or basement rock) to that just above the soil-vegetative layer is critical in controlling terrestrial water quantity and quality (FAO/ITPS, 2015a). Approximately 65% of the water falling on land is either stored within or evaporated from the soil and plants (Oki and Kanae, 2006). Of the water stored on land, over 95% is stored in the vadose (shallow) and saturated zones (groundwater) of the soil, excluding the water still retained in glaciers (Bockheim and Gennadiyev, 2010). Although soil water in the upper, more biologically active layer of soils comprises only 0.05% of the world's store of freshwater (FAO/ITPS, 2015a), the upward and downward fluxes of water and energy through the soil are vast and strongly linked. These figures clearly indicate the importance of soil water for the Earth's land–water–energy balance, including the interchange between soil water and precipitation via transpiration, and a potential positive feedback as the climate warms in the future (Huntington, 2006).

Figure 1.1 Generalized hydrological pathways in a natural landscape (top) and an urban setting (bottom)



Source: WWAP.

Wetlands

Although only about 2.6% of land is covered by inland water bodies (FAO/ITPS, 2015b), wetlands, including rivers and lakes,[4] play a disproportionately large role in hydrology per unit area. The case for wetland conservation is often made in terms of hydrological processes, including groundwater recharge and discharge, flood flow alteration, sediment stabilization and water quality (Maltby, 1991). Coastal wetlands also play an important role in water-related DRR: mangroves, for example, and to a lesser extent saltmarshes, can reduce the energy of waves and currents, stabilizing sediment with their roots and reducing flood risk from storm surges.

1.3.3 Land use and land use change

Direct human-induced *land use and land use change* (LULUC) considers the influences of the terrestrial components (including land cover – e.g. natural forest versus croplands) of ecosystems, and in some cases wetlands, on hydrology. LULUC is an important determinant of local, regional and continental-scale water cycles.

Ecosystems make important contributions to precipitation recycling from local to continental scales. Globally, up to 40% of terrestrial rainfall originates as upwind land evaporation, with this source accounting for over half of rainfall in some regions; the remainder originates from the oceans (Keys et al., 2016). The contribution of vegetation to local precipitation can be much higher. There are even areas where vegetation is the main or only source of local surface water, as in the case of vegetation capturing water from clouds in the seasonal absence of local precipitation (Hildebrandt and Eltahir, 2006). Rather than being regarded as a 'consumer' of water, vegetation is perhaps more appropriately viewed as a water 'recycler' (Aragão, 2012).

At the local scale, crop and soil management in fields have a major influence on local field hydrology (FAO, 2011b). Notably, apart from its extent, all cropland and pasture is under active and usually intensive management. Factors influencing cropland hydrology include the type of crop and the use of chemicals, crop spacing, crop rotation and particularly soil disturbance through tillage, among other interventions. These can all be adjusted to manage crop water availability, groundwater recharge, evaporation rates, surface runoff, erosion and plant nutrient availability, among other factors, and exert significant effects on water availability and quality both within and off farms, including at landscape scales (FAO, 2011b).

Precipitation recycling at continental scales is illustrated in Figure 1.2. Other examples include evaporation in the Congo River Basin, which is a major source of rainfall for the Sahel region, and the Rio de la Plata Basin in Uruguay and Argentina, where 70% of the rainfall originates as evaporation from the Amazon forest (Van der Ent et al., 2010). As such, deforestation and other LULUC affecting the Amazon water cycle threaten agricultural production outside the Amazon (Nobre, 2014). Similarly, the Gulf of Guinea and moisture from across Central Africa play an important role in generating flows for the Nile via the Ethiopian Highlands (Viste and Sorteberg, 2013). Vegetation removal probably has the most severe impacts on rainfall in drier areas, contributing to increased water scarcity, land degradation and desertification in those areas (Keys et al., 2016).

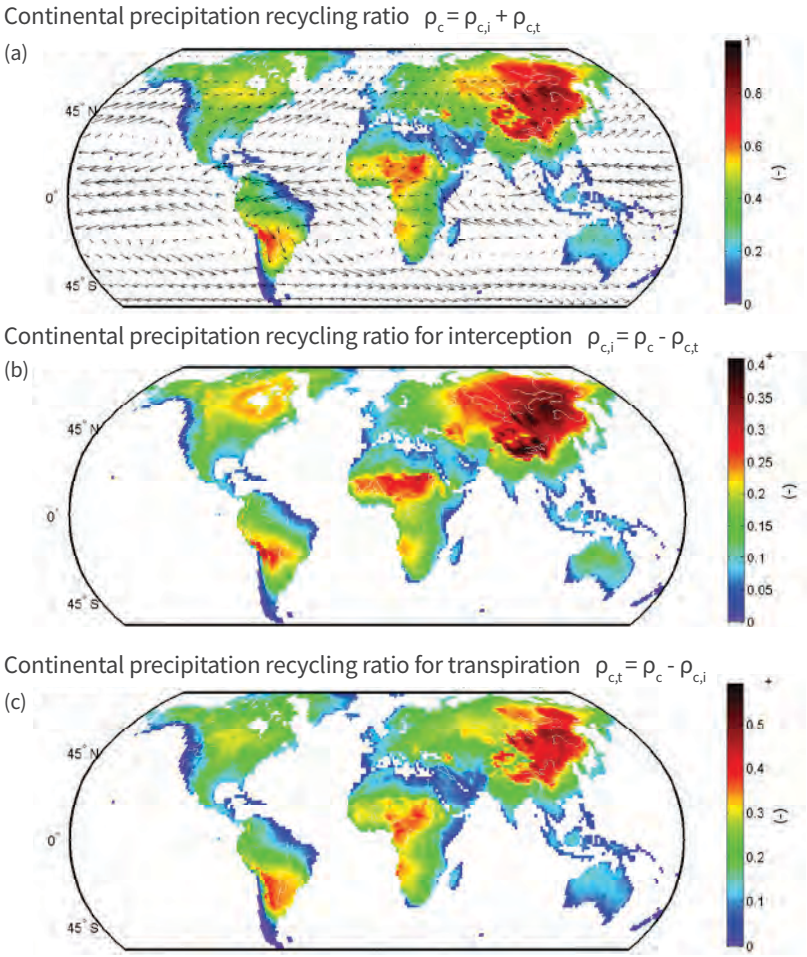
Land use decisions in one place may therefore have significant consequences for water resources, people, the economy, and the environment in distant locations. Precipitation recycling creates interdependencies among countries that need not necessarily be adjacent to each other nor share the same basin (Figure 1.3). The influence of LULUC on the movement of moisture and subsequent precipitation challenges the 'watershed' as being the common unit of management. The watershed as a unit applies best to surface and groundwater management, but recent advances in hydrology have revealed 'atmospheric watersheds' – otherwise known as 'precipitationsheds' (Keys et al., 2017).

1.3.4 Variations in hydrology within and between ecosystem types

There is a high degree of variation in the impacts of ecosystems on hydrology both within and between ecosystem types or subtypes, their location and condition, climate and management. This cautions to avoid generalized assumptions about NBS, as site-specific knowledge on their field deployment is required. For example, trees can increase or decrease groundwater recharge according to tree type, density and location (Borg et al., 1988; Ilstedt et al., 2016). The tree–soil and moisture–groundwater relationships are also dependent on the size and age of the trees in question (Dawson, 1996). Forests typically have much greater evaporation rates than grasslands where rainfall exceeds 2,000 mm per year, but comparable rates where rainfall is less than 500 mm per year (Zhang et al., 2001). Wetlands are widely reported to 'act like a sponge', thus reducing floods and preventing droughts, but some headwater wetlands can increase downstream flooding (Bullock and Acreman, 2003). The hydrological performance of soils also varies widely between soil types, their condition and their management (FAO/ITPS, 2015a). It should not be assumed that 'natural' ecosystems are necessarily better in terms of hydrology. Much depends on what is required from an area or landscape, including non-hydrological benefits and how these may measure up to the overall management costs.

[4] The Ramsar Convention on Wetlands (1971) adopts an extremely broad definition of wetlands as *"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres"* (Article 1). This definition is also adopted by the Convention on Biological Diversity (CBD, 1992) and is therefore the one used in this report. 'Wetlands' therefore include rivers, lakes, reservoirs, mangroves and permanently saturated soils (notably peatlands), among other types. However, terminology varies between countries and user groups, with many regarding wetlands only as natural shallow, heavily vegetated areas, such as 'swamps', 'mires' and 'fens' etc. Therefore, care needs to be taken if referring to 'wetlands' generally or a subset of wetlands – with qualification as appropriate.

Figure 1.2 **Continental precipitation recycling, 1999–2008**



Note: The colour scale of (b) ends at 0.41, which is the global average fraction of direct evaporative fluxes (interception); the colour scale of (c) ends at 0.59, which is the global average fraction of delayed evaporative flux (transpiration). The arrows in (a) indicate the vertically integrated moisture fluxes.

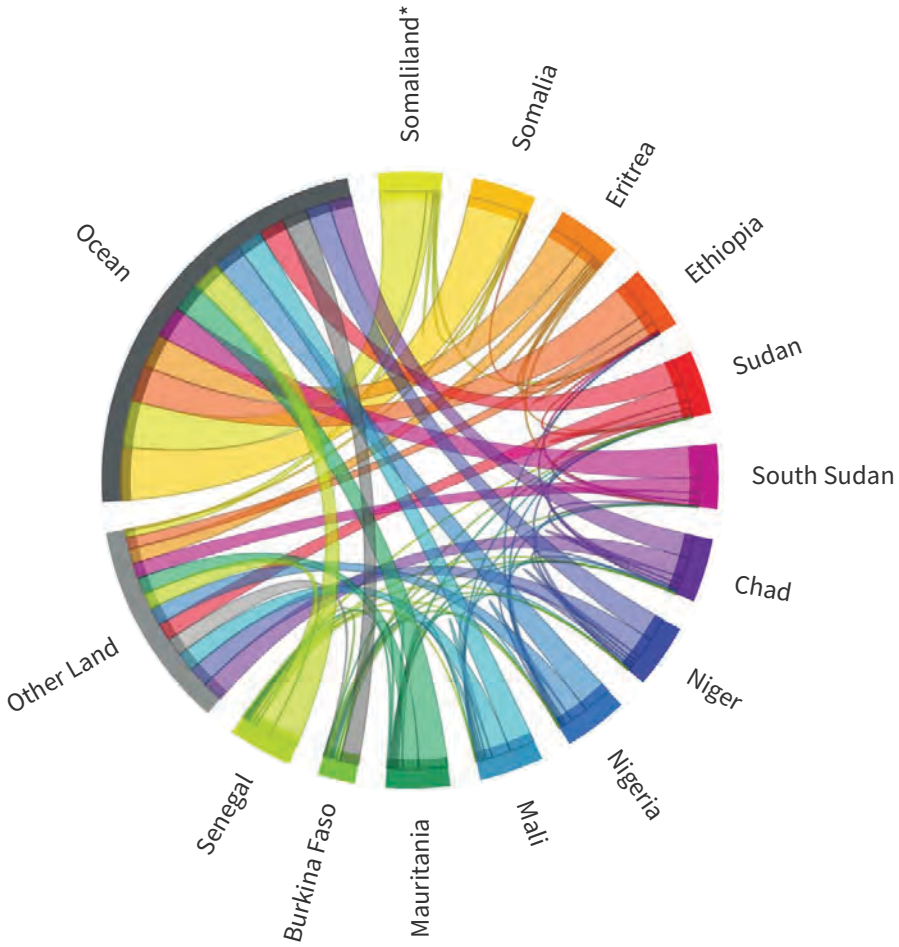
Source: Van der Ent et al. (2014, fig. 2, p. 477).

1.3.5 The role of biodiversity

Biodiversity is relevant to NBS in two ways. Firstly, biodiversity has a functional role in NBS whereby it underpins ecosystem processes and functions and, therefore, the delivery of ecosystem services (Hooper et al., 2005). Soil biota, for example, constitute an important living community in the soil system, providing a wide range of essential soil services by shaping metabolic capacity and soil functions (Van der Putten et al., 2004). Reductions in soil biodiversity tend to be associated with negative impacts on soil organic carbon, soil moisture and infiltration, and therefore runoff, erosion and groundwater recharge (FAO, 2011b). Collectively, these impact water quality, notably in relation to nutrient loads and sedimentation (FAO/ITPS, 2015a). Similarly, forests, grasslands and wetlands in their natural state tend to be more biodiverse, have different hydrological profiles and deliver better overall ecosystem services than in a managed or disturbed state. Biodiversity also enhances resilience, or a system's capacity to recover from external pressures such as droughts or management mistakes (Fischer et al., 2006).

Secondly, biodiversity is relevant to NBS in the sense of achieving biodiversity 'conservation' objectives, irrespective of its functional role regarding water. Since NBS are based on enhancing ecosystem extent, condition or health, as a general rule they tend to support biodiversity conservation as a significant co-benefit. However, this is not necessarily always the case. For example, using an existing natural wetland to deal with excess nutrient loads would certainly change its ecological character and therefore the biodiversity it supports. Whether this should be done depends on the potential carrying capacity of the wetland, possible ecosystem tipping points and what the desired characteristics and uses of the wetland are (WWAP, 2017). In Europe, restoring underused farmland to more natural areas, for example as riparian zones protecting rivers or for improving watershed services, can lead to the loss of unique biodiversity in cases where farming was required to sustain it (CBD, 2015). Such observations caution for the need, where appropriate, to include biodiversity in NBS impact assessments and, where indicated, biodiversity safeguards in NBS applications.

Figure 1.3 Sources of precipitation for the Sahel region



Note: The width of the flow corresponds to the fraction of precipitation received in the country/[territory]. The colour of a flow corresponds to the country/[territory] in which that moisture flow falls as precipitation. When two countries/[territories] exchange moisture with one another, the colour of that flow corresponds to the country with the larger (net) fraction received as rainfall. Starting from the ocean, countries/[territories] are listed clockwise from East to West.

* Somaliland is an autonomous region of Somalia, subject to the Somali Federal Government.

Source: Keys et al. (2017, fig. 6, p. 18). © 2017 Reprinted by permission from Elsevier.

1.3.6 Ecosystem functions, process and benefits to people (ecosystem services)

The water-related processes and functions of ecosystems can be managed to deliver benefits to people as 'ecosystem services'. All ecosystem services are dependent on water, but there are specific ecosystem services that directly influence the availability and quality of water, which are variously referred to as, for example, watershed services (Stanton et al., 2010), water services (Perrot-Maître and Davies, 2001) or water-related ecosystem services (Coates et al., 2013). Some of these key services are listed in Table 1.1.

For simplicity, water-related ecosystem services can be grouped into those that relate to the *movement* of water (e.g. evaporation, overland flow and infiltration into the ground), the *storage* of water (principally in soils, groundwater and wetlands) or the *transformation* of water, including its quality (Acreman and Mountford, 2009). Together these underpin the three dimensions of water resources challenges of most, if not all, sectors and issues: water availability (supply or quantity), water quality and moderating risk and extremes (including water-related disaster risk). Hence, Chapters 2, 3 and 4 of this report explore how NBS contribute ecosystem services to help manage water in each of these three areas and make significant contributions to key water resources management challenges, including: drinking water quality; sanitation and hygiene (WaSH); water security for food security and sustainable agriculture; building sustainable urban settlements; managing wastewater; DRR; land degradation, drought and desertification; and climate change adaptation (and mitigation).

Water-dependent ecosystem services include products directly obtained from ecosystems (e.g. food, fibre and energy), benefits derived from ecosystem processes (e.g. air quality and climate regulation), supporting services (e.g. nutrient cycling and soil formation) and cultural services (e.g. recreation).

Table 1.1 Examples of ecosystem services and some functions they perform

Ecosystem service category	Example ecosystem functions and benefits
Water-related ecosystem services*	
Provisioning services – Products obtained from ecosystems	
Freshwater supply	Providing freshwater for human consumption and human needs
Regulating services – Benefits obtained from the regulation of ecosystem processes	
Water regulation	Regulating the presence of water over time and space – surface waters and groundwater discharge/recharge
Erosion regulation	Soil stabilization (links to natural hazard regulation and supports provisioning services)
Sediment regulation	Regulating the water-driven formation and flow of sediments through the system, including deposition to maintain coastal wetlands and built land
Water purification and waste treatment	Nutrient and pollution uptake, processing and retention, particle deposition
Natural hazard regulation	Water-related disaster risk reduction
- Coastal protection	- Attenuates/dissipates waves, buffers winds
- Flood protection	- Stores water or slows water flows to reduce flood peaks
- Drought protection	- Provides sources of water during drought periods
Climate regulation/moisture recycling	Influencing local and regional precipitation and humidity and local/regional cooling effects through evaporation
Water-dependent ecosystem services (other services or co-benefits)**	
Provisioning services – Products obtained from ecosystems	
Food and fibre	Fisheries, agricultural products, non-timber forest resources
Energy	Hydropower and bioenergy
Genetic resources	Source of genetic materials, e.g. for agriculture, medicines
Biochemicals, natural medicines, pharmaceuticals	Chemicals, medicines and pharmaceuticals derived from living biota
Regulating services – Benefits obtained from the regulation of ecosystem processes	
Air quality regulation	Carbon dioxide and oxygen cycling, air pollution control
Climate regulation	Carbon sequestration – regulation of greenhouse gas emissions and atmospheric loadings
Pest and disease regulation	Influencing the existence, extent and severity of human, plant and animal pests and diseases Integrated pest management that enhances natural pest regulation can reduce pesticide use – improving water quality and soil condition and its role in water cycling
Pollination	Sustaining animal pollination of plants to support crop production and biodiversity
Supporting services – Services that are necessary for the provision of all other services	
Nutrient cycling	Maintains overall ecosystem functioning
Primary production	Supports all life on earth
Soil formation	Maintains the regular production of soil to support most other terrestrial ecosystem services
Cultural services – Non-material benefits that people can derive from ecosystems	
Spiritual, religious and totemic values	Beliefs held that depend on the existence of ecosystems (nature)
Aesthetic values	Benefits derived through ecosystems being considered beautiful, appealing or visually appreciated etc.
Recreation and eco-tourism	Socio-economic benefits (e.g. livelihoods) based on tourism and recreation, including sport (e.g. recreational fishing)

*Water-related ecosystem services are those that directly influence the quantity and quality of water and therefore underpin NBS.

**Water-dependent ecosystem services are those that rely on water but play no, or a limited, role in the quantity or quality of water and are among the co-benefits of NBS.

Source: Based on Millennium Ecosystem Assessment (2005) and Russi et al. (2012).

Figure 1.4 Natural, or green, infrastructure solutions for water management across a landscape



Source: Infographic 'Natural Infrastructure for Water Management', © IUCN Water 2015.

The social and economic contexts within which ecosystem services are set are important in terms of designing NBS that meet societal needs but can also be effectively implemented. For example, where ecosystem restoration is proposed to rectify a problem caused by the previous loss of ecosystem services, it is essential to know what drivers, both direct and indirect, caused such loss. Unless these drivers can be addressed it is unlikely that the NBS will succeed.

1.3.7 Green infrastructure

Green infrastructure (for water) refers to the natural or semi-natural systems that provide water resources management options with benefits that are equivalent or similar to conventional grey (built/physical) water infrastructure. Green infrastructure is the application of an NBS. The terms *ecological* and *natural infrastructure* are often used to describe similar assets. Typically, green infrastructure solutions involve a deliberate and conscious effort to utilize ecosystem services to provide primary water management benefits as well as a wide range of secondary co-benefits, using a more holistic approach (UNEP-DHI/IUCN/TNC, 2014). Green infrastructure is becoming increasingly recognized as an important opportunity for addressing the complex challenges of water management and can be used to support goals in multiple policy areas (Table 1.2). If deployed over larger areas, green infrastructure can deliver landscape-scale benefits (Figure 1.4).

The question whether green or grey infrastructure solutions are to be preferred has been subject to debate (Palmer et al., 2015). The 'grey' perspective argues that the broad links between grey water infrastructure and economic development are well established, that socio-economic development is curtailed in countries that have insufficient grey infrastructure to manage water, that many developing countries are consequently 'held hostage to their hydrology', and that therefore more grey infrastructure is needed (Muller et al., 2015). An NBS approach has been advocated partly because of the adverse environmental and social impacts associated with large-scale grey infrastructure. In this case, the argument offered is that a redesign of conventional approaches is needed, one that works with natural systems rather than against

Table 1.2 Green infrastructure solutions for water resources management

Water management issue (primary service to be provided)		Green Infrastructure solution	Location				Corresponding Grey Infrastructure solution (at the primary service level)
			Watershed	Floodplain	Urban	Coastal	
Water supply regulation (incl. drought mitigation)		Re/afforestation and forest conservation	■				Dams and groundwater pumping Water distribution systems
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Water harvesting*	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
Water quality regulation	Water purification	Re/afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
	Erosion control	Re/afforestation and forest conservation	■				Reinforcement of slopes
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
	Biological control	Re/afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
	Water temperature control	Re/afforestation and forest conservation	■				Dams
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (shading of water ways)			■		
Moderation of extreme events (floods)	Riverine flood control	Re/afforestation and forest conservation	■				Dams and levees
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Establishing flood bypasses		■			
	Urban stormwater runoff	Green roofs			■		Urban stormwater infrastructure
		Green spaces (bioretention and infiltration)			■		
		Water harvesting*	■	■	■		
		Permeable pavements*			■		
	Coastal flood (storm) control	Protecting/restoring mangroves, coastal marshes and dunes				■	Sea walls
		Protecting/restoring reefs (coral/oyster)				■	

*Built elements that interact with natural features to enhance water-related ecosystem services.

Source: UNEP-DHI/IUCN/TNC (2014, table 1, p. 6).

> The bulk of NBS applications, including in urban landscapes, essentially involve the management of vegetation, soils and/or wetlands (including rivers and lakes)

them, with NBS providing alternatives or complements to grey infrastructure, as these can be equally or more cost-effective and provide many co-benefits that are often forgotten when water management becomes too narrowly defined and implemented (Palmer et al., 2015). The green versus grey infrastructure debate is, however, a false dichotomy (McCartney and Dalton, 2015). It suggests that it is necessary to choose one or the other, whereas in reality the choice is usually which blend of each is most appropriate and at what scale. There are examples where nature-based approaches offer the main or only viable solution (for example, landscape restoration to combat land degradation and desertification) and examples where only a grey solution will work (for example supplying water to a household through pipes and taps), but in most cases green and grey infrastructure can and should be working together. In any event, water management is already based on a combination of green and grey, since ecosystems are always the origin of the water that is subsequently managed through grey infrastructure. Some of the best examples of the deployment of NBS are the ways it can be used to improve the performance of grey infrastructure. For example, the economic life expectancy of the Itaipu Hydropower Dam in Brazil/Paraguay, one of the world's largest, was increased six-fold by applying improved landscape management and farming practices in the catchment to reduce sedimentation in the reservoir, whilst simultaneously improving farm productivity and farmer's incomes (Kassam et al., 2012).

1.3.8 Co-benefits of NBS

A key feature of NBS is that they tend to deliver groups of ecosystem services (Table 1.1) together – even where only one is the target of management. NBS usually offer multiple water-related benefits and often help address water quantity, quality and risks simultaneously. In addition, NBS often offer co-benefits beyond water-related ecosystem services. For example, constructed wetlands used for wastewater treatment can provide biomass for energy production (Avellán et al., 2017). Ecosystem creation or restoration can create or improve fisheries, timber and non-timber forest resources, biodiversity, landscape values and cultural and recreational services, which in turn can lead to added socio-economic benefits that include improved livelihoods and poverty reduction as well as new opportunities for employment and the creation of decent jobs (WWAP, 2016). The value of some of these benefits can be substantial and tip investment decisions in favour of NBS. Another key advantage of NBS is the way in which they contribute to building overall system resilience.

1.4 Mounting attention to NBS

1.4.1 Environment, development and water

In the early stages of the modern development agenda, the relationship between development and environment tended to be characterized as one of trade-offs, and particularly so regarding water. Environmental impacts were well known but regarded as an acceptable cost of development. More recently, the dialogue on water and environment has significantly shifted towards the ways in which the environment can be managed to support human water needs (Figure 1.5). A similar shift in attention can be traced in the business community and various policy forums. The net result has been a significant shift towards NBS in recent times and particularly so within the past ten years.

1.4.2 The business case for NBS

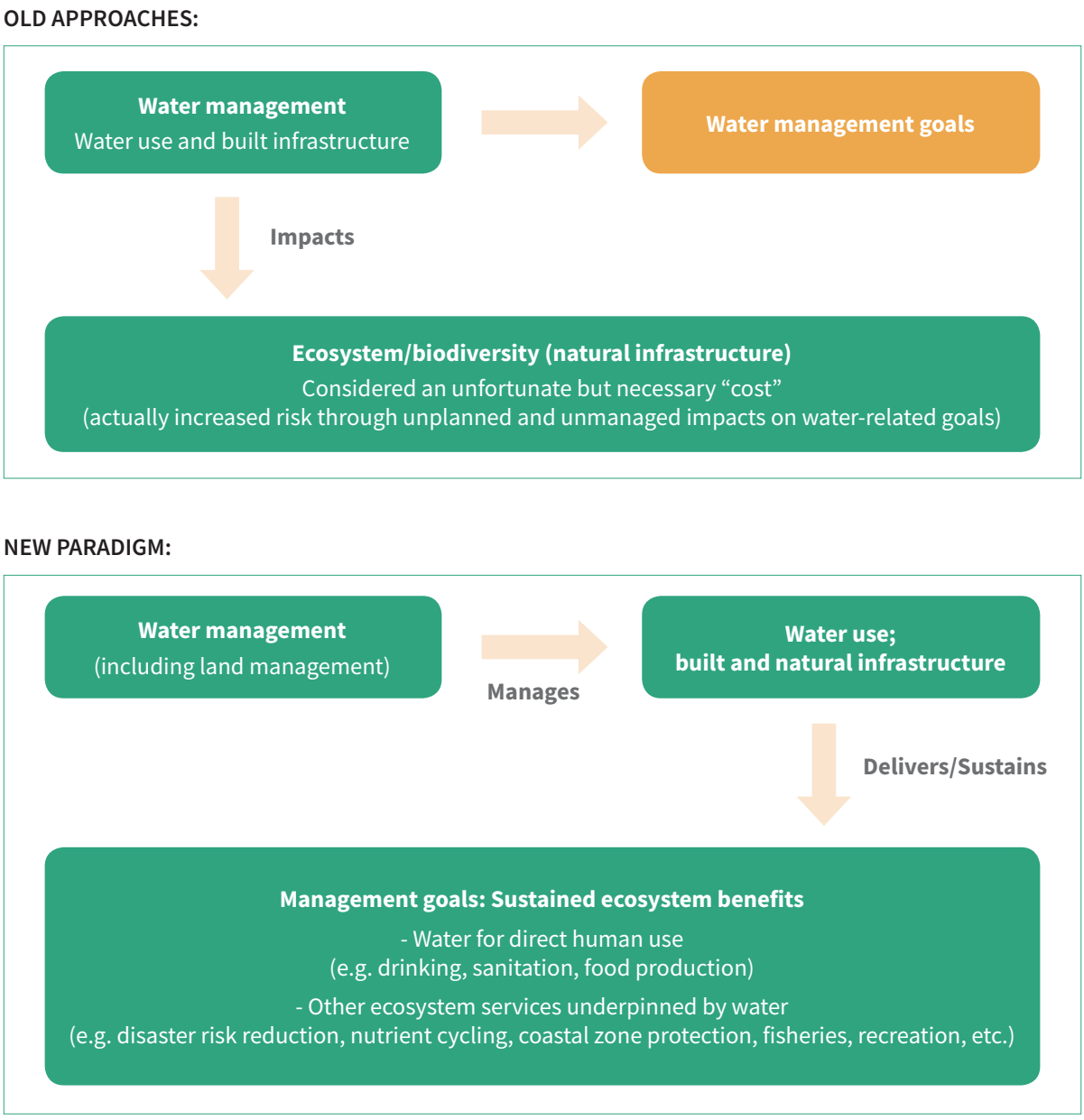
Businesses are increasingly interested in investing in natural capital and NBS, driven by a convincing business case.[5] Business drivers for NBS include: resource limitations; regulatory requirements; climate change and severe weather events; stakeholder concerns; direct financial benefits; operational, financial and reputational gains from environmental co-benefits; and operational, financial and reputational gains from social co-benefits.

1.4.3 The multilateral environment agreements and global frameworks on food security, disaster risk reduction and climate change

A timeline can be traced through the research agenda, with attention to NBS or similar terminology emerging around 1990 (coinciding with the 1992 United Nations Conference on Sustainable Development, from which emerged the Convention on Biological Diversity (CBD, 1992), the United Nations Convention to Combat Desertification (UNCCD, 1994) and the United Nations Framework Convention on Climate Change (UNFCCC, 1992)), and escalating from 2000–2005 onwards (Figure 1.6). A key factor was increasing attention to the concept of ecosystem services from about 2000 onwards and improved efforts to value these, enabling better engagement with policymakers. A milestone was the Millennium Ecosystem Assessment (2005).

[5] For a detailed overview of the business case, please visit the Natural Infrastructure for Business platform at www.naturalinfrastructureforbusiness.org/.

Figure 1.5 Evolving approaches to the water–ecosystem nexus. Emphasis has shifted from looking at impacts on ecosystems to managing ecosystems to achieve water management objectives

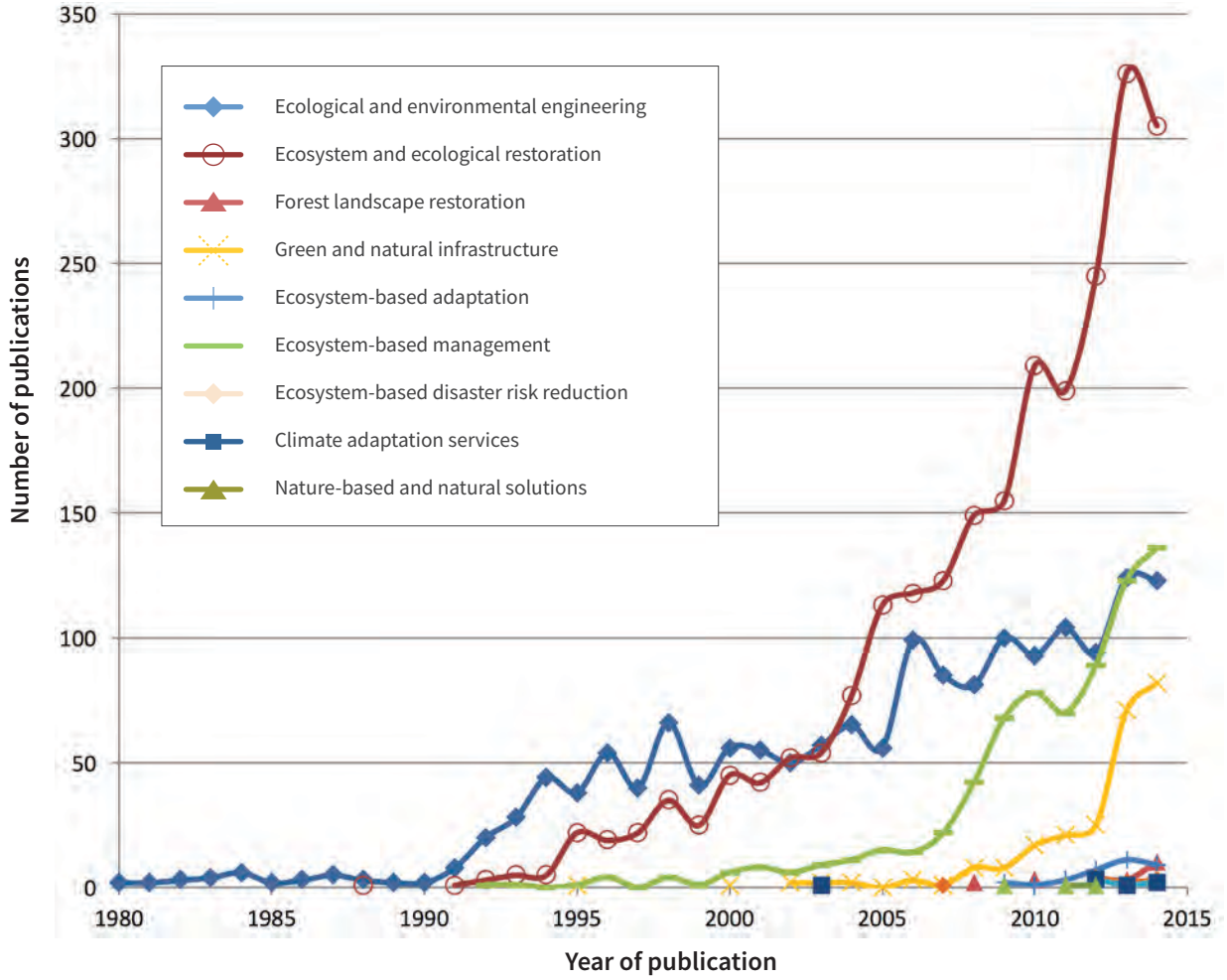


Source: Coates and Smith (2012, fig. 2, p. 171).

Prior to 2010, the Convention on Biological Diversity addressed freshwater largely through the lens of mitigating the impacts of water management on biodiversity. But in parallel with broader efforts to link biodiversity more explicitly with development, a significant milestone was the adoption of reference to water-related ecosystem services under Aichi Biodiversity Target 14, *"By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded…"* (CBD, 2010, para. 13). This was the precursor to the first explicit expression of the positive relationship between ecosystems and water in the global sustainable development agenda in the outcome document of the 2012 UN Conference on Sustainable Development (Rio+20) (UNCSD, 2012), *The Future We Want*, in its paragraph 122: *"We recognize the key role that ecosystems play in maintaining water quantity and quality and support actions within respective national boundaries to protect and sustainably manage these ecosystems."*

NBS are also increasingly and more explicitly recognized in other forums. They are at the heart of preventive and restorative measures to combat land degradation under the UNCCD: in 2015, its twelfth Conference of the Parties linked implementation to the SDGs and particularly

Figure 1.6 Trends in the number of research papers mentioning NBS and related approaches, 1980–2014



Note: 'Nature-based' and 'natural' solutions are terms not in wide use in the academic community and trends in their use are therefore not well reflected there.

Source: Cohen-Shacham et al. (2016, fig. 8, p. 23, based on data from Web of Science).

its Target 15.3: *"By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world"*. Nature-based approaches for DRR have long been recognized (Renaud et al., 2013). However, the role of ecosystems in DRR has only recently received significant attention in global frameworks, as illustrated by the increased attention to ecosystems in the Sendai Framework for Disaster Risk Reduction 2015–2030 compared to its predecessor, the Hyogo Framework for Action 2005–2015 (UNEP, 2015). The current global agenda on food security has also further embraced the central role of NBS as captured, for example, by *The Reviewed Strategic Framework 2010–2019* of the Food and Agriculture Organization (FAO) of the United Nations, endorsed by the FAO Conference in June 2013 (FAO, 2014a). NBS-like approaches have also recently been embedded in the *Voluntary Principles for Responsible Investment in Agriculture and Food Systems* approved by the Committee on World Food Security in October 2014; for example, its Principle 6: *"to conserve and sustainably manage natural resources, increase resilience, and reduce disaster risks"* (CFS, 2014).

NBS are central to addressing climate change. UN-Water stressed that the impacts of climate change are largely on hydrology and water resources (UN-Water, 2010). The changing water cycle is central to most of the climate change-related shifts in ecosystems and human well-being and the impacts of climate change arising from ecosystem change (SEG, 2007; IPCC, 2014). This implies that ecosystem-based management should be the primary means of climate change adaptation – and this largely involves using NBS for water. NBS are already recognized in the climate change agenda. National Adaptation Programmes of Action, under the UNFCCC, often highlight ecosystem-based adaptation approaches. The strong interdependencies between the carbon and water cycles also create significant synergies between climate change

mitigation and adaptation. For example, *Reducing Emissions from Deforestation and Forest Degradation* (REDD+) is the application of a nature-based approach for managing the global climate, primarily for climate change mitigation, but the role of trees in hydrology creates substantial links to adaptation. Also, around 25% of greenhouse gas emissions arise from land use change (FAO, 2014b) and water loss is implicated in many trends in land degradation; peatlands, for example, play a significant role in local hydrology, but this type of wetlands also stores twice the carbon of the entire world's forests and when drained, peatlands are a source of massive greenhouse gas emissions (Parish et al., 2008).

1.4.4 Linking NBS with the 2030 Agenda for Sustainable Development and its SDGs

NBS embody the three basic principles of implementing the SDGs: indivisibility (one goal cannot be achieved at the expense of any others), inclusion (leave no one behind) and acceleration (by focusing on actions that have multiple development dividends).

Aichi Biodiversity Target 14 and the outcomes of Rio+20 (as above) contributed to the incorporation of ecosystems into SDG 6 through its Target 6.6 (*"By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes"*) in recognition of the role of ecosystems in the achievement of the overarching water goal (SDG 6) and its other targets. In addition to Target 6.6, SDG 14 (Oceans) and particularly SDG 15 (Terrestrial Ecosystems), ecosystems are also mentioned in the SDGs with regards to food security in Target 2.4 and also with reference to water (*"By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality"*). Even within SDGs 14 and 15, only Target 15.3 is specific about why ecosystems should be safeguarded or restored, and it refers, again, to water (land degradation, drought and flooding). NBS can contribute to achieving many other SDGs and their Targets, even if currently not explicitly mentioned. Such linkages are explored further in subsequent chapters and summarized in Chapter 7.

1.5 Assessing NBS in the context of this report

It is clear that there is increasing recognition of NBS in the water agenda. Chapters 2, 3 and 4 of this report consider NBS for managing water availability, quality and risks, respectively. Chapter 5 provides examples of experiences with NBS at regional levels. Each provides further details of NBS, including sector-based examples.

> Ecosystem-based management should be the primary means of climate change adaptation – and this largely involves using NBS for water

However, despite a long history of, and growing experience with, application of NBS, there are still many cases where water resources policy and management ignore NBS options – even where they are obvious and proven to be efficient. There are also still too many cases where NBS are deployed based on uncertain science and then do not deliver on their stated impacts. Chapter 6, therefore, considers known constraints to applying NBS based on experience from assessments in Chapters 2 to 5, plus other sources of information, and ways and means to overcome these. All of these essentially centre on creating the right enabling conditions for the consideration of NBS on a more level playing field across the water agenda, where they can be fairly assessed against other options. Chapter 7 draws conclusions and potential responses, paying particular attention to the opportunities that NBS provide to help Member States (and other stakeholders) to achieve their water resources management and related sustainable development objectives, including with regards to the 2030 Agenda for Sustainable Development.

The previously referenced lessons from history beg pertinent questions: Can the same catastrophes that beset earlier civilizations be avoided? Are societies any better placed in the twenty-first century than millennia ago? The current status of ecosystems (see Prologue, for example) certainly does not bode well. The knowledge about how the water–food–energy–ecosystem relationship can be managed, especially when it comes to influencing socio-political drivers of change, remains incomplete. Much will depend on the balance that can be achieved between the degradation, conservation and restoration of water-related ecosystems and how ecosystem hydrological processes can be better managed to help achieve multiple water management objectives. Irrespective of whether catastrophe looms, there is an imperative to escalate social, economic and hydrological efficiency gains in water resources management, in which NBS will certainly play an important role. This report sets out to assess how this can be done.

2 NBS FOR MANAGING WATER AVAILABILITY



FAO | Amani Alfarra and Antony Turton

With contributions from[6]: David Coates and Richard Connor (WWAP); Marlos De Souza and Olcay Ünver (FAO); UNIDO Industrial Resource Efficiency Division and John Payne (John G. Payne & Associates Ltd); Matthew McCartney (IWMI); Ben Sonneveld (ACWFS-VU); Rebecca Welling (IUCN); Tatiana Fedotova (WBCSD); and Daniel Tsegai (UNCCD)

Pantanal wetlands (Brazil)



2.1 Introduction

Most Member States are challenged by an induced scarcity of water, at least locally if not nationally, exacerbated by the failure to expedite policy-directed solutions. Water scarcity is influenced by both demand and supply. Although there are examples of how NBS can influence demand (for example reducing crop water requirements in irrigation), they mainly address water supply through managing water storage, infiltration (sorptivity) and transmission so that improvements are made in the location, timing and quantity of water available for human-related needs. An NBS approach is a key means for addressing overall water scarcity through supply-side management, not least because the approach is recognized as the main solution for achieving sustainable water for agriculture (see Section 2.2.1) – by far the most critical need for achieving overall water resources sustainability because of its dominance in current water demand and for future challenges (see Prologue).

Water availability (particularly scarcity) is influenced by water quality. For example, improving water quality enables its re-use. Disastrous floods and droughts represent the extremes of variation in water availability. The current chapter focuses on how NBS can help Member States achieve their national water availability challenges, apart from those related to water quality and extremes, which are covered in Chapters 3 and 4, respectively, although relevant linkages remain.

Ecosystems exert a major influence on the quantity of water available in time and space (see Chapter 1). Most notably the soil–vegetation interface is the key determinant of the fate of precipitation by influencing infiltration from the land surface, and hence groundwater recharge, surface runoff and soil moisture retention in the plant root zone (of particular importance to agriculture), and finally recycling

[6] Authors would like to thank Sarah Davidson of WWF-US for helpful comments.

water back to the atmosphere through evaporative fluxes. NBS essentially involve managing these pathways, either through ecosystem conservation or rehabilitation, and through various land use and management approaches, whether at small or landscape scales or in urban or rural settings. In addition, structural approaches involving physical changes in the landscape, such as creating small depressions for water harvesting or tapping underexploited water in landscapes (Box 2.1), have been presented as NBS, although some of these arguably function simply as small-scale grey infrastructure. Structural approaches are included here particularly where they are deployed in conjunction with managing the living components of landscapes. Depending on interpretations, they can be viewed as NBS or examples of hybrid (but small-scale) green/grey infrastructure approaches.

BOX 2.1

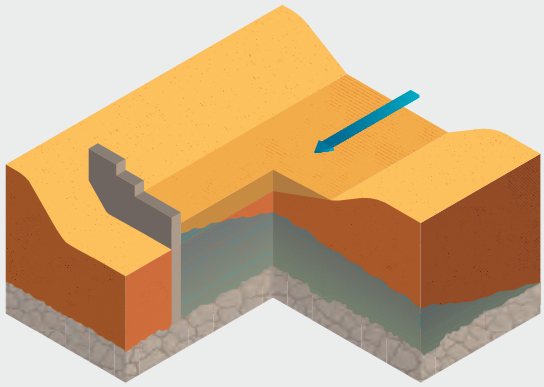
NATURE-BASED WATER STORAGE IN DRY RIVERS IN AFRICA

The riverbeds of many seasonal (also known as ephemeral) rivers and streams that crisscross arid and semi-arid lands form shallow groundwater reservoirs, which are recharged every time the rivers flow. Communities can draw water from these alluvial aquifers during the dry season, using a variety of simple means. Yet, despite its high storage potential, this storage solution is currently under-utilized in many regions of Africa, in particular for productive purposes such as agriculture (Lasage et al., 2008; Love et al., 2011).

The Shashe, Tuli and Sashane Rivers in the arid south of Zimbabwe exemplify the large potential of this type of water storage. Even after the exceptionally dry 2015–16 rainy season, the riverbeds of these seasonal rivers contained sufficient water for irrigation. Yet tapping into this resource for productive purposes remains a major challenge (Critchley and Di Prima, 2012).

'Sand dams' (i.e. walls across the river in the sand) have been used in the Sashane irrigation gardens in southern Zimbabwe in conjunction with low-cost, low-lift solar-powered pumps. The 'sand dams' gradually increase the thickness of the sediment layer in the river (through heightening the dam in stages), thus increasing both the volume of water stored and its accessibility. The technology allows farmers to access water for supplementary irrigation and mitigate the risks related to water availability. It can also enable farmers to extend the cropping season into the dry period and harvest a second (cash or staple) crop, providing opportunities for enhancing income and livelihoods.

Figure | A schematic of a sand dam



Source: Based on www.metameta.nl

The sustainable use of this nature-based storage can be supported by the creation of a community monitoring device that ensures that all water users have correct and symmetrical information on actual groundwater levels – a critical element in sustainably managing such a common pool resource (Ostrom, 2008).

Considering that one-fifth of Africa consists of arid and semi-arid lands, and assuming that 1% of these lands are suitable for agriculture and suitably located near a sand river, sand rivers could potentially provide water storage for up to 60,000 km² of irrigated land in Africa. This is significant when compared with the 130,000 km² of irrigated land that existed in 2010 (You et al., 2010), and more so because they are located in areas where moisture deficits are a major recurring challenge.

Contributed by Annelieke Duker (IHE Delft), Eyasu Yazew Hago (Mekelle University), Stephen Hussey (Dabane Water Workshops), Mieke Hulshof (Acacia Water), Ralph Lasage (Institute for Environmental Studies (IVM) of the Vrije Universiteit Amsterdam), Moses Mwangi (South Eastern Kenya University) and Pieter van der Zaag (IHE Delft).

The case study of Tarun Bharat Sangh in Rajasthan, India, presents an excellent example of the way in which low-cost community-led landscape approaches can improve both groundwater recharge and surface water availability through combining the management of soil, vegetation and structural (physical) interventions. The NBS approach delivers significant socio-economic gains across multiple sectors and interests, and also illustrates how landscape management can improve local climates, including precipitation patterns (Box 2.2).

There are a few examples where either NBS or grey (built) infrastructure is the only option to improve water availability, but usually both should be considered, designed and operated in harmony. Each approach should leverage the benefits of the other in order to harness synergies in improving overall system performance (Figure 2.1).

2.2 Sector and issue-based case studies

2.2.1 Agriculture

Given the importance of water to food security, sustainable agriculture and nutrition (HLPE, 2015), the challenge of feeding growing populations will increasingly become a central issue in most national development policies. While almost 800 million people are currently hungry, by 2050 global food production would need to increase by 50% to feed the more than 9 billion people projected to live on our planet (FAO/IFAD/UNICEF/WFP/WHO, 2017). It is now accepted that this increase cannot be achieved through business-as-usual and that transformational change in how we produce food is required (FAO, 2011b; 2014a). Agriculture will need to meet projected increases in production through improved resource use efficiency whilst simultaneously reducing its external footprint, and water is central to this process. This topic has been analysed in considerable depth. A cornerstone of solutions is the 'sustainable ecological intensification' of food production that enhances ecosystem services in agricultural landscapes, for example through improved soil and vegetation management (FAO, 2014a). The approach is now mainstream as reflected, for example, in the *Reviewed Strategic Framework 2010–2019* of the Food and Agriculture Organisation of the United Nations (FAO, 2013b).[7] Its Strategic Objective 2 highlights the critical role of biodiversity and ecosystem services in the achievement of the objectives of this framework, including *"to take advantage of the potential of the bioeconomy to increase the contributions of agriculture, and forestry and fisheries to economic development, while generating income and employment and providing livelihood opportunities for family farms and the more general population in the rural areas. Production systems must meet this challenge*

[7] Adopted by the 38th Session of the FAO Conference in June 2013 in its decision C 2013/7.

BOX 2.2

NBS BENEFITS AT SCALE – LANDSCAPE RESTORATION TO IMPROVE WATER SECURITY IN RAJASTHAN, INDIA

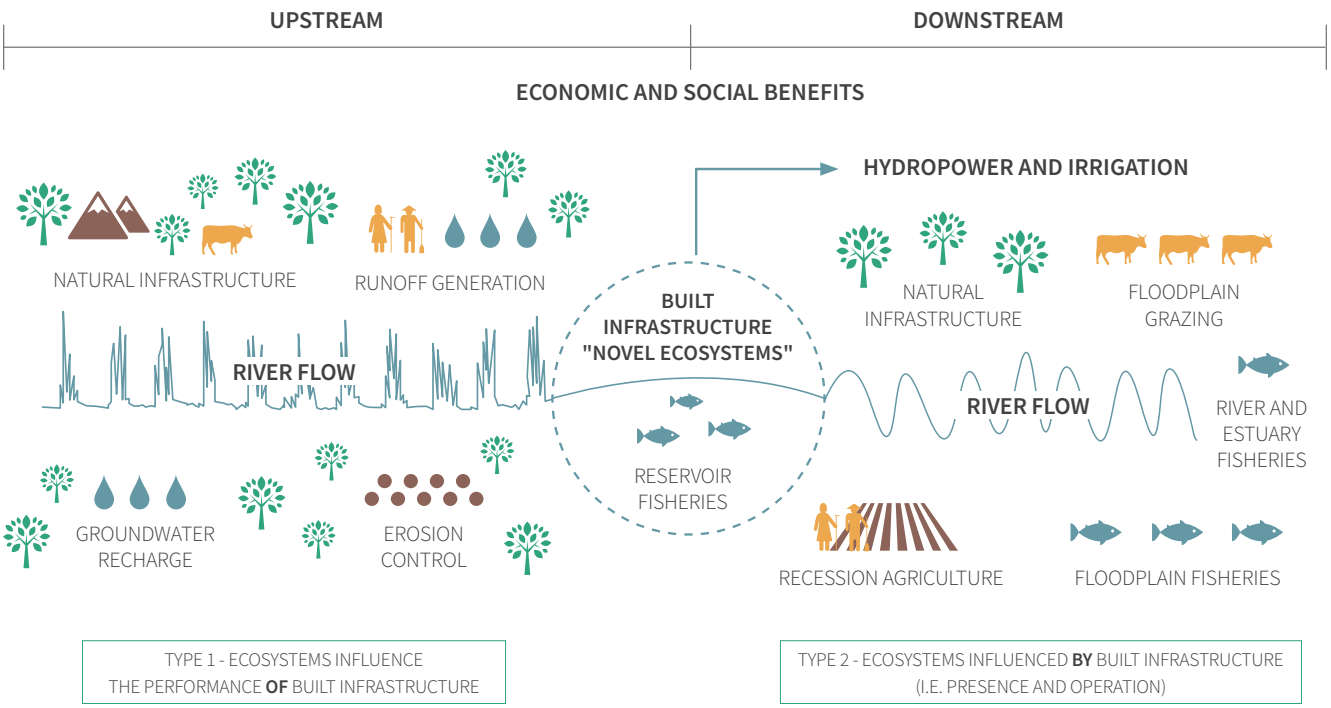
Unusually low rainfall in 1985–86, combined with excessive logging, led to the worst droughts in the history of Rajasthan. The district of Alwar, one of the poorest in the State, was severely affected. The groundwater table had receded below critical levels and the State declared parts of the area 'dark zones', which meant the severity of the situation warranted restrictions on any further groundwater extractions. Tarun Bharat Sangh, a non-governmental organization (NGO), supported local communities to undertake landscape-scale restoration of local water cycles and water resources. With leadership provided by women, who customarily take responsibility for providing their families with safe freshwater, traditional local initiatives for water were revived by bringing people together on the issues of management of forests and water resources. Activities centred on the construction of small-scale water harvesting structures combined with the regeneration of forests and soils, particularly in upper catchments, to help improve the recharge of groundwater resources.

The impact has been significant. For example, water was brought back to a 1,000 villages across the State; five rivers that used to run dry after the annual monsoon season are now flowing again and fisheries in them re-established; groundwater levels have risen by an estimated six metres; productive farmland increased from 20% to 80% of the catchment; crucial forest cover, including in farmlands, which helps to maintain the integrity and water-retaining capacity of the soil, has increased by 33%; and the return of wildlife such as antelope and leopard has been observed. Everard (2015) undertook a science-based assessment of the programme confirming its claimed socioeconomic benefits.

These innovative water solutions improved water security in rural India (SIWI, 2015).

Source: Singh (2016).

Figure 2.1 The relationship between built infrastructure and ecosystem services



Source: CGIAR WLE (2017, fig. 1, p. 5, developed using some results from WISE-UP to Climate).

through innovations that increase agricultural productivity and efficiency in a context of a sustainable use of natural resources, reduced contamination, cleaner energy utilization, and increased mitigation of, and adaptation to, climatic change, as well as the delivery of environmental services." (FAO, 2013b, item 53).

Water is not considered independently in this approach, which looks at improving overall ecosystem performance, for example nutrient cycling (and hence fertilizer use efficiency and therefore water quality), pest and disease regulation, pollination, and prevention of soil erosion. Improvements in water cycling (water regulation) are a central and cross-cutting requirement and outcome.

Previous attention to water use in agriculture has tended to focus on irrigation due to its high levels of water withdrawal. However, the Comprehensive Assessment of Water Management in Agriculture (2007) pointed out that the main opportunities to increase productivity are in rainfed systems that account for the bulk of current production and family farming (and hence livelihood and poverty reduction benefits).

The benefits of NBS can apply to farming at all scales, from small-scale family farming (FAO, 2011b) to large-scale 'industrial' agriculture. Economic viability and ecosystem sustainability are two sides of the same coin (Scholes and Biggs, 2004). For example, a recent study of highly simplified and intensive mono-cropping systems demonstrated that landscape diversification not only delivers improved water, nutrient, biodiversity and soil management, but simultaneously increases crop production (Liebman and Schulte, 2015). Agricultural systems that conserve ecosystem services by using practices such as conservation tillage, crop diversification, legume intensification and biological pest control perform as well as intensive, high-input systems (Badgley et al., 2007; Power, 2010). The ability to resist and recover from various forms of stress, including droughts and floods, as well as pests and disease, are among the effects of increased biological diversity in agricultural systems noted in a recent review (Cardinale et al., 2012). These approaches are also a fundamental strategy for improving the resilience of agriculture in the face of climate change (FAO, 2014a).

The World Overview of Conservation Approaches and Technologies (WOCAT, 2007) undertook a detailed analysis of 42 in-depth case studies of soil and water conservation initiatives worldwide, mainly but not exclusively related to agriculture. Soil and water conservation measures can be grouped into:

- **Conservation agriculture** – characterized by systems incorporating three basic principles: minimum soil disturbance, a degree of permanent soil cover, and crop rotation.

- **Manuring/composting** – where organic manures and composts are intended to improve soil fertility and simultaneously enhance soil structure (against compaction and crusting) and improve water infiltration and percolation.
- **Vegetative strips/cover** – for example using grasses or trees in various ways. In the case of strips, these often lead to the formation of bunds and terraces due to 'tillage erosion' – the downslope movement of soil during cultivation. In the other cases, the effects of dispersed vegetation cover are multiple, including increased ground cover, improved soil structure and infiltration, as well as decreased erosion by water and wind.
- **Agroforestry** – describes land use systems where trees are grown in association with agricultural crops, pastures or livestock. Usually, there are both ecological and economic interactions between components of the system. There is a wide range of potential applications, from shelterbelts, to trees with coffee, to multi-story cropping.
- Three **structural approaches** that are often supported by living landscape components:
    - Water harvesting – which involves the collection and concentration of rainfall runoff for crop production, or for improving the performance of grass and trees, in dry areas where moisture deficit is the primary limiting factor.
    - Gully control – which encompasses a set of measures that address this specific and severe type of erosion, where land rehabilitation is required. There is a whole range of different and complementary measures, but structural barriers dominate – often stabilized with permanent vegetation. Commonly, such technologies are applied over a whole sub-catchment.
    - Terraces – with a wide variety of different terrace types, from forward-sloping terraces to level or backward-sloping bench terraces, with or without drainage systems.

Of these technologies, conservation agriculture (Box 2.3) has become the flagship of an alternative agricultural paradigm for intensifying crop production that not only improves and sustains productivity but also delivers important environmental services (Kassam et al., 2009; 2011a; FAO, 2011c).

Opportunities for improved on-farm management practices that target green water[8] (rainfed crops) can significantly improve water availability for crop production. Using moderate estimates (25%) for reductions in soil evaporation and improved water harvesting through modifying tillage regimes or mulching in a dynamic global vegetation and water balance model, Rost et al. (2009) estimated that global crop production could be increased by nearly 20% from on-farm green water management practices alone. This translates into a water use benefit of about 1650 km³ per year (based on increases in net primary productivity). Falkenmark and Rockström (2004) suggested an improvement of green water productivity by 1530 km³ per year through a combination of similar techniques. Although these authors consider their estimates to be conservative, these predictions remain uncertain. Nevertheless, they are a useful indication of the scale of potential benefits on offer. For example, the latter figures suggest that potential gains are roughly equivalent to crop production from 50% of current irrigation water withdrawals, or 35% of total water withdrawals. That is, more than the projected increase in global water demand between now and 2050. Where combined with other measures to improve sustainability, these benefits are even more impressive. For example, a review of agricultural development projects in 57 low-income countries found that more efficient use of water, reduced use of pesticides and improvements in soil health had led to average crop yield increases of 79% (Pretty et al., 2006).

> There are a few examples where either NBS or grey (built) infrastructure is the only option to improve water availability, but usually both should be considered, designed and operated in harmony

There are also significant opportunities for NBS to improve water use efficiency in irrigation and this can have a high impact due to the fact that irrigation accounts for 70% of current water withdrawals (HLPE, 2015). NBS for increasing water use efficiency in irrigation are based on improving catchment management to enhance groundwater and reservoir recharge (Box 2.1), including through reduced siltation that increases reservoir storage capacity and improved soil health (as for rain-fed systems) through increased soil moisture retention, for example. Better management of the soil ecosystem in irrigated fields can also yield significant water savings (Box 2.4).

[8] Green water is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products. For more details, see: waterfootprint.org/en/water-footprint/what-is-water-footprint/.

BOX 2.3

CONSERVATION AGRICULTURE – AN APPROACH TO SUSTAINABLE PRODUCTION INTENSIFICATION

Conservation agriculture involves the simultaneous application of three practical principles based on locally formulated practices (Friedrich et al., 2008; Kassam et al., 2011a): minimizing soil disturbance (no-till seeding); maintaining a continuous soil cover of organic mulch and/or plants (main crops and cover crops including legumes); and cultivation of diverse plant species that, in different farming systems, can include annual or perennial crops, trees, shrubs and pastures in associations, sequences or rotations, all contributing to enhanced system resilience. The elimination or minimization of mechanical soil disturbance avoids or reduces the shattering of topsoil structure and pores, as well as the loss of soil organic matter and the soil compaction that occur with tillage. Stagnari et al. (2009) concluded that, when compared to conventional tillage agriculture, conservation agriculture results in *"improved soil structure and stability; increased drainage and water-holding capacity; reduced risk of rainfall runoff* (see Figure below) *and reduced pollution of surface waters with pesticides of up to 100% and fertilizers up to 70%; and about one quarter to one half lower energy consumption and lower CO_2 emissions"*.

Figure | The same field with sections under tillage (right) and conservation agriculture/no tillage (left) immediately after a heavy rainstorm



Note: Soil compaction and loss in water infiltration ability caused by regular soil tillage leads to impeded drainage and flooding in the ploughed field (right) and no flooding in the no-till field (left). Photograph taken in June 2004 in a plot from a long-term field trial 'Oberacker' at Zollikofen close to Berne, Switzerland, started in 1994 by SWISS NO-TILL.

Photos: Wolfgang Sturny

The economic benefits of conservation agriculture have been established in various systems around the world, from smallholder agricultural systems in Latin America and sub-Saharan Africa to large-scale commercial production systems in Brazil and Canada (reviewed in Govaerts et al., 2009). Currently, about 1.8 million km² of croplands are under conservation agriculture, representing about 12.5% of global cropland extent, an increase of 69.2% since 2008/09 (Kassam et al., 2017). However, uptake is highly variable between regions. For example, in some South American countries 70% of croplands are under conservation agriculture, in others the area is negligible. Differences appear to have more to do with perceptions, agricultural policies, farmer field support and incentives rather than bio-geological-climatic factors, suggesting that the enabling policy environment is a key factor constraining further uptake (Derpsch and Friedrich, 2009).

The environmental co-benefits of these, and other, NBS approaches to increasing sustainable agricultural production are substantial – mediated largely through decreased pressures on land conversion and reduced pollution, erosion and water requirements. For example, food systems (meaning both food consumption patterns and methods of food production) account for 70% of the projected loss of biodiversity by 2050 under business-as-usual (Leadley et al., 2014).

NBS also offer opportunities to reduce conflicts between sectors over water use through improved system performance. For example, tensions have been rising between mining and agriculture interests in the Limpopo Province of South Africa where the Njelele Dam, used primarily for agriculture, is likely to be totally silted up within a decade due to the nearby Makhado Colliery. However, a planned open-pit mine of 20 km long and 1 km wide provides an opportunity to use waste rock to build an

engineered aquifer to replace the function of Njelele Dam as a storage device, thereby reducing possible conflict (Turton and Botha, 2013). The area is also affected by climate change with some models showing a potential 5 °C increase in ambient temperature (Scholes et al., 2015), causing massive evaporative losses from a reservoir and highlighting the need for subsurface storage instead (Box 2.1). This helps align the needs of society, creating a new social licence to mine in a water-constrained area.

2.2.2 Urban settlements

NBS for addressing water availability in urban settlements are of great importance, given that the majority of the world's population is now urbanized. Managing water flows through urban landscapes can improve water resources availability (Lundqvist and Turton, 2001). A wide range of options is available for consideration. Many NBS are multi-functional, addressing water availability (scarcity/supply), water quality and risks. They can be grouped into:

- Catchment management outside urban areas that improve the supply into urban areas (including surface water and groundwater sources) – almost always in conjunction with improved water quality.
- Improved recycling of water within urban water cycles, for example wastewater re-use enabled through NBS to improve wastewater quality (see Chapter 3 and WWAP, 2017).
- The deployment of green infrastructure within urban boundaries.

Catchment measures to improve water supplies to cities are covered in further detail in Chapters 3 and 5, which emphasize their impact on improving water quality. However, these measures can also directly improve the quantity of water available to urban users by utilizing the ability of the natural infrastructure of catchments to naturally store and release water, and in particular regulate downstream flows (and groundwater recharge). This is particularly beneficial as it helps to regulate variations in supply and to reduce water scarcity during dry periods. These attributes of natural landscapes usually work in harmony with, and improve, grey-infrastructure approaches to urban water supply (Box 2.5).

Urban green infrastructure is becoming increasingly popular, as witnessed by escalating investment, for example (Bennett and Ruef, 2016). Green infrastructure (see Chapter 1, Section 1.3.7) is retrofitted to improve the hydrological performance of older urban landscapes or incorporated in the design of new areas, due to its cost-effectiveness and its multiple benefits (UNEP-DHI/IUCN/TNC, 2014). Examples of measures to regulate water supply for urban settlements include reforestation, the restoration or construction of wetlands, new connections between rivers and floodplains, water harvesting, permeable pavements and green spaces (bioretention and infiltration). Urban green infrastructure essentially reinstates and manages the hydrological pathways at the land/water interface and hence the fate of precipitation, including runoff and groundwater recharge.

BOX 2.4

THE SYSTEM OF RICE INTENSIFICATION (MORE PRODUCTIVITY WITH LESS WATER)

Rice is a staple for nearly half the world's population. Irrigated, lowland rice cultivation, which covers about 56% of the total rice-cropped area, produces about 76% of the world's total rice crop (Uphoff and Dazzo, 2016). The system of rice intensification (SRI) is an approach that includes re-establishing the ecological and hydrological functioning of soils, based on modifications in standard crop and water management practices rather than relying on the introduction of new varieties or on the use of ever more agrochemical inputs. It has taken root at an international scale, moving far beyond its origins in Madagascar (Kassam et al., 2011b). Of particular interest here is the SRI practice keeping the soil moist but not continuously flooded so that soil status is mostly aerobic rather than always saturated and anaerobic. Results vary considerably between regions, but SRI can become labour-saving over time, while saving water (by 25–50%) and seed (by 80–90%), reducing costs (by 10–20%), and raising paddy output by at least 25–50%, often 50–100% and sometimes even more (Uphoff, 2008). Zhao et al. (2009) confirm the positive effect of SRI on rice yield and on nitrogen and water use efficiency. Gathorne-Hardy et al. (2013) showed that SRI methods increased paddy yields by a substantial 58%, while reducing water applications. At the same time, SRI offers opportunities for significant reductions in greenhouse gas emissions as a result of the shift from anaerobic to aerobic conditions in the soil that results in reduced methane emissions (that are not offset by increased N_2O emissions) and reduced embodied emissions in the electricity used to pump water for irrigation (Gathorne-Hardy et al., 2013; Dill et al., 2013). In addition to improving rice production efficiency, including crop water requirements, the benefits of SRI collectively make rice production more environmentally friendly (Uphoff and Dazzo, 2016). They also increase resilience and therefore are a key approach for adaptation to climate change (Thakur et al., 2016). Perception of climate change and the need for moisture-conserving technology is a key driver for SRI adoption, particularly in drylands (Bezabih et al., 2016).

BOX 2.5

LANDSCAPE RESTORATION IMPROVES MULTIPLE WATER OUTCOMES FOR THE TANA RIVER, KENYA

The Tana River in Kenya provides 80% of the drinking water for Nairobi, generates 70% of the country's hydropower and irrigates about 645 km² of farmland. Steep hillsides and areas adjacent to rivers have been converted to agriculture, resulting in erosion. Sedimentation has reduced the capacity of reservoirs and increased the costs of water treatment for Nairobi. A US$10 million investment in sustainable land management will be disbursed over 10 years, leading to a return of US$21.5 million in economic benefits over a 30-year timeframe. Interventions include: improved riparian management, the terracing of hillslopes, the reforestation of degraded lands, measures to encourage grass strips in farms, and the mitigation of road erosion. In terms of water supply, the storage capacity of reservoirs will be maintained as a consequence of reduced sedimentation. Revenues for the hydropower company will improve as a direct result of this action. The Nairobi City Water and Sewerage Company has also benefited from avoided filtration, lowered energy consumption and reduced sludge disposal costs. The benefits of reduced sedimentation are maintained across a range of climate change scenarios.

Sources: Baker et al. (2015); TNC (2015); and Simmons et al. (2017).

This regulation of urban water flows particularly increases urban water storage and therefore resilience to variations in water availability, whether for flood management or as a buffer against water scarcity. Urban food gardens also help increase the use of urban rainfall and reduce agricultural water demand in rural areas whilst also shortening food supply chains, translating into further water savings through avoided food waste. Urban green infrastructure can also significantly improve urban climates through shading and the cooling effects of evaporation – thus enhancing the quality of life for citizens as a co-benefit.

Green buildings are an emerging phenomenon that is developing new benchmarks and technical standards that embrace many NBS solutions. Crucial in this regard is the alignment of regulatory requirements to incentivize, or even mandate, NBS as the new normal (discussed further in Chapter 6). China's 'sponge city' concept and programme represents a good example of NBS improving urban water supplies at scale, based largely on deploying green infrastructure approaches in urban landscapes, primarily to improve water availability (Box 2.6).

In terms of supporting the expansion of NBS in cities, UNESCAP (2017), for example, has provided a self-paced e-learning course on *Shifting Towards Water-Resilient Infrastructure and Sustainable Cities*. Interlinkages between SDGs 6, 8, 11 and 13 are presented with an overview of the best practices, policy briefs, holistic strategies and approaches to good urban governance. This course was designed to sensitize policy makers and to foster utilization of the full benefits of water-resilient infrastructure, in order to achieve inclusive, safe and sustainable cities with SDG-readiness.

2.2.3 Energy and industry

Biofuels and hydropower are particularly relevant in terms of NBS for water supply in the context of energy production. Biofuel crops potentially use large amounts of water and can increase water scarcity, among other impacts (Mielke et al., 2010). However, NBS for biofuel crops are essentially the same as those for agriculture, as described earlier in Section 2.2.1. Applications of NBS for improving water supply for hydropower essentially involve improved catchment management approaches that regulate water supplies to hydropower installations (usually via reservoirs), and reductions in the sediment loads to reservoirs in order to increase dam storage efficiency (and power plant operational costs). Box 2.5 provides a case study of the Tana River watershed (Kenya) where benefits of NBS approaches include increased revenues for the hydropower company as a result of improved water supply to the reservoir. The benefits of NBS to improve hydropower dam operation efficiency can be substantial and represent good examples of how green and grey infrastructure can be complementary (Box 2.7).

The relationship of ecosystems to the water–energy nexus and the possible responses to challenges through an IWRM/ecosystem approach, using tools such as payment for environmental services (PES), sustainable dam management and strategic water basin investment, were explored more fully in Chapter 9 of WWAP (2014), which provided additional details and references.

Industry is increasingly investing in NBS to improve water security for its operations. The World Business Council for Sustainable Development (WBCSD) has collected case studies from companies investing in such solutions (WBCSD, 2015a). For example, the Volkswagen Group in Mexico operates a production plant in the Puebla Tlaxcala Valley where water supply is insufficient for the growing city of Puebla. The company partnered with the Comisión Nacional de Áreas Naturales Protegidas (National Commission for Protected Natural Areas) to secure a reliable water supply. Analysis found that groundwater replenishment in the valley was highly contingent upon

BOX 2.6

CHINA'S 'SPONGE CITY' CONCEPT

The central Government of China recently initiated the 'sponge city' project for the purpose of improving water availability in urban settlements. The 'sponge city' concept uses a combination of NBS and grey infrastructure to retain urban runoff for eventual reuse. The project's objective is *"70% of rain water to be absorbed and reused through improved water permeation, retention and storage, purification and drainage, as well as water saving and reuse. This goal should be met by 20% of urban areas by the year 2020 and by 80% of urban areas by the year 2030"'* (Embassy of the Kingdom of the Netherlands in China, 2016, p. 1). Through the 'sponge city' project, the negative impacts of urban construction on natural ecosystems are expected to be mitigated.

"The city-wide deployment of nature-based solutions such as green roofs, pervious pavements and bioremediation along with the restoration of urban and peri-urban wetlands and rivers lie at the heart of the national initiative"' (Xu and Horn, 2017, p. 1).

By 2020, 16 pilot 'sponge cities' will be constructed across an area of over 450 km², with over 3,000 planned construction projects and total investments of RMB 8.65 billion (about US$1.25 billion) (Embassy of the Kingdom of the Netherlands in China, 2016). Initial results include alleviation of urban waterlogging, improvement of water-related ecosystems, promotion of industrial development and improved overall public satisfaction. The central policy planning, actively aligned with the local-level implementation, has integrated the 'sponge city' concept in urban regulatory planning and ecological restoration at city and district levels in Shenzhen and Guangdong provinces.

Examples of measures include the installation of green roofs, walls and permeable pavement, as well as the revitalization of degraded lakes and wetlands, which absorb excessive rainwater. Raingardens and bioretention swales are then used to collect runoff and remove certain pollutants. Some of this water is then sent back to the natural system and stored to ensure availability of water for irrigation and cleaning purposes during periods of drought (Xu and Horn, 2017).

Contributed by UNESCAP.



Photo: © Syrnx/Shutterstock.com

the functionality of the ecosystems and that deforestation on the volcanic slopes had increased water runoff, thereby reducing aquifer recharge. Over six years, tree planting, pits and earthen banks have enabled more than 1.3 million m^3 per year of additional water for aquifer recharge – more water than the Volkswagen Group in Mexico consumes annually (WBCSD, 2015b).

In 2013, the United Nations Industrial Development Organization (UNIDO) led the Lima Declaration on Inclusive and Sustainable Industrial Development (ISID), with Point 7 calling for the promotion of *"the sustainable use, management and protection of natural resources and the ecosystem services they provide"* (UNIDO, 2013, item 7). This built momentum on the topic, leading up to the 2030 Agenda for Sustainable Development, and particularly Targets 6.4 and 6.6 on water scarcity and ecosystems, respectively (WWAP, 2015). It provides an example of how NBS are being mainstreamed into relevant policy reform arenas.

2.2.4 Combating desertification

Desertification is driven by multiple pressures, but the process is a direct result of (if not defined by) the degradation of the ability of land to retain water. Desertification and the associated land degradation and drought, as natural disasters, are covered further in Chapter 4, but examples provided here of NBS that restore water in landscapes, including groundwater and agricultural soils, are recognized approaches to combat desertification (and land degradation and drought) when applied in relevant vulnerable areas. Since ecosystem degradation is the underlying cause of desertification, NBS present the only feasible means to combat it at any large scale. NBS are, therefore, at the forefront of efforts to restore land productivity in affected areas. For example, the UNCCD promotes NBS as a central means for combating land degradation (UNCCD Science-Policy Interface, 2016). Critical to these approaches are moisture recycling, soil water retention and enhanced infiltration benefits of landscape restoration.

2.2.5 Water, sanitation and hygiene

Although the contribution of NBS to improving WaSH outcomes are mainly related to water quality (see Chapter 3), WaSH goals are also much more easily achieved when there is adequate water supply for all uses – domestic, industrial and agricultural – as well as supply being effectively managed to prevent contamination. Mitigating the impacts of desertification, land degradation and drought is just one example by which NBS support WaSH outcomes through improving water resources availability and accessibility. Benefits of NBS often favour the most disadvantaged and vulnerable, such as minority communities, rural communities and women. An NBS approach can improve public health, particularly in developing countries, by helping to ensure safe water and adequate sanitation (Brix et al., 2011).

BOX 2.7

WATERSHED SERVICES PROVIDE A FIVE-FOLD INCREASE OF THE OPERATIONAL LIFE EXPECTANCY OF THE ITAIPU HYDROPOWER DAM IN THE PARANÁ RIVER BASIN IN BRAZIL

Efficient hydropower generation from the Itaipu Dam reservoir in the Paraná III Basin, located in the western part of Paraná State, Brazil, on the Paraguayan border, is affected by soil management in the watershed. Sediments entering the reservoir reduce storage and shorten the reservoir's life, while increasing maintenance costs and therefore electricity generation costs, providing a financial incentive to improve watershed management. The programme *Cultivando Água Boa* (cultivating good water) has established a partnership with farmers to achieve mutual goals of sustainability (Mello and Van Raij, 2006; Itaipu Binacional, n.d.). A cornerstone of the *Cultivando Água Boa* programme is the partnership developed through the Brazilian No-Till Federation (FEBRAPDP) that includes measuring impacts of farm management through a scoring system indicating how much each farm is contributing to improving the water conditions (Laurent et al., 2011). This enables farmers to be considered as 'water producers' by the National Water Agency, which assigns values to the ecosystem services generated by farms participating in the programme and compensates farmers for their proactive approach (ANA, 2011). Overall, the life expectancy of the dam complex has been increased from its original figure of some 60 years when the dam was built to some 350 years now. Additionally, other environmental benefits are delivered (such as reduced nutrient runoff) and, importantly, farm productivity and sustainability have increased – presenting a win-win scenario for farmers and the hydropower company.

2.3 The influence of moisture recycling on water availability

Chapter 1 (see Section 1.3.3) highlights the important influence of evaporative fluxes on regional and global moisture recycling and subsequent precipitation. This influence on water availability can be substantial: for example, 70% of the rainfall for the Río de la Plata Basin in Argentina/Uruguay originates as evaporation from the Amazon forest (Van der Ent et al., 2010). Land use decisions in one place may therefore significantly influence water availability in distant locations. This is particularly important considering that vegetation removal probably has the most severe impacts on rainfall

in drier areas, contributing there to increased water scarcity, land degradation and desertification (Keys et al., 2016).

The influence of LULUC on the movement of moisture, and subsequent precipitation, challenges the 'watershed' as being the common unit of management, indicating that 'atmospheric watersheds' – otherwise known as 'precipitationsheds' (Keys et al., 2016) – should also be considered. However, this presents considerable challenges to governance of water resources availability (Keys et al., 2017). There are few efforts currently to address this aspect of managing water resources availability but some examples do exist. The Global Environment Facility is supporting a multi-functional landscape-scale programme that recognizes the critical role the Amazon Basin plays in climate regulation regionally and globally, with an investment cost of US$683 million, including co-financing (GEF, 2017). The programme is designed to improve policies, investments in protected areas and integrated landscape management, in order to avoid, among other things, the high risk of the Amazon ecosystem as a whole reaching a tipping point of run-away natural forest dieback due to drought and fire. Such an event would be immensely difficult to stop and have massive socioeconomic consequences through reduced water availability for, among other things, dependent agriculture (located mainly outside the basin) and the life expectancy of regional energy infrastructure (i.e. dams).

2.4 Challenges to enabling NBS for water availability

The main challenges to upscaling NBS applications for most actors, including regulatory authorities, local government, industry, business, agriculture and civil society include:

Enabling policy environments. Policy environments often discourage, and in some cases prohibit, NBS uptake. An enabling policy environment is needed to promote NBS adoption where warranted. For example, in agriculture, subsidies and incentives provided to farmers often need to be realigned to support sustainability, including the adoption of NBS. NBS should also become further integrated across a broader range of corporate best practices and harness different branding opportunities on offer, entering new markets or shifting public perceptions about good corporate citizenship (WBCSD, 2015a).

Awareness/perceptions. Much needs to be done to build a better information base and awareness of NBS. Water shortages and extremes (floods and droughts) create moments when awareness is heightened, increasing the opportunity to consider NBS options. Civil society is a key player in influencing policy environments and investment, and can be better informed. Small and medium enterprises have a large cumulative impact and need to become more informed and involved.

Technical. Many stakeholders are often risk-averse, typically preferring tried and tested solutions, creating a barrier for the adoption of alternative (non-conventional) engineering solutions. Since the effectiveness of NBS varies greatly at the local level (Burek et al., 2016), it is essential that they are carefully planned, designed and built to help planners/engineers select the right location and correct NBS option to unlock the maximal benefit. This in turn requires a reliable assessment of expected performance during the design phase, resulting in a more accurate cost–benefit analysis. There is a strong business case to be made for partnering with nature but this generally needs to be proven, because it is often considered "alternative" rather than mainstream. However, where large corporations make detailed assessments and proceed to implement NBS, the results can be significant, as demonstrated by the water footprinting initiative initiated in 2009 by SAB-Miller in conjunction with the World Wide Fund for Nature (WWF).[9] Now that NBS are clearly more visible in some policy agendas, they run the risk of being downgraded through more misapplications where performance does not meet expectations. To counter this, a much better knowledge base on NBS is required, including expanded and impartial science-based evaluations of their performance. Some NBS can take time and many stakeholders prefer more guaranteed faster results. Moreover, NBS are also poorly integrated in supporting disciplines, such as civil engineering, resulting in a skill shortfall.

Financial. Good data may be lacking to inform evidence-based investment options. NBS have inherent variability, depending on location and other factors that need to be understood, if adoption is to be sufficiently de-risked. Financial incentives and improved market-based instruments to adopt NBS (see Sections 5.2.2 and 6.2) would help strengthen the business case and facilitate decision making.

Institutional. NBS often require high levels of cross-sectoral and institutional cooperation. This should be encouraged to accelerate actions, with consideration being given to stewardship of resources as a mechanism for engagement. An enabling policy environment can go a long way to promote cooperation. Mandating that NBS be considered in investment choices, for example, can stimulate cooperation between those with NBS knowledge and those making investment choices. Standards, regulations, guidelines and incentives governing NBS are not common or uniform across national economies. This also constrains industry, which prefers certainty.

[9] For more details, please see www.wwf.org.uk/updates/wwf-and-sabmiller-unveil-water-footprint-beer.

> Although included in IWRM principles in theory, in practice NBS are not well integrated in IWRM approaches and are often absent

NBS call for improved landscape-scale approaches to water resources management. IWRM has been an aspiration for decades (Allan, 2003) but has often failed due to entrenched sectoral interests, political and governance barriers (Jønch-Clausen, 2004), and the lack of collective responsibility (Goldin et al., 2008). In addition, although included in IWRM principles in theory, in practice NBS are not well integrated in IWRM approaches and are often absent. For example, water managers typically function in isolation, but integrated land and water management is necessary (Bossio et al., 2010). The concept of integrated land and water resource management continues to gain currency around the world with growing emphasis on the inclusion of ecosystem services as quantifiable benefits. Given that NBS are scale-dependent and involve multiple ecosystem services in addition to water regulation, it is usually necessary to take scale into consideration (Hanson et al., 2012). This also requires improved attention to managing the impacts of land and water use on coastal zones and marine resources. The 'source to sea' (S2S) model (Box 2.8) is an approach that promotes such landscape-scale integrated governance arrangements that can balance development objectives across sectors, taking ecosystem service flows into account and enabling coordination and integration across the different management objectives (Granit et al., 2017). Such approaches also need to link cycles of water, waste and energy (FAO, 2014c).

2.5 NBS, water availability and the SDGs

Sustainable resource use cross-cuts the SDGs, as does water availability. Without sufficient water, most economic and social progress is constrained. Water and sanitation linkages across the SDGs and their targets were explored by UN-Water (2016a). NBS for water availability contribute to all targets in SDG 6 (on water) that in turn translate into the improved benefits of water availability in general. There are, however, many approaches to managing water availability, including through demand-side management, the improvement of water quality, and re-use and improvement of grey infrastructure, in addition to NBS. Linkages between NBS and the SDGs for water quality and risk reduction are covered in Chapters 3 and 4, respectively, while Chapter 7 provides a general assessment of overall opportunities. The fact that so many SDGs are interlinked by water-related issues makes it difficult to isolate NBS for water scarcity from broader land and water management. This Section, therefore, highlights only some of the areas where NBS provide promising opportunities to address water availability *vis-à-vis* other options, bearing in mind the complexities of this topic.

By far the greatest potential for NBS to improve water availability, compared to other options, is in agriculture, through efficiency gains in rainfed and irrigate systems. This is, therefore, a key element of achieving SDG 2 (*"End hunger, achieve food security and improved nutrition and promote sustainable agriculture"*) and in particular a fundamental need to achieve its Target 2.4 (*"… ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality"*), underpinning the achievement of other targets in SDG 2, which, in turn, reinforce numerous other improvements in human well-being (including health, poverty reduction and environmental sustainability). NBS for addressing water availability in, and for, urban areas form another promising area, compared to alternative options, and are therefore contributing to SDG 11 (*"Make cities and human settlements inclusive, safe, resilient and sustainable"*). The co-benefits of NBS for water availability, and most notably their capability to improve the external impacts of agriculture on ecosystems, provide significant opportunities to make major contributions to SDG 12 (*"Ensure sustainable consumption and production patterns"*) and 15 ("*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"*). Particular note is made of NBS being the most feasible means to combat desertification and therefore achieving Target 15.3 (*"Combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world"*). Insofar as NBS mitigate downstream impacts into coastal/marine areas they also offer significant potential to achieve SDG 14 (*"Conserve and sustainably use the oceans, seas and marine resources for sustainable development"*). As most NBS involve improving system resilience, and in many cases increasing carbon storage (notably through soil and vegetation management), they also contribute significantly to SDG 13 (*"Take urgent action to combat climate change and its impacts"*).

Many more interlinkages could be pointed out, some also with high potential for the application of NBS for water availability. This topic is explored further in Chapter 7. For current purposes, it is concluded that NBS for water availability has very promising potential to contribute to the achievement of the SDGs, either in conjunction with or as an alternative to other approaches.

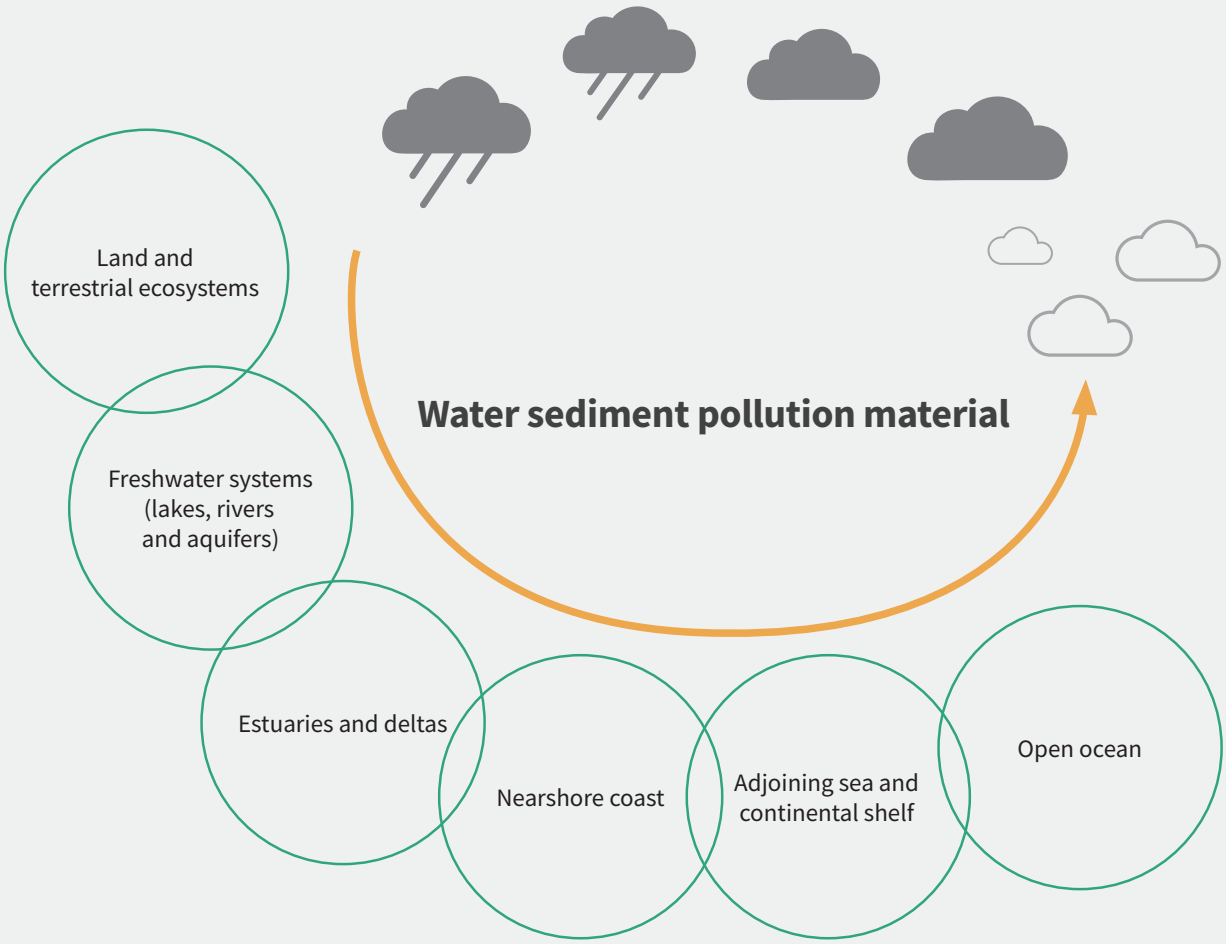
BOX 2.8

THE S2S APPROACH

The 'source to sea' (S2S) approach integrates and respects interdependencies between upstream land and water management and downstream quality of deltas and coastal areas, interconnected through surface, subsurface flows, rivers, canalized networks and infrastructural routings.

S2S considers the dynamic interface between land and oceans – that captures a key development and environmental challenge of our time – to address the increasing pressures on, and degradation of, the land and water resource base that especially affect the poor who cannot compensate through adopting expensive measures. Direct and indirect drivers of land and water resources upstream translate into increasing pressures downstream, including through estuaries and into coastal areas and beyond to oceans. Downstream communities are most often unable to influence or manage these upstream drivers. Moreover, countries that share watersheds require close international collaboration to consolidate concerted land and water management that assures long-term deliveries of cross-border water flows against required quality. S2S provides one approach to managing these threats, as it accounts for land and water uses in up- and lowland areas as well as the needs of those dependent on coastal and marine resources.

Figure | Key flows of water, sediment, pollution and material connect geographical segments from S2S



Source: Adapted from Granit et al. (2017, fig. 1, p. 5).

3 NBS FOR MANAGING WATER QUALITY



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Constructed wetlands for wastewater treatment plant



3.1 Water quality challenges, ecosystems and sustainable development

The serious challenges of water pollution and deteriorating water quality worldwide result in risks to human and ecosystem health, while reducing the availability of freshwater resources for human needs, as well as the ability of water-related ecosystems to provide goods and services, including natural water purification. Driven by population growth and urbanization, industrialization, the expansion and intensification of agriculture, and the impacts of climate change, evidence of the extent of freshwater quality degradation is widespread (see Prologue). Particularly concerning is the pollution of freshwater ecosystems, and ultimately coastal and marine ecosystems. Major types of pollutants include chemicals and nutrients. Increasing salinity levels and rising water and air temperatures can also have significant impacts (UNEP, 2016a). The global loss of freshwater wetlands, which have a unique capacity to filter and improve water quality, is of particular concern; it is estimated that 64–71% of wetland extent has been lost since 1900 (Davidson, 2014).

Agricultural runoff is the principal source of nutrient loading and other pollutants, such as pesticides. Inadequate management of municipal and industrial wastewater accounts for another major source of water pollution (UNESCO, 2015a), particularly in low-income countries where only an estimated 8% of this type of wastewater undergoes treatment of any kind (Sato et al., 2013). Unsafely managed sanitation has led to the contamination of drinking water sources by pathogenic pollutants, causing waterborne diseases (UNEP, 2016a). Polluted urban stormwater runoff, effluents from mining and extractive industries, including industrial spills, sediment loading and solid waste transport into water bodies, also have direct impacts on the quality of surface waters and

> Declining water quality and increasing water pollution will hamper the prospect of achieving many of the SDGs, as well as other international agreements

groundwater, sometimes causing severe chemical and heavy-metal pollution. Emerging pollutants (including antibiotics, hormones and other pharmaceuticals, personal care products, household and industrial chemicals) present new water quality challenges. For example, multi-resistant waterborne pathogens and endocrine-disrupting compounds may pose significant risks to human health and ecosystems (UNESCO, 2015b). Specific data on the extent of pollution and water quality degradation are often lacking, further amplifying the challenges related to water quality management (UN-Water, 2016a).

Climate change also contributes to the degradation of water quality by affecting the seasonal quantity of water available (or lack thereof) and its temperature, thus modifying its physico-chemical and biological parameters (Delpla et al., 2009). More frequent and intense flooding can lead to the dispersal of contaminants through runoff, and sea level rise can lead to higher salinity. Increases in water scarcity and changes to the hydrological cycle affect the spatial extent, productivity and function of freshwater ecosystems, including their ability to provide ecosystem services, with effects often reaching far downstream or into coastal areas (Parry et al., 2007). Changes to precipitation and stream flows that lower the amount or availability of water also lead directly to reduced water quality (Finlayson et al., 2006). The resulting lower water quality levels, in effect, are themselves a form of scarcity when water is no longer directly usable for many productive uses (Aylward et al., 2005).

The degradation of water quality translates directly into environmental, social and economic risks, impacting human health, limiting food production, reducing ecosystem functionality and hindering economic growth (UNESCO, 2015a). Water quality is thus central to the concept of sustainable development, which was brought to the forefront of action through the 2030 Agenda for Sustainable Development and the SDGs and is addressed in more detail in Section 3.5, below. Declining water quality and increasing water pollution will hamper the prospect of achieving many of the SDGs, as well as other international agreements such as the Aichi Biodiversity Targets.

3.2 NBS for sustaining or improving water quality

3.2.1 Protecting source water quality

Healthy watersheds collect, store, filter and deliver water to communities of all sizes. Source water protection reduces water treatment costs for urban suppliers, contributes to improved access to safe drinking water in rural communities, and can potentially also provide water of adequate quality for other uses such as agricultural irrigation.

The potential benefits of watershed protection for enhancing the quality of water available for human settlements, and cities in particular, are massive. For example, a recent modelling exercise by Abell et al. (2017) estimated that land conservation and/or restoration activities (such as forest protection, reforestation and the use of cover crops in agriculture) could lead to a 10% (or more) reduction in sediments or nutrients (phosphorus) in watersheds that currently cover 37% of the world's ice-free terrestrial surface (4.8 million km^2). More than 1.7 billion people (over half of the world's urban population) living in the 4,000 cities in the area covered by this study could therefore potentially benefit from improved water quality as a result of NBS applied to their source watersheds, including "780 million people who live in watersheds located in countries in the bottom-tenth percentile of the Human Development Index (as of 2014)" (Abell et al., 2017, p. 71).

Forests, wetlands and grasslands, as well as soils and crops, when managed properly, provide high-value 'green infrastructure' for enhancing source water protection. They play important roles in regulating water flows and maintaining water quality by reducing sediment loadings, through the prevention of soil erosion and by capturing and retaining pollutants (UNEP-DHI/IUCN/TNC, 2014). Forested riparian buffers serve to prevent pollution of rivers while providing shade that helps to reduce thermal pollution (Parkyn, 2004). Grasslands are widely used to manage water quality and can sometimes provide water of a better quality than forests (Chapter 1). Upstream wetlands can also provide significant water quality benefits, due to their natural ability to facilitate effluent filtration and pollutant absorption (TEEB, 2011).

Rehabilitating landscapes, in particular restoring functionality in agricultural systems, is now a widespread approach promoted at scale. It is not only effective in improving water quality but also provides multiple benefits (Box 3.1).

Various land management interventions to protect or restore catchments are available and usually adopted together, depending on local circumstances (Table 3.1). They are usually supported by diverse financial and other incentives such as, for example, payments for environmental services (PES) schemes (see Section 5.2.2), often using innovative public–private partnerships, for example various water funds (Box 3.6) that operate in several countries.

BOX 3.1

THE US CONSERVATION RESERVE PROGRAM TO PROTECT WATER QUALITY

The Conservation Reserve Program (CRP) by the United States Department of Agriculture (USDA) aims to remove environmentally sensitive private land from agricultural production and to re-establish grass and trees to protect water quality, reduce erosion and increase wildlife habitat. As of August 2016, nearly 100,000 km² were enrolled in a CRP contract.

Participation in the programme by farmers is voluntary as it involves actions on land they legally own. Farmers offer their land for enrolment in the programme and the Farm Service Agency evaluates and ranks the offers using an environmental benefits index. Factors considered in the index include wildlife habitat cover benefits, water quality benefits from reduced erosion, runoff and leaching, on-farm benefits of reduced erosion, enduring benefits, air quality benefits, and cost.

In exchange for setting aside and revegetating lands, participating farmers receive rental payments and cost-share assistance in contracts ranging from 10 to 15 years. Rental rates are paid annually and are based on local dryland cash rental rates for farmland. Cost-share assistance is available to pay up to 50% of the costs of establishing approved practices to achieve the conservation goals. Each year the programme pays out roughly US$2 billion to farmers in rents and cost-share.

The programme has been shown to reduce runoff of nitrogen and phosphorus from farms by more than 90% and 80%, respectively. More than 110,000 km² of wetlands have been restored and soil erosion was reduced by 180 million tonnes per year. In addition, carbon sequestration is calculated at an average of 49 million tonnes of CO_2 equivalent per year. The approach also improves farm resilience, sustainability and productivity.

Sources: USDA Farm Service Agency (2008; 2016).

Contributed by Michael McClain (IHE Delft).

Nature-based source water protection measures are often less costly than managing impacts downstream (e.g. water treatment at point of use; see Chapter 6). A higher quality of source water translates into water treatment cost savings (Gartner et al., 2013) and potentially avoided capital costs of expanding or building new treatment facilities (TEEB, 2009).

3.2.2 Reducing the impacts of agriculture on water quality

The two pathways through which agriculture influences water quality are through point and non-point (diffuse) pollution. Point source pollution, such as the impacts of untreated (or insufficiently treated) wastewater from intensive livestock rearing or food-processing facilities, lies more in the realm of industrial operations and is covered in Section 3.2.4.

Non-point source pollution from agriculture remains by far the greater problem worldwide, including in developed countries (see Chapter 1). However, it is also the one most amenable to NBS. Pollution from this source mainly arises due to two interrelated causes (FAO, 2011b). Firstly, the over-application of agrochemicals that subsequently infiltrate into groundwater or runoff to surface water, often encouraged by perverse subsidies. Secondly, 'modern' mechanical farming techniques, and in particular the removal of vegetation and intensified ploughing, which degrades the soil/vegetation layer ecosystem and reduces its ability to deliver several ecosystem services that are important to maintain water quality. For example: reduced nutrient cycling in soils leads to increased fertilizer leaching and runoff, and reduced fertilizer use efficiency, which in turn promotes increased application of fertilizer to compensate. Similarly, reduced pest and disease regulation services in farming landscapes encourage increased pesticide application, which in turn further erodes the ecosystem through impacts on non-target organisms, promoting increased pesticide application. Exposing bare soil to the elements in farming systems, particularly on slopes, drastically increases erosion and subsequent impacts on water quality (see Chapter 1). These impacts perpetuate a detrimental, and costly, cycle that goes against the interests of farmers: they do not benefit from, and in fact pay for, the loss of fertilizers and/or pesticides from their fields and farmers recognize the importance of keeping soil on their farms for their own livelihood sustainability. It has become well accepted that the key approach that will enable agriculture to increase its production while becoming more sustainable is the concept of sustainable ecological intensification (FAO, 2011b; 2014b). This essentially involves reinstating ecosystem services in landscapes to underpin sustainable productivity increases whilst simultaneously bringing external impacts within acceptable limits. Improved water quality will be one of these important benefits.

There has been much progress in this approach in recent years, helped by the fact that farmers, through improved farm productivity and sustainability, and other stakeholder groups can mutually benefit. For example, '**conservation agriculture**', which incorporates practices aimed at minimizing soil disturbance in order to ensure a degree of permanent soil cover and regular crop rotation, is a flagship approach to sustainable production intensification,

Table 3.1 Categories of common source water protection activities

Source water protection activity	Description	Source water protection activity	Description
Targeted land protection	Targeted land protection is a term that broadly encompasses all of the conservation activities undertaken to protect targeted ecosystems, such as forests, grasslands or wetlands. Agroforests — where trees or shrubs are grown among crops or pastureland — may also be the focus of protection. Targeted land protection is typically undertaken as a preventative measure that reduces the risk of adverse environmental impacts in the future, such as through increased sediment or nutrient loadings that may result from changing land uses. Accordingly, these types of conservation activities differ from those that are focused on reducing the current loading of pollutants.	Ranching best management practices (BMPs)	Ranching BMPs are changes in land management practices on ranchlands that can be channelled toward achieving multiple positive environmental outcomes. Silvopasture is the practice of combining trees with forage pasture and livestock. Ranching BMPs are normally implemented to maintain or improve the quality of water and soils through the improvement of grazing management practices, range structures (e.g. access roads, fencing, grade stabilization), or land treatments (e.g., brush management, range seeding, edge of field treatments). These types of improvements typically seek to reduce sediment and nutrient loadings (e.g. phosphorus, nitrogen), as well as potentially harmful pathogens from livestock waste.
Revegetation	Revegetation involves the restoration of natural forest, grassland or other habitat through planting (direct seeding) or by enabling natural regeneration; includes pastureland reforestation (active or passive forest restoration on grazing lands). Revegetation restores the ability of nature to: 1) hold soil in place and reduce erosion, 2) naturally filter pollutants from overland flow and 3) help infiltrate runoff water into the soil.	Fire risk management	Fire risk management involves the deployment of management activities that reduce forest fuels and thereby reduce the risk of catastrophic fire. Also commonly referred to as "forest fuel reduction", fire risk management seeks to achieve fuel reduction goals through mechanical thinning and/or controlled burns. Fire risk management is typically employed in areas where forests are prone to catastrophic wildfires. The abrupt removal of forest cover and damage to ground cover and soils from catastrophic fires can be particularly problematic when the fire is followed by a large rainstorm, as these events can cause large-scale erosion of unsecured hillsides. Accordingly, similar to targeted land protection, fire risk management seeks both to preserve the integrity of healthy forests and reduce the future risk of increased sediment and nutrient transport, which differs from other activities that are aiming to reduce current annual loadings of pollutants.
Riparian restoration	Riparian restoration involves restoring natural habitat that is at the interface between land and water along the banks of a river, stream or lake. These strips are sometimes referred to as riparian buffers. Riparian zones comprise the area where land and a river, stream or lake interface. Riparian restoration seeks to reestablish riparian functions and related physical, chemical and biological linkages between terrestrial and aquatic ecosystems (Beschta and Kauffman, 2000). The key features of healthy riparian areas are native trees with deep, soil-binding roots. Grass and shrubs are also important ground covers and bio-filters. Riparian buffers are especially important as they are the last defence against pollutants flowing into streams. They can provide critical habitat at the water's edge, and through shading, they can help reduce water temperatures. Temperature regulation has important implications for the ability of water to maintain adequate levels of dissolved oxygen, can be critical for the survival of aquatic species and is linked to reduced incidence of algal blooms (Halliday et al., 2016).	Wetland restoration and creation	Wetland restoration and creation involves the re-establishment of the hydrology, plants and soils of former or degraded wetlands that have been drained, farmed or otherwise modified, or the installation of a new wetland to offset wetland losses or mimic natural wetland functions. Wetlands are areas where water covers soil all or part of the time. Wetlands protect and improve water quality, provide fish and wildlife habitat, store floodwaters and maintain surface water flow during dry periods. Accordingly, the holistic nature of wetland restoration, including the reintroduction of animals, is important. Typically, a wetland is created through the excavation of upland soils to elevations that will support the growth of wetland species through the establishment of an appropriate hydrology. Wetlands may be installed or restored via this or other approaches such as removing underground drainage tiles, installing dykes or plugging open ditches.
Agricultural best management practices (BMPs)	Agricultural BMPs are changes in agricultural land management that can be channelled towards achieving multiple positive environmental outcomes. A wide variety of agricultural BMPs exist, including practices such as cover crops, conservation tillage, precision fertilizer application, irrigation efficiency, contour farming and agroforestry. In the context of existing water funds, agricultural BMPs are primarily in reference to modifying land management practices on croplands, specifically those focused on reducing erosion and nutrient runoff. These practices can help protect drinking supplies, as well as help to protect other uses such as recreation, animal habitat, fisheries and agricultural uses such as irrigation and stock watering.	Road management	Road management involves the deployment of a range of avoidance and mitigation techniques that aim to reduce the environmental impacts of roads, including those impacts related to negative effects on soils, water, species and habitats. The environmental effects of roads include displaced and compacted soils; altered conditions that change soil pH, plant growth and the vegetative community structure; reconfigured landforms that can result in changed hydrologic regimes; and/or the increased number and extent of landslides and debris flows, which can affect terrestrial and aquatic systems. Mitigation techniques for managing roads may include site-level actions to reduce erosion and improve road-stream crossings, or implementing access management and closing and decommissioning roads.

Source: Adapted from Abell et al. (2017, table 2.4, p. 39).

> In most cases green and grey infrastructure can and should be working together

the adoption of which is rapidly spreading (see Chapter 2, Box 2.3). The approach is multifunctional but one of its important benefits is improved water quality through improved nutrient cycling, and hence reduced fertilizer use and soil erosion. A range of other nature-based management interventions is widely used to reduce the impacts of agriculture on water quality, such as:

Riparian grass and **tree buffers** along rivers and lake edges are a common and cost-effective approach in reducing the nutrient and sediment runoff from agricultural land to aquatic ecosystems. These vegetated areas have well-developed root systems, organic surface layers and understory vegetation that serve as physical and biological filters for runoff water and sediment that may be laden with nutrients and other agrochemicals.

Field borders and **buffer strips**, which are vegetated strips along agricultural fields, can help reduce water pollution from agricultural land (Box 3.2) by immobilizing sediment and nutrient transport in overland runoff and increasing infiltration to minimize the runoff volume eventually carried to watercourses.

Vegetative waterways (wet buffer strips and other types of wet zones) are drainage channels that remain under the vegetation cover where runoff conveyed from fields is filtered of sediment, nutrients and other agro-chemicals through the physical contact with the vegetation and the filtering effect of the subsoil and underlying soil in the channel.

In most cases, the efficiency of these interventions depends on the vegetation type and other factors such as runoff velocity and infiltration rates, as well as the maintenance from erosion or clogging by sediment, in the case of drainage channels.

Water and sediment control basins (generally over steeper land slopes) are designed to divert runoff and to temporarily detain and release water through a piped outlet or through infiltration. They contribute to reducing erosive overland flows that may entrain sediment and nutrients, allowing for increased infiltration. A commonly used type of such basins is dry detention basins, which are grassed depressions or basins created by excavation into which runoff is channelled that facilitates the slow filtration of sediment and nutrient uptake by the vegetation. Another type is bioretention structures, which are typically pits backfilled with soil, mulch and vegetation used to retain runoff for infiltration through the filter bed components, with reliance on biological and biochemical reactions within the soil matrix and around the root zones of the plants.

Wetlands in agricultural landscapes are effective at reducing nutrient and suspended sediment loads from agricultural areas to downstream receiving waters, providing habitat mosaics and offering various ecosystem services and benefits to the landscape function. A review of on-farm wetlands in the United Kingdom (UK) and Ireland (Newman et al., 2015) indicated that all types of agricultural wetland systems, with the exception of nitrate in integrated constructed wetland systems (open ponds), offer high levels of removal for many pollutants, including total nitrogen, ammonium/ammonia, nitrate and nitrite, total and soluble reactive phosphorus, chemical oxygen demand, biological oxygen demand and suspended solids. Agricultural wetlands, however, require careful planning and maintenance in order to perform their optimum design function over a prolonged period of time.

Ecohydrology (see Chapter 1, Box 1.1) is an approach that integrates consideration of the water–biota interplay from molecular to catchment scale, using many of the above-mentioned approaches, among others, to improve the ways in which water is managed across landscapes. It is especially relevant for reducing pollution from agriculture (UNESCO, 2016).

BOX 3.2

WATER QUALITY IMPROVEMENT USING BUFFER STRIPS IN EUROPEAN FARMLANDS

Cross-Compliance requirements in the Common Agricultural Policy of the European Union (EU) have, since 2005, required that all farmers receiving direct payments comply with standards on good agricultural and environmental condition of land by establishing buffer strips along watercourses. In 2015, approximately 90% of European farmland (1.56 million km²) conformed with the standards (EC, 2017a). There has been, however, no systematic analysis of the impacts of buffer strips across European farms on water quality. Nutrient loads to European rivers have decreased due to a suite of nutrient reduction measures required under the EU Nitrates Directive and other policy actions, and it is difficult to isolate the contribution of riparian buffers alone.

Contributed by Michael McClain (IHE Delft).

There is rapidly growing interest in incorporating green infrastructure in urban planning and design to manage and reduce pollution from urban runoff

Where land is taken out of agricultural production, some of these interventions can reduce the cropping area. However, this need not reduce overall production since system-wide improvements may ensue. For example, landscape diversification in simplified highly intensive mono-cropping systems not only delivers improved water quality outcomes, among others, but simultaneously increases crop production in remaining areas to compensate for the area lost to crops (Liebman and Schulte, 2015). Agricultural systems that conserve ecosystem services by using practices, such as conservation tillage, crop diversification, legume intensification and biological pest control, have been shown to perform as well as intensive, high-input systems (Badgley et al., 2007; Power, 2010).

3.2.3 Improving water quality in human settlements

There is rapidly growing interest in incorporating green infrastructure in urban planning and design to manage and reduce pollution from urban runoff (UNEP-DHI/IUCN/TNC, 2014). Examples include using green walls, roof gardens, trees in streets and vegetated infiltration or drainage basins to support wastewater treatment and reduce stormwater runoff. Wetlands and other sustainable drainage features are also widely used within urban environments to mitigate the impact of polluted stormwater runoff and wastewater (Scholz, 2006; Woods Ballard et al., 2007). However, in-stream water quality can fail to significantly improve if elements are not joined up using a holistic approach to managing water in urban environments (Lloyd et al., 2002; Gurnell et al., 2007).

These approaches provide further co-benefits improving the quality of life for residents (Cohen-Shacham et al., 2016). Ecohydrology-based approaches, such as the integrated planning and management of green areas and waterways in urban areas, known as 'Blue–Green' networks (University of Łódź/City of Łódź, 2011), can help improve water quality in urban areas. For instance, the development of a sequential sedimentation/biofiltration system for urban stormwater purification is used for the enhancement of water retention in urban areas for adaptation to climate change, while improving health and quality of life for urban dwellers (Zalewski, 2014).

Constructed wetlands that mimic the functionality of natural wetlands are among the most commonly used NBS for treating domestic wastewater. They use wetland vegetation, soils and their associated microbial functions to remove excess nitrogen, phosphorus, potassium and organic pollutants. Both natural and constructed wetlands also biodegrade or immobilize a range of emerging pollutants. Among 118 pharmaceuticals monitored in conventional wastewater treatment influents and effluents, nearly half were removed only partially with an efficiency of less than 50% (UNESCO/HELCOM, 2017). Studies have demonstrated that constructed wetlands can provide an alternative solution for the removal of emerging pollutants from domestic wastewater and thereby effectively complement conventional wastewater treatment systems. The effectiveness of constructed wetlands to remove various pharmaceuticals has been demonstrated in Ukraine (Vystavna et al., 2017; UNESCO, forthcoming) (Box 3.3), as well as by other studies at pilot scale (Matamoros et al., 2009; Zhang et al., 2011) and full scale (Vymazal et al., 2017; Vystavna et al., 2017). These results suggest that, for some of these emerging pollutants, NBS work better than grey solutions and in certain cases may be the only solution.

NBS can also increase the quality of reclaimed water through managed aquifer recharge (MAR) (see Section 4.2.3), where the quality of partially treated wastewater is improved by biophysical processes as it infiltrates through soils and sediment (Box 3.4).

3.2.4 Reducing the impacts of industry on water quality

The opportunities for NBS for industrial wastewater treatment depend on the pollutant type and its loading. For many polluted water sources, grey infrastructure solutions may continue to be needed. However, industrial applications of NBS, particularly constructed wetlands for industrial wastewater treatment, are growing. A review of 138 applications in 33 countries made clear that constructed wetlands have been used for many types of industrial effluents (Vymazal, 2014). During the last two decades, constructed wetlands applications for wastewater treatment have been demonstrated on industrial effluents like petrochemical, dairy, meat processing, abattoir, and pulp and paper factory effluents. Applications to wastewaters from breweries, tanneries and olive mills have been recently added (Vymazal, 2014; De la Varga et al., 2017).

Constructed wetlands have gained a place in dairy wastewater treatment as being particularly suitable for the treatment of wastewater from dairy parlours, cheese production, other food industries and wineries (De la Varga et al., 2017). NBS for managing industrial wastewater often provide a 'win-win' situation for industry and stakeholders, by creating a number of socio-economic co-benefits (see Section 3.4).

BOX 3.3

REMOVAL OF PHARMACEUTICALS IN A CONSTRUCTED WETLAND IN UKRAINE

A study on the removal of pharmaceuticals in a pilot-scale constructed wetland in Ukraine, under the UNESCO International Initiative on Water Quality case study on *Emerging Pollutants in Water and Wastewater of East Ukraine: Occurrence, Fate and Regulation*, indicates the high potential of constructed wetlands to remove pharmaceuticals from wastewater, with removal rates for different pharmaceuticals ranging from 5 up to 90% (see Figure). The study furthermore examined the relationship between pollutant removal rates and operating conditions of the wetland, by comparing measurements at the beginning of the wetland operation in 2012 and three years later in 2015, after changing its operational settings (the increase of the water residence time, the growth of the macrophytes cover and the installation of the aeration system). After the change of the operational settings, the removal efficiency of most pharmaceuticals increased (see Figure).

Figure | Removal rates for different pharmaceuticals in a pilot-scale constructed wetland in different operating conditions in 2012 and 2015



Source: Based on UNESCO (Forthcoming).

The constructed wetland was even more efficient in removing difficult compounds such as carbamazepine and diclofenac – pharmaceuticals that are among those detected in highest concentrations in treated wastewater. Since such a high removal efficiency could also be attributable to different management parameters of the wetland, further studies are needed to establish the relationships between the constructed wetland maturation and the pollutant removal rate.

Sources: Vystavna et al. (2017); UNESCO (Forthcoming).

Contributed by Yuliya Vystavna (Czech Academy of Sciences), Yuriy Vergeles (National University of Urban Economy, Ukraine) and Sarantuyaa Zandaryaa (UNESCO-IHP).

BOX 3.4

ENHANCING GROUNDWATER SUPPLIES AND WATER QUALITY BY USING SOILS FOR TERTIARY TREATMENT OF WASTEWATER IN ISRAEL

The secondary-treated effluent of the Shafdan wastewater treatment plant is infiltrated into the sandy coastal plain of Israel where its quality improves further as it infiltrates into the aquifer for subsequent recovery. Annually, about 110–130 million m^3 of effluent are diverted to five infiltration basins (each with about ten sub-basins) that are flooded in cycles of three to five days, with a drying period of one day. The effluent is then recovered from two rings of production wells surrounding the infiltration basins. Through soil aquifer treatment, the water quality is significantly improved and used for unrestricted irrigation, increasing thus the water availability in the arid regions of Israel.

Source: Goren (2009).

Contributed by Catalin Stefan (Technical University of Dresden, through GRIPP: gripp.iwmi.org*/).*

3.3 Nature-based water quality monitoring – biological monitoring

Although not strictly an NBS as specifically defined in this report (see Chapter 1), biological monitoring is an important and useful tool that uses aquatic organisms (invertebrates, algae and fish) and changes in their behaviour, resulting from external pressures such as a change in the quality of water, to monitor water quality, thus contributing to the achievement of water quality management objectives. Biological monitoring provides relatively low-cost solutions for water quality monitoring that can help to fill water quality data and information gaps. Biological monitoring, or biomonitoring, using indicator species sensitive to a wide range of stressors such as pollutants, can be highly effective in supporting local water management. Biomonitoring tools have over the years been included as part of water resource management practice, not only for water quality monitoring but also as indicators of general aquatic ecosystem health. Biomonitoring is also integrated in modern water quality monitoring techniques (Box 3.5).

Being a direct measure of the health of the ecosystem, biomonitoring is highly intuitive to the lay public and can thereby also contribute to awareness-raising among communities (Aceves-Bueno et al., 2015). In South Africa, for example, the mini-stream assessment scoring system (mini-SASS)[10] is used for community-based water quality monitoring and stewardship, supporting participatory management of water resources (Graham et al., 2004). It also provides a tool for citizen monitoring, which together with traditional knowledge is gaining increasing attention in water management, particularly as developments in sending technology, data processing and visualization have improved (Lansing, 1987; Huntington, 2000; Minkman et al., 2017; Buytaert et al., 2014).

South Africa provides an example where biomonitoring has been used extensively. Based primarily on monitoring of invertebrates using the SASS index (Dickens and Graham, 2002), supplementary biological indicators have been developed based on fish, riparian vegetation and diatoms, which have been incorporated into South Africa's River Eco-Status Monitoring Programme, involving two government departments, a research agency and a number of civil society organizations, thereby providing an example of the participatory management of water resources (DWA, n.d.). Biological indicators are furthermore used in South Africa for river health monitoring; reporting on the state of the environment; as input for the determination of environmental flows or water requirements; for the classification of water resources into management classes; and for setting resource quality objectives which are legally binding on all government departments. Biological measures of ecosystem health have also been included in SDG Target 6.6 on water-related ecosystems.

[10] For more information, see www.minisass.org.

BOX 3.5

USING *DAPHNIA* AND *ALGAE* TO MONITOR WATER TOXICITY AND EARLY DETECTION OF POLLUTION SURGES – RHINE WATER QUALITY STATION IN WORMS, GERMANY

Aquatic organisms are used to monitor the overall health status and water quality of the Rhine River, both in the river water (*in situ*) and in laboratory analyses (*ex situ*) in the Rhine Water Quality Station, Germany. A freshwater crustacean *Daphnia* is used in 'alarm' water toxicity monitoring for its toxicological reactions to water pollutants. As toxicological reactions of *Daphnia* to a particular pollutant, or to a high pollution load, is relatively quick, it allows for an early detection of unusual pollution incidents. Early detection of such water pollution is important for immediate measures needed for the protection of the drinking water supplies and ecosystems from toxic or high pollution loads. The Rhine water quality control station also uses *algae* as a biotest for an online (30-minutes interval) monitoring of toxic substances such as herbicides.

Contributed by Sarantuyaa Zandaryaa (UNESCO-IHP)[*].

[*] Personal communication with the Rhine Water Quality Station team. For more information, see www.rheinguetestation.de/

3.4 Co-benefits and limitations of NBS for water quality

3.4.1 Environmental and socio-economic co-benefits

Mainstreaming NBS in water quality management provides not only promising cost-effective solutions, but also additional environmental and socio-economic benefits from the same investments.

Environmental co-benefits of NBS for water quality include protecting and enhancing biodiversity, and reducing or reversing the trend in the loss and degradation of terrestrial and aquatic ecosystems and their services (enhanced water availability and ecosystem services). Improved water quality offers environmental benefits that can extend into downstream coastal areas, which can suffer from eutrophication linked to excess nutrients in upstream watersheds, and often beyond by supporting improved ocean health. NBS for water quality offer also additional functionality and services, including habitat improvement, carbon sequestration, soil stabilization, groundwater recharge and flood mitigation (Haddaway et al., 2016).

The **socio-economic benefits** of improved water quality are related to reducing public health risks and enhancing economic development and/or sustainable livelihoods

– especially for rural areas and communities – thus contributing to the reduction of social inequalities affecting women, disadvantaged groups, the poor and people living in slums/informal settlements. In general, the poorest people may have the most to gain from NBS for improved water quality, especially where they lack access to improved water sources and are at risk of food insecurity. However, implementing NBS for water quality management generates additional co-benefits that would not necessarily be provided by grey solutions alone. One example is job creation, including jobs that are directly linked to the implementation of the NBS themselves.

3.4.2 Limitations of NBS for water quality

NBS provide promising applications as alternative or complementary water quality management interventions. Yet, there are still challenges and limitations, which can hamper their widespread use in some applications. Technical limitations of NBS are their limited capacity to remove certain pollutants, especially in industrial and mining applications where effluents have high concentrations. While there is evidence, for example, that wetlands can remove 20–60% of metals in water and trap and retain 80–90% of sediment from runoff, there is less information on the capacity of many wetland plants to remove some toxic substances associated with pesticides, industrial discharges and mining activities, although some wetland plants have been found to accumulate heavy metals in their tissues at 100,000 times the concentration found in the surrounding water (Skov, 2015). It is therefore necessary to recognize the limited carrying capacity of ecosystems and to determine the thresholds where the addition of contaminants and toxic substances will lead to irreversible damage.

Another limitation can be the longer retention time required to remove some pollutants. Research shows that the relatively slow passage of water through wetlands can provide sufficient time for pathogens to lose their viability or to be consumed by other organisms in the ecosystem. However, there is also the potential for accumulation for toxic substances in wetlands, in effect turning wetlands into potential 'hotspots' where high levels of contamination can prove detrimental to wetland ecosystem functioning and health (Skov, 2015). Consequently, hybrid approaches, where NBS complement conventional water treatment technologies, can provide suitable solutions, especially to reduce heavy nutrient loading. As NBS may require longer retention times, they need to be balanced with the rate of conventional treatment, maybe involving larger ecosystems areas, and corporate and regulatory requirements (see Chapter 6).

NBS can support the delivery of water services in ways that are complementary and integrated with conventional water infrastructure (UNEP-DHI/IUCN/TNC, 2014). Therefore, it is important that NBS, both for water quality and other water management goals, are considered in conjunction with other options, based on standardized approaches to potential costs and benefits. This should include due consideration to the wide array of

Technical limitations of NBS are their limited capacity to remove certain pollutants, especially in industrial and mining applications where effluents have high concentrations

environmental and socio-economic co-benefits (including the increased capacity to adapt to a changing climate) that NBS deliver in addition to the primary water quality benefits. Combining NBS and grey infrastructure in water management plans also enhances the sustainability of the grey water infrastructure.

Broader stakeholder involvement and community participation is important in the implementation of NBS, especially the involvement of those whose livelihoods depend on the goods and services provided by landscapes. As NBS for water quality and their specific applications depend on many factors, there is a challenge related to the lack of well-established historic evidence of positive impacts of NBS, allowing for comparisons with other solutions. This may increase the perceived risk or level of uncertainty of such projects, compared to the well-established performance of conventional water treatment technologies (UNEP-DHI/IUCN/TNC, 2014). Filling this information gap is key for enabling NBS for water quality to stand on equal footing with that of conventional alternatives.

These limitations of NBS in water quality management applications can be reduced by:

- improving the knowledge base and promoting research and innovation on NBS for managing water quality, including testing NBS in different hydrological, environmental, socio-economic and management conditions;
- enhancing capacity by sharing and disseminating knowledge and developing educational programmes focusing on NBS as an integral part of water quality management;
- incorporating NBS in policies and legal and regulatory frameworks on water quality management, encouraging investment in and implementation of NBS;
- promoting private sector investment in NBS through examples that make the business case for NBS for managing water quality (Box 3.6; see also Section 5.2.2); and
- collaborating with civil society to raise awareness on the potential of NBS for water quality management, advocating for policy changes supporting NBS and promoting NBS to political leaders.

3.5 The potential for NBS to contribute to water quality-related SDGs

The range of benefits and 'co-benefits' provided by NBS for managing water quality have significant potential to contribute to the achievement of the SDGs, enabling societies to transition to sustainability. Because improving water quality also improves water availability (for multiple uses), and in some cases reduces water-related risks, there are many potential links across most of the SDGs and their targets.

Table 3.2 provides an overview of only the most obvious and direct linkages between improved water quality and the SDGs where NBS offer particular promise.

SDG 6 ***Ensure availability and sustainable management of water and sanitation for all***: NBS for managing water quality support the achievement of all targets of SDG 6. A wide range of NBS, such as watershed protection for improving water quality in source watersheds and constructed wetlands in order to reduce nutrients and other pollution from different sources, are essential for achieving Target 6.3. NBS may contribute to Targets 6.1 and 6.2 by reducing the human health risks of unsafe drinking water and sanitation through, for example, source water protection and alternative solutions to sanitation, such as ecological sanitation. All NBS for managing water quality are means to implement Target 6.6 in the context of SDG 6.

NBS are particularly prominent in improving the impacts of agricultural systems on water quality and therefore key to achieving SDG 2 (to promote sustainable agriculture, *inter alia*), since reducing impacts on water quality is a key determinant of sustainability in agriculture, particularly regarding Target 2.4. The health benefits (SDG 3) of NBS contributions to improve water quality are self-evident. Likewise, this and other NBS approaches to reducing land-based pollution make a major contribution to conserving and sustainably using the oceans, seas and marine resources (SDG 14), most notably by reducing nutrient inputs (Target 14.1). Green infrastructure (NBS) is an integral part of building resilient infrastructure (SDG 9). In a similar vein, green infrastructure is an essential component of building safe, resilient and sustainable cities (SDG 11).

The environmental co-benefits of NBS to improve water quality are particularly relevant as they contribute to supporting biodiversity and ecosystems in general (SDG 15, in addition to SDG 14 mentioned above). Terrestrial and aquatic ecosystems are intricately connected. Particularly, NBS using ecosystem functions and services through watershed protection, natural or artificial wetlands, reforestation, and buffer land directly support Targets 15.1, 15.2 and 15.4. NBS for water quality, such as buffer strips and riparian vegetative areas, contribute to Targets 15.3 and 15.5 on combatting desertification and land degradation and reducing habitat and biodiversity loss. The implementation of NBS for water quality contributes also to Target 15.9: *to integrate ecosystem and biodiversity values into development strategies*.

Additional linkages can be made to SDG 7 (clean energy). As most NBS require very little (if any) external energy, they can reduce energy demands of conventional wastewater treatment technologies. The NBS that improve nutrient and chemical use efficiency in agriculture are particularly relevant to SDG 12 ('Responsible consumption and production'), and similarly NBS to manage urban runoff (heavy metals and chemicals) contribute in particular to Target 12.4 (to reduce the release of hazardous chemicals to water and soil). The environmental and socio-economic benefits resulting from NBS for managing water quality also support SDG 1 (end poverty), and other aspects of SDG 2, through, for example, enhancing livelihoods, especially in rural areas.

BOX 3.6 WATER FUNDS AS A MEANS TO IMPLEMENT NBS FOR SOURCE WATERSHED PROTECTION

Water funds are institutional platforms developed by cities and conservation practitioners that can address governance issues by bridging scientific, jurisdictional, financial and implementation gaps. Research over the past 15 years has demonstrated their ability to enable downstream users to invest in upstream habitat protection and land management to improve water quality and quantity, with successful cases, for example, in Quito, San Antonio (Texas) and recently in Nairobi (Abell et al., 2017). The Nairobi Water Fund aims to demonstrate how investments in NBS in the Upper Tana watershed, which covers approximately 1.7 million ha and supplies 95% of Nairobi's drinking water, can create a twofold return on investment. A business case found that a US$10 million investment in water fund activities, such as riparian buffers, reforestation and implementation of improved agricultural practices, could be expected to return an estimated US$21.5 million in economic benefits over a 30-year timeframe (TNC, 2015).

Contributed by Elisabeth Mullin Bernhardt (UN Environment).

Table 3.2 Water quality in the SDGs

SDG	Target	
SDG 6 **Water and sanitation**	6.1	Achieve universal and equitable **access to safe and affordable drinking water** for all
	6.2	Achieve **access to adequate and equitable sanitation** and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
	6.3	I**mprove water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally**
	6.6	**Protect and restore water-related ecosystems**, including mountains, forests, wetlands, rivers, aquifers and lakes
SDG 1 **Poverty**	1.4	Ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as **access to basic services**, ...
SDG 2 **... promote sustainable agriculture**	2.4	... ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems ... and that progressively improve land and soil quality
SDG 3 **Health**	3.3	End the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, **water-borne diseases** and other communicable diseases
	3.9	Substantially reduce the number of deaths and illnesses from hazardous chemicals and air, **water and soil pollution and contamination**
SDG 7 **Clean energy**	7.3	Double the global rate of improvement in energy efficiency
SDG 9 **Build resilient infrastructure...**	9.4	... upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes ...
SDG 11 **Sustainable cities**	11.3	... enhance inclusive and sustainable urbanization ...
	11.6	... reduce the adverse per capita environmental impact of cities ...
SDG 12 **Sustainable consumption and production**	12.4	Achieve the environmentally sound management of **chemicals and all wastes** throughout their life cycle, in accordance with agreed international frameworks, and significantly r**educe their release to air, water and soil** in order to minimize their adverse impacts on human health and the environment
SDG 14 **Conserve and sustainably use the oceans, seas and marine resources for sustainable development**	14.1	... prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
SDG 15 **Ecosystems**	15.1	Ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

Source: Adapted and updated from UNESCO (2015a, p. 7).

4 NBS FOR MANAGING WATER-RELATED RISKS, VARIABILITY AND CHANGE



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With contributions from[11]: Peter Burek (IIASA); Karen Villholth, Matthew McCartney and Paul Pavelic (IWMI); Daniel Tsegai (UNCCD); Tatiana Fedotova (WBCSD); and Giacomo Teruggi (WMO)

Flooded wastewater treatment plant after Hurricane Harvey (USA)

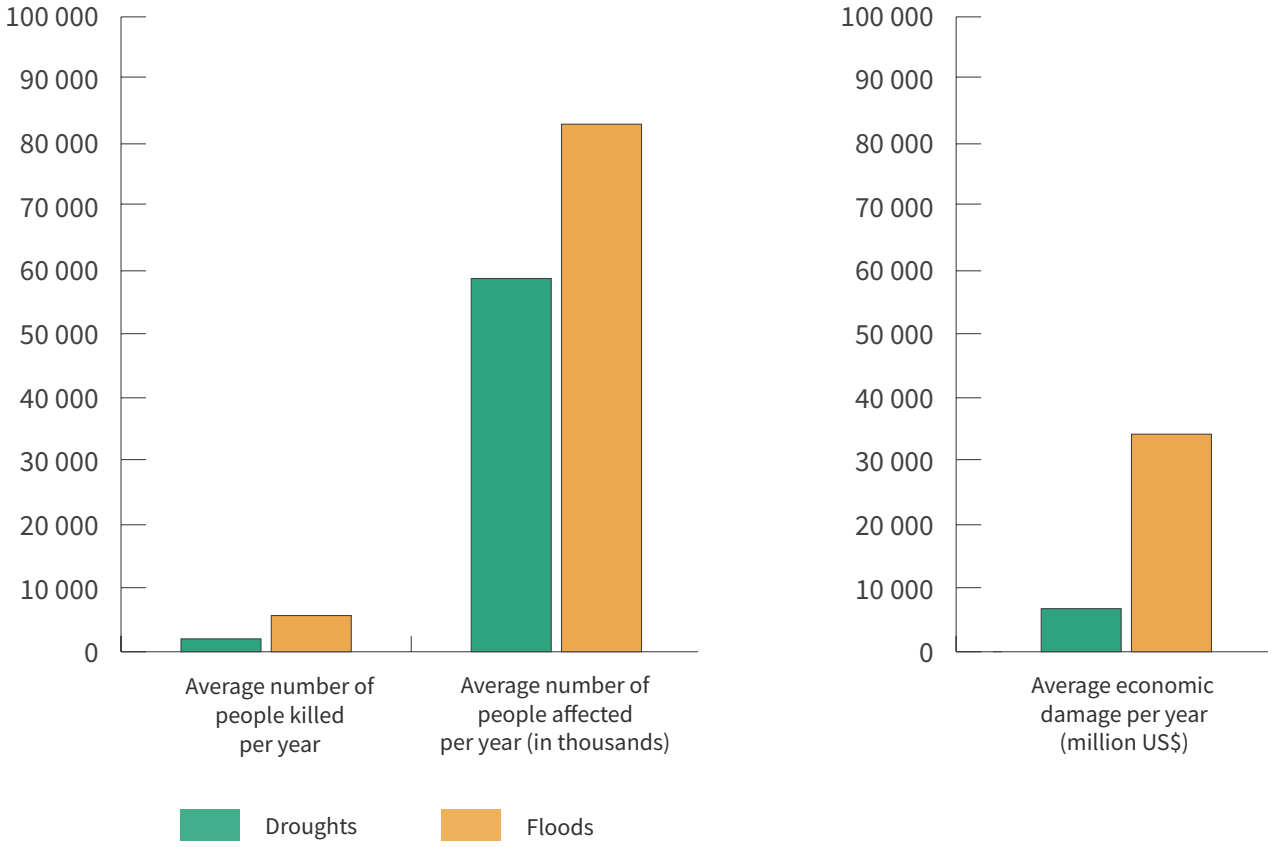


4.1 NBS in the context of water variability and change, and global sustainable development agreements

Water resources variability has a significant impact on development (Hall et al., 2014). Around 30% of the global population is estimated to reside in areas and regions routinely impacted by either flood or drought events – the major water-related disasters through which water variability manifests itself. According to the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED, n.d.), who analysed the data for the ten-year period of 2006–2015 as summarized in the World Disasters Report (IFRC, 2016), about 140 million people are affected, and worldwide close to 10,000 people die from water-related disasters annually (Figure 4.1). If extreme temperatures are combined with droughts, or storms with floods, the numbers of casualties almost triples. To put this in context, the average number of annual water-related disaster deaths from floods and droughts together is in the same range as the number of annual deaths from terrorism, while the number of people affected by floods and droughts (displaced, having lost their income or home, etc.) is about five times more that the number of people living with HIV. Average global economic loss from floods and droughts is over US$40 billion per year across all economic sectors. Storms add another US$46 billion in economic losses annually, on average. The number of deaths, affected people, and economic losses varies significantly by year and continent, with Africa and Asia being the most affected in terms of all three indicators. These numbers are projected to increase to US$200–400 billion by 2030, according to various estimates. Such losses strongly affect water, food and energy security and consume most of the current total development aid flow (OECD, 2015a).

[11] Authors would like to thank Sarah Davidson of WWF-US for helpful comments.

Figure 4.1 Average annual impacts of droughts and floods globally, 2006–2015



Source: Based on data from CRED (n.d.).

Climate change modifies (and has already modified) the pattern of global runoff (Milly et al., 2005), with some studies suggesting an increase of global runoff of approximately 4% by 1 °C global temperature rise (Labat et al., 2004). But most importantly, climate change increases the frequency, intensity and severity of extreme weather events (O'Gorman, 2015), which may result in increasing frequency and magnitude of water-related extremes (IPCC, 2012; Mazdiyasni and AghaKouchak, 2015). Although the uncertainties associated with climate projections do not yet in many cases allow for robust quantitative statements about climate change impacts on water at large, and on water variability in particular, some historic evidence and projections suggest that flood hazards may intensify, particularly in parts of South, South-East and North-East Asia, as well as tropical Africa and South America – due to changes in precipitation patterns affecting the hydrological cycle. Hirabayashi et al. (2008) illustrated that the frequency of floods will increase in most regions, except for North America and central to western Eurasia. The frequency of droughts is also projected to increase globally, with only northern high latitudes, eastern Australia and eastern Eurasia showing decrease or no significant changes. Several regions are projected to have increases in both flood and drought frequency.

Not all water resources variability arises from natural climate variability or anthropogenic climate change. As noted in the Prologue, ecosystem degradation, through for example land use change, wetlands loss and land degradation, is an important driver of increasing water-related risk and in many cases the leading cause of risk and disasters. This implies that ecosystem restoration should be a primary response to reducing those risks, through applying NBS.

Agriculture is perhaps the economic sector that is most affected by increasing variability of water resources globally, and certainly the most vulnerable in socio-economic terms due to the dependency of rural communities in developing countries. It absorbs on average 84% of adverse economic impacts of droughts, and 25% of all damages from climate-related disasters (FAO, 2015). Scientists, farmers and even the business community consider variability, casted as 'extreme weather events', as one of the most likely production risks over the next ten years (WEF, 2015). The welfare gains obtained from only mitigating hydrological variability at large by securing water to existing irrigators globally was assessed at US$94 billion for 2010 (Sadoff et al., 2015).

Damages to various industries and urban infrastructure, particularly from catastrophic flooding, are equally significant. The US$43 billion in economic losses and US$16 billion insured losses due to the 2011 flooding in Thailand had a pronounced impact on the insurance industry and on foreign direct investment (Munich Re, 2013). Uncertainties in flood damage estimates, however, can be large (Wagenaar et al., 2016).

At the same time, water variability (i.e. the natural seasonal flow regime and the flooding associated with it) provides significant socio-ecological benefits, for capture fisheries and flood recession agriculture, for example. These benefits in large deltaic systems, such as the Mekong Delta, may be one or two orders of magnitude higher than annual costs of damage from extreme floods (MRC, 2009). Similarly, it is the seasonal variability in rainfall that creates opportunities for water storage, using either green or grey infrastructure, to provide water for both ecosystems and people over drier periods. Hence, managing variability is not about eliminating it, but rather minimizing damages and maximizing the opportunities it provides. This dichotomy is best addressed through NBS. In addition, climate change exerts its impacts primarily through ecosystems and hydrology. Therefore, the primary response to both progressive change and variability of water resources and flows is ecosystem-based adaptation – a concept that translates into a range of NBS.

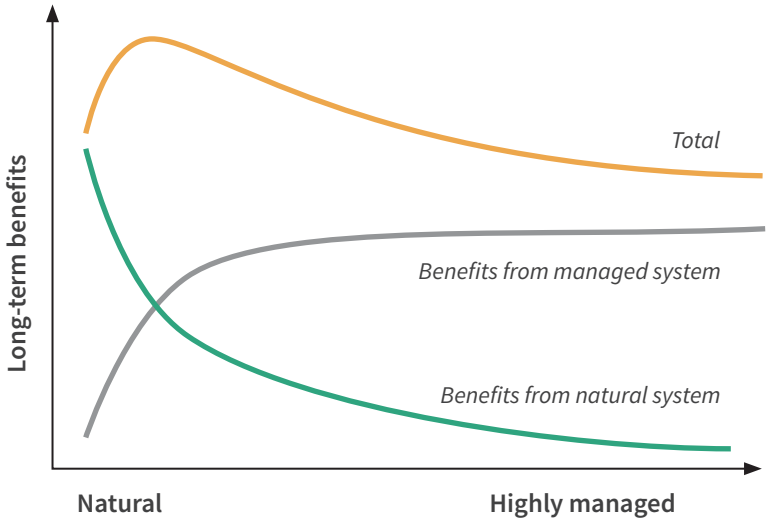
Some recent trends, like increasing water surface storage development on the one hand, and ageing water infrastructure on the other, point to a need for innovative solutions that embed ecosystem services' perspectives, resilience and livelihood considerations more prominently in planning and management processes that explicitly address water variability. These needs are exacerbated by rapid population growth, urbanization and other increasing pressures on water resources. Large grey water infrastructure is seen by many countries as the solution to dealing with water resources variability, particularly as climate change-induced increases in variability are anticipated. Hence, more large grey infrastructure (such as dams and flood protection embankments) is being built and planned. The ageing existing grey infrastructure adds an additional challenge – that it might not be in line with the vision according to which it was designed, nor effective since the hydrological parameters on which it was designed are now changing. The appropriate response is to recognize the significant risk reduction benefits that ecosystems and green infrastructure offer and to design green and grey infrastructure in tandem to maximize system performance and achieve greater benefits for people, nature and the economy. Such is the essence of an NBS approach.

Many SDG targets address various aspects of water-related disaster management and variability, either explicitly or implicitly. Target 1.5 aims to *"build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to ... shocks and disasters"*. Targets 2.4 and 9.1 focus on 'resilient agricultural practices' and 'resilient infrastructure', respectively. Target 11.5 aims to *"reduce the number of deaths and the number of people affected, … decrease the direct economic losses … caused by disasters, including water-related disasters, with a focus on protecting the poor and … vulnerable"*. Target 13.1 is to "*strengthen resilience and adaptive capacity to climate-related hazards and natural disasters ...*", while Target 15.3 aims to *"restore degraded land…, including land affected by desertification, drought and floods"*. There are obvious synergies between these targets (UN-Water, 2016b) and these synergies may only become stronger if NBS are seen as the supporting concept to all of them.

Many international policy fora and initiatives noted the need to move away from a reactive approach to floods to pre-emptive ones, i.e. risk reduction. It is in the flood risk reduction area that NBS are perceived to excel. The concept of 'living with floods', which, among other things, includes a range of structural (and non-structural) approaches that help to 'be prepared' for a flood, can facilitate application of relevant NBS to reduce flood losses and, most importantly, risk (see Section 5.4). In addition to the 2030 Agenda for Sustainable Development, the Sendai Framework for Disaster Risk Reduction (2015–2030) also calls on relevant UN agencies to strengthen existing and implement new global mechanisms to raise awareness and improve understanding of water-related disaster risks and their impact on society, and to advance strategies for DRR (UNISDR, 2015). This framework also recognizes the need to shift from primarily post-disaster planning and recovery to proactive reduction of risks to prevent disasters taking place. It stipulates that strategies should also consider a range of ecosystem-based solutions. If widely implemented, NBS could therefore shift the way water resources are managed, especially in the context of high-impact floods and droughts. The primary role of NBS here is to increase resilience in order to reduce the likelihood that a disaster will happen, although they can also play a role in post-disaster recovery. NBS should be part of the planning and preparatory actions that are required for decreasing disaster risk, vulnerability and exposure, and for increasing societal resilience when and after disaster strikes.

NBS are also reflected upon in the New Urban Agenda (NUA), a framework for urban sustainability adopted in 2016 in the awareness that by 2050, urban populations will double and expand to 70% of the global population. The NUA aims to influence how cities are planned, designed, financed, developed, governed and managed. Specifically citing links to the SDGs, NUA touches on water and NBS: e.g. paragraph 101 references water and NBS, while paragraph 157 references nature-based innovation (UNGA, 2016). However, how exactly this complex agenda can and will be managed, rolled out and implemented remains to be seen. Finally, the 2015 Paris Agreement on Climate Change (UNFCCC, 2015) puts a very significant emphasis on adaptation, which by all means will not be possible without rolling out a range of NBS that deal with increasing water variability and extremes induced by changing climate.

Figure 4.2 Changes in benefit flows with ecosystem modification



Source: Acreman (2001, fig. 3).

4.2 Examples of NBS to moderate risks, variability and change

Most of the water resources management interventions have an element of NBS in them (UNEP-DHI/IUCN/TNC, 2014) and the same is true for interventions that deal with management of water variability and change. When a natural (e.g. aquatic) ecosystem is modified, some of the 'natural benefits' extracted from it are lost, but can be replaced by benefits from modifications. However, there is a 'tipping point' (which is very difficult to identify) in this process where the sum of all benefits reaches the maximum, and further modifications will only decrease the total flow of benefits (Acreman, 2001; Figure 4.2). Accordingly, NBS may be located in any part of this spectrum ranging from 'purely natural' (an unmodified wetland that may have a natural, even if limited, capacity to regulate flows), to a concrete dam built across a natural river, but with ecologically relevant components and operating rules, like dedicated releases for environmental purposes.

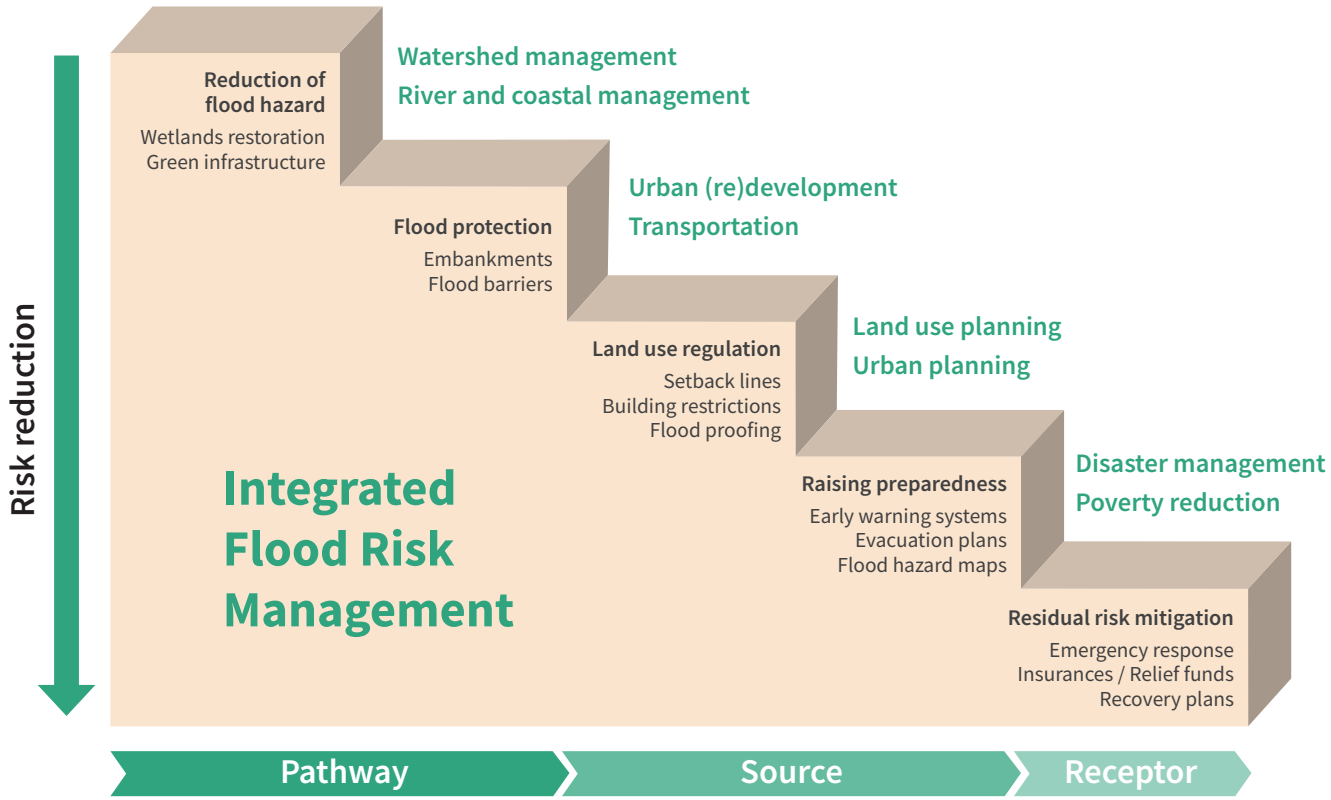
Various NBS exist at various stages of development and implementation, ranging from conceptual approaches and general guidelines to commonly adopted practices. They are all important and useful in their own right as they either have already demonstrated their potential, or will demonstrate it when adopted.

4.2.1 NBS for flood management

One example of a holistic NBS framework is the WWF's *Natural and Nature-Based Flood Management: A Green Guide* (or *Flood Green Guide* – FGG; WWF, 2017). FGG supports communities at a local level in using NBS for flood risk management. It suggests that flood risk management measures should be site-specific, integrated and balanced across all sectors concerned, and based on the concept of integrated flood management defined by the Associated Programme on Flood Management (WMO, 2009), a joint programme of the World Meteorological Organization (WMO) and the Global Water Partnership (GWP). The key principles of the FGG are:

- design flood management methods to maximize the net benefits of floodwaters while minimizing flood risk, since flooding can be a natural and beneficial process;
- apply flood risk management with a watershed perspective to understand how a particular community's flood risk relates to the rest of the watershed;
- consider non-structural methods in flood management, and then if needed include structural, natural, nature-based or hard engineering, as part of an integrated approach;
- recognize the multiple social, economic, environmental and political aspects affected by flood management in a watershed;
- integrate flood risk reduction and adaptation to a changing climate into flood recovery and reconstruction, so that flood recovery improves community resilience to future extreme events, avoids introduction of new social or environmental vulnerabilities, and enhances community adaptation capacity to climate uncertainties;
- support social equity and comply with local/national laws and institutions, including informal social norms and customs during decision-making processes; and
- strengthen resilience processes and livelihoods, and empower women and/or disadvantaged social groups.

Figure 4.3 An illustration of the WMO SPR concept



Source: Adapted from WMO (2017, fig. 4, p. 14). Courtesy of Giacomo Teruggi (WMO).

Flood management, as any type of disaster management, considers several interlined components: vulnerability and exposure to floods, combined with the hazard, result in the overall flood risk. One way to illustrate this is the WMO source to pathway to receptor (SPR) concept (WMO, 2017). The SPR allows the distinction between flood hazards, pathways resulting in exposure of 'receptors', and consequences of floods to people and property. NBS can play a role in the source (e.g. through wetland restoration or land use practices) and in the pathway (e.g. through various ways of increasing conveyance and storage capacity) (Figure 4.3).

Burek et al. (2012) is an example of a large-scale, regional analysis of the potential that NBS may have in flood risk reduction. Using a simulation modelling approach, the study evaluated the effectiveness (in terms of flood peak reduction) of a large range (25) of Natural Water Retention Measures (NWRM) in Europe, aggregating them into several major scenarios/portfolios. The cost of implementation was also assessed. The study illustrated that NBS could reduce 1:20 year flood peaks by up to 15% locally, although at a regional level, peak flow reductions of only 4% were observed. Although at first sight such reductions might seem small, only a few percentage points can make the difference between a flood and a disaster. NBS were found to be able to reduce flood peaks more effectively for smaller catchments and for lower return periods (floods that occur more frequently). At the same time, the study noted cases when NBS could locally increase flood peaks. This points to the need for NBS to be carefully located and designed.

For the UK, the most effective measures were found to be the 'green city' scenario (a combination of measures in urban areas like green infrastructure, green roofs, rain gardens, park depressions and infiltration devices), followed by improved 'crop practices' (a combination of methods such as mulching and tillage). For the Rhine and Rhone regions, the most effective scenarios were those that reduce the flood peaks along the river, e.g. polders. For the Elbe to Ems region, afforestation, closely followed by crop practice and grassland, were found to be the most effective measures, since a lot of the area has a high potential for land use conversion. For the Po and the Baltic regions re-meandering has the most potential to reduce flood peaks,

> Flood management policies in some countries started to look more closely at solutions that involve working with natural processes

Figure 4.4 Most effective regional NBS measures to reduce flood peaks for a 20-year flood



Source: Burek et al. (2012, fig. VI-1, p. 90).

and it was also found to be quite effective for almost all the other regions. Crop practices was the most effective measure for Iberia, Atlantic France, the Danube River Basin, the Balkan, Southern Italy and Greece. Crop practice was also a quite successful measure for Denmark and Northern Germany (Figure 4.4). Clearly, these examples illustrate that the choice of NBS is, unsurprisingly, dependent on the predominant land use type and social, ecological and hydrological settings.

Flood management policies in some countries started to look more closely at solutions that involve working with natural processes. 'Natural flood management' in the UK, for example, seeks to restore or enhance catchment processes that have been affected by human intervention. Dadson et al. (2017) analysed over 20 types of flood management measures, grouped into three main categories: i) water retention through management of infiltration and overland flow, ii) managing the hydrological connectivity between system components and the conveyance of water through it, and iii) making space for water storage through, for example, floodplains (Table 4.1). The authors summarize the evidence available at present for each of the measures, and attempted a semi-quantitative analysis of the impacts of several flood management interventions on the reduction of flood risk (Figure 4.5).

The summary concludes, among other things, that i) appropriately chosen land-use and land cover interventions can reduce local peak water flows after moderate rainfall events; ii) the evidence does not suggest that these interventions will have a major effect on nearby downstream flood risk for the most extreme events; iii) the evidence available for the downstream effects of upstream land-use changes at large catchment scales is more limited, but at present it does not suggest that realistic land-use changes will make a major difference to downstream flood risk; iv) long-term monitoring is needed to separate the effects of land management from those of climatic variability, without this it is unwise to extrapolate the findings from individual studies to larger scales, or to settings with different soil and vegetation types. (Dadson et al., 2017).

Table 4.1 Catchment-based measures that contribute to flood management

Flood risk management theme	Specific measure	Examples
Retaining water in the landscape: water retention through management of infiltration and overland flow	Land use changes	Arable to grassland conversion, forestry and woodland planting, restrictions on hillslope cropping (e.g. silage maize), moorland and peatland restoration
	Arable land use practices	Spring cropping versus winter cropping, cover crops, extensification, crop rotation
	Livestock land practices	Lower stocking rates, restriction of the grazing season
	Tillage practices	Conservation tillage, contour/cross slope ploughing
	Field drainage (to increase storage)	Deep cultivations and drainage to reduce impermeability
	Buffer strips and buffer zones	Contour grass strips, hedges, shelter belts, bunds, riparian buffer strips, controls on bank erosion
	Machinery management	Low ground pressures, avoiding wet conditions
	Urban land use	Increased permeable areas and surface storage
Retaining water in the landscape: managing connectivity and conveyance	Management of hillslope connectivity	Blockage of farm ditches and moorland grips
	Buffer strips and buffering zones to reduce connectivity	Contour grass strips, hedges, shelter belts, bunds, field margins, riparian buffer strips
	Channel maintenance	Modifications to maintenance of farm ditches
	Drainage and pumping operations	Modifications to drainage and pumping regimes
	Field and farm structures	Modifications to gates, yards, tracks and culverts
	On-farm retention	Retention ponds and ditches
	River restoration	Restoration of river profile and cross-sections, channel realignment and changes to planform pattern
	Upland water retention	Farm ponds, ditches, wetlands
Making space for water: floodplain conveyance and storage	Water storage areas	On- or off-line storage, washlands, polders, impoundment reservoirs
	Wetlands	Wetland creation, engineered storage scrapes, controlled water levels
	River restoration/retraining	River reprofiling, channel works, riparian works
	River and water course management	Vegetation clearance, channel maintenance and riparian works
	Floodplain restoration	Setback of embankments, reconnecting rivers and floodplains

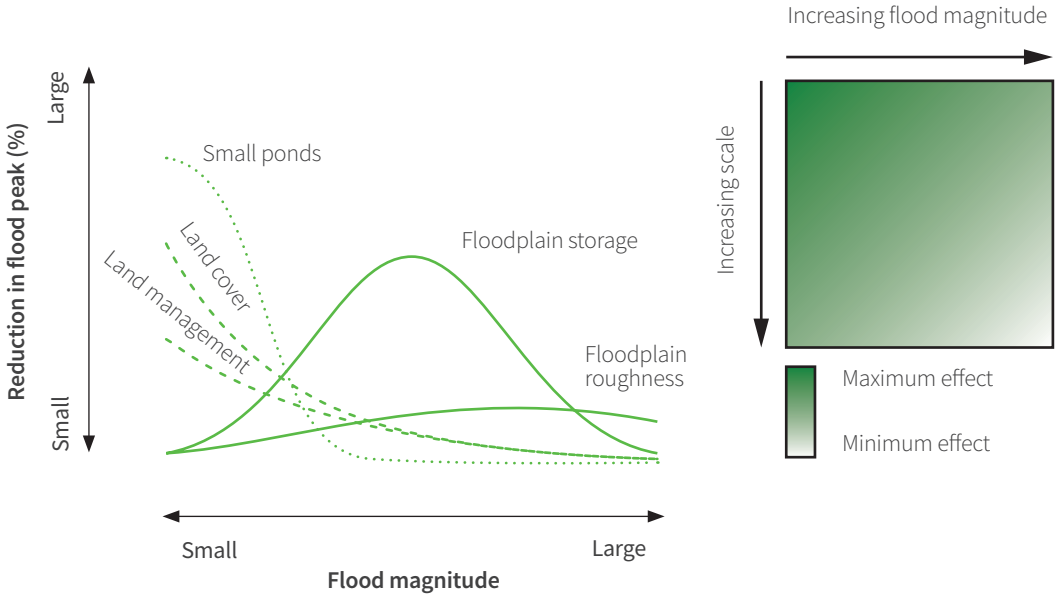
Source: Dadson et al. (2017, table 1, p. 4).

The same is probably true for any other region. Since monitoring programmes are expensive and require long time-frames, some insights on the possible impacts of land use change on flood impacts and risks may be drawn form analyses of a 'shocking land use' change, e.g. associated with warfare (Lacombe and Pierret, 2013). Such studies suggest that large-scale land use change impacts have profound and durable hydrological effects. This knowledge also helps predict the potential impacts that NBS may have on risk reduction, by reversing negative land use change through land restoration.

4.2.2 NBS for drought management

Drought is on the other end of the spectrum of water-related variability. Droughts are usually chronic (building up and persisting in the long term), as opposed to floods, which are acute (short-term and abrupt). Droughts do not only occur in drylands, as is sometimes portrayed, but can also pose a disaster risk in regions that are normally not water-scarce (Smakhtin and Schipper, 2008). Drought is very complex and its global pattern can be described by a range of indicators (Eriyagama et al., 2009). Carrão et al. (2016) is perhaps the most recent and comprehensive analysis of drought

Figure 4.5 **Effect of different NBS interventions on flood peak reduction (left) and combined effect of basin-wide interventions with flood magnitude (right)**



Source: Dadson et al. (2017, fig. 3, p. 18).

risk at the global scale, identifying three independent determinants: hazard, exposure and vulnerability. Drought hazard was derived from historical precipitation deficits, exposure is based on an aggregation of gridded indicators of population and livestock densities, crop cover, and water stress; and drought vulnerability has been computed as the composite of high-level factors of social, economic and infrastructural indicators, collected at both the national and sub-national levels. The maps of hazard and risk (Figure 4.6) illustrate that with proper measures to reduce exposure and vulnerability, drought risk can be considerably reduced even in very drought-hazardous regions like Australia and the Southern USA. It is in these contexts that the role of NBS can be most significant.

> Droughts do not only occur in drylands, as is sometimes portrayed, but can also pose a disaster risk in regions that are normally not water-scarce

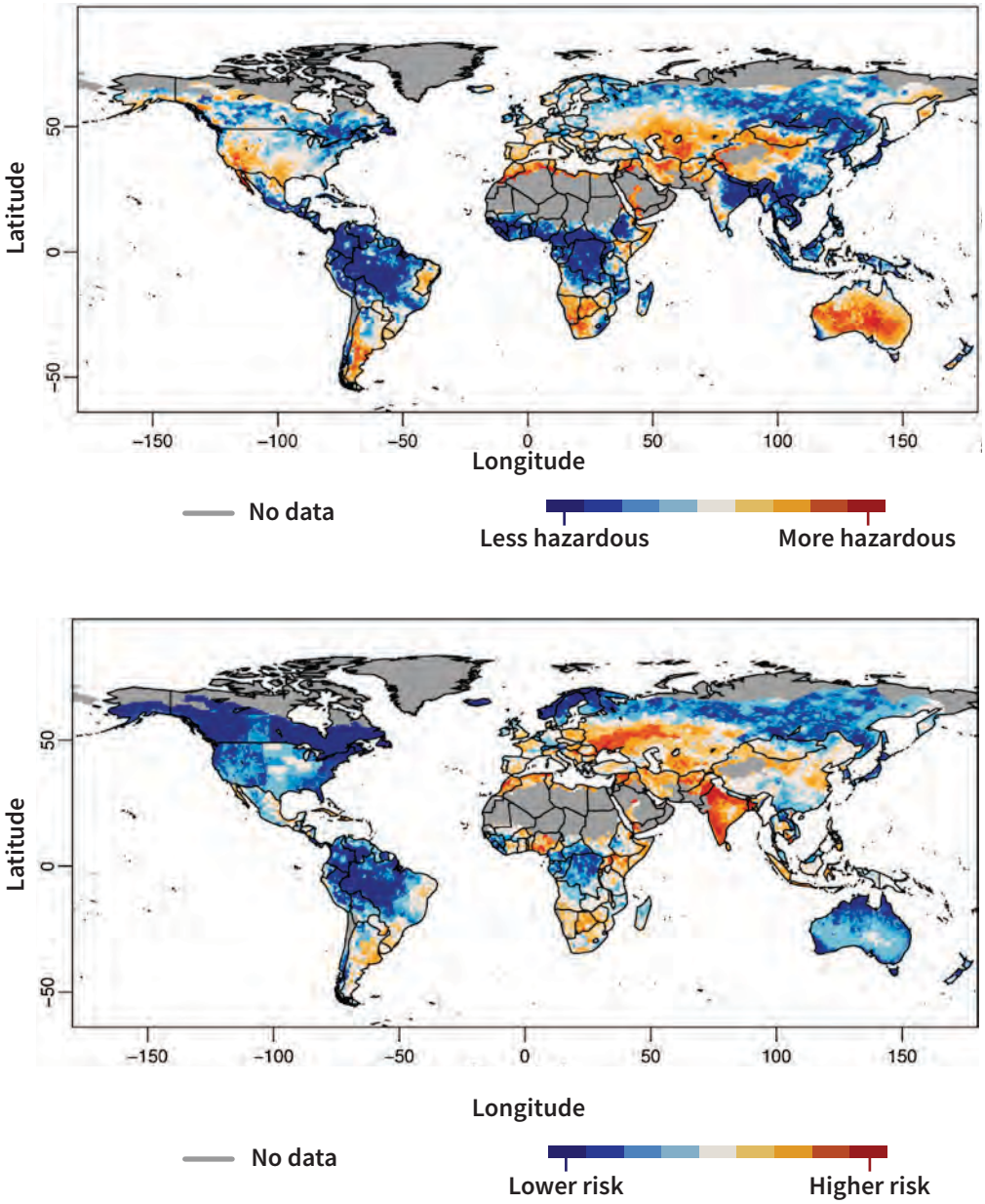
In recent decades, the frequency, intensity and duration of droughts have been steadily increasing, in part due to climate change. In 2015–16, the El Niño weather phenomenon caused the worst and most damaging droughts around the world. According to the USA's National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), 2016 smashed the record for the hottest year since reporting began in 1880. This was due in large part to one of the strongest El Niño events ever recorded (NASA, 2017).

International response to drought focused on 'stop and go' measures which are aimed at reacting. A shift to more proactive and risk-based measures must be promoted (Wilhite et al., 2007). NBS that help alleviate the adverse impacts of droughts are normally multipurpose and may be used in contexts beyond just managing variability and change (Table 4.2). In fact, the mix of potential NBS for drought mitigation is essentially the same as those for water availability (see Chapter 2).

4.2.3 NBS for managing multiple risks

NBS can be used to manage more than one risk and be applicable to both flood and drought risks, for example. As already mentioned earlier (e.g. Table 4.1), wetlands – both natural and constructed – can play a role in reducing disaster risk. Both natural and constructed wetlands demonstrate a capacity for flood management and flood and storm risk mitigation by acting as natural barriers, working as a natural sponge trapping rain and surface runoff, mitigating land erosion and the impact of storm surges (often by diverting surface water into underlying aquifers) or protecting coastlines from storms. As the

Figure 4.6 Global maps of drought hazard (top) and risk (bottom)



Source: Adapted from Carrão et al. (2016, figures 3 and 9, pp. 115 and 120).

frequency of natural hazards increases, understanding the functions of wetlands as NBS can help to augment resilience, both locally and at larger scales.

One example of the massive wetlands' potential as NBS is the case of Yangtze River Basin in China, home to 400 million people, which recorded a large torrential storm in 1998, resulting in 4,000 causalities and US$25 billion in damage. The highlight of the policy response *'32 Character Policy'* of the Chinese government was to restore 2,900 km² of floodplains with the capacity to hold 13 billion m³ (i.e. 13 km³) of water (Wang et al., 2007) as a disaster risk management strategy. A wetland conservation network was established across the Yangtze River Basin to manage the water quality, preserve local biodiversity and expand wetland-based nature reserves (Pittock and Xu, 2010).

Another example is the case of the earthquake and tsunami that struck Chile in 2010, resulting in US$30 billion loss and severely impacting the assets and livelihoods of the coastal wetland communities (Yali National Reserve, Valparaíso) (OECD/UNECLAC, 2016). Post this event, the government announced the protection of the majority of these coastal wetlands as a Ramsar site, acknowledging the large-scale benefits of wetland ecosystems in DRR. Yet another example is Hurricane Katrina, which made history in the USA as the deadliest disaster event (80% of the city flooded; 1,500 casualties and nearly 900,000 people displaced) and highlighted the failure of existing DRR strategies that growingly focused on the city's floodwalls and levees – entirely grey infrastructure. As noted in the Prologue, wetlands loss in the Mississippi Delta, through sediment trapping in upstream dams, was a major factor contributing

Table 4.2 NBS for managing drought risks in the Horn of Africa

Case studies	Interventions – NBS	Outcomes
Improving food and water security in the Abreha we-Atsebeha watershed (Ethiopia)	• Soil and stone bunds, trenches and percolation pits • Erosion gullies converted in water harvesting sites • Springs developed as sources of drinking water • Fruit trees and naturally occurring species planted	• Community food self-sufficiency by transforming degraded land into productive farmland • Improved irrigation systems through water harvesting and storing • Enhanced vegetation cover resulting in better soil quality
Sustainable water resources and livelihoods in the Lake Haramaya watershed (Ethiopia)	• Soil and water conservation measures • Water user regulations, allocation and pricing • Diversified livelihood options • Enhanced agricultural productivity through better seeds, fertilizers and efficient irrigation	• Reduction of water disputes and conflicts through the establishment of water laws to regulate water use • Improved crops and livestock productivity through ponds and higher water use efficiency through drip irrigation • Enhanced societal resilience and vulnerability to drought
Water harvesting for economic empowerment in Kitui County (Kenya)	• Small-scale irrigation • Sunken sand dams • Water storage and distribution structures	• Increased water supply benefited health and livelihoods • Biodiversity conservation and enriched ground water through the construction of sunken sand dams • Reduced potential for conflict over water
Building drought resilience in Aswa-Agago sub-catchment (Uganda)	• Improved water point infrastructures • Water harvesting structures • Environmental conservation • Emergency revolving fund and water user committees	• Improved water quality resulted in a decrease in water-borne diseases • Increased knowledge of environmental conservation measures such as planting multipurpose trees
Restoring water quality in Lake Kako (Uganda)	• Catchment management • Planting trees and other vegetation	• Enhanced capacity to use local material to create technology • Acquired skills in catchment management and conservation of land

Source: Based on GWPEA (2016).

to elevated impacts of the hurricane. Post Katrina, the State of Louisiana Legislature established the Coastal Protection and Restoration Authority, and the City of New Orleans reformulated its building codes to benefit from the risk reduction services of wetlands (Jacob et al., 2008; Rogers et al., 2015).

However, the hydrological functions of natural ecosystems, like wetlands and floodplains, are much less understood than those provided by grey infrastructure. Consequently, they are even more neglected in policy appraisal and natural resource and development planning and management. Natural systems can, in some circumstances, help buffer the negative impact of extreme hydrological events, reducing the risks for people. They do this in two ways. First, by attenuating the immediate physical impacts, and second, by helping people survive and recover in the aftermath of significant events. However, the role that natural systems play is complex. Their effects on water flows and storm surges depend on many factors, including other land features, which vary widely across locations. Moreover, natural systems are dynamic, meaning that their role may change over time. Sometimes, they might mitigate hazards, while under other circumstances they might contribute to the natural processes that generate hazards. For example, headwater wetlands in Southern Africa have been shown to attenuate flood flows at the start of the rainy season when they are relatively dry, but generate runoff and contribute to flood flows later in the wet season when they are saturated (McCartney et al., 1998). The lack of a detailed quantitative understanding of the regulating functions of natural systems and the ways to interpret them in the context of DRR remains the major science gap. It is often unclear which functions exactly are performed and how those functions change over time (i.e. between seasons and between years – cf. Bullock and Acreman, 2003). The lack of both quantitative information and a recognized method to incorporate regulating functions into DRR-related decision-making processes, makes it difficult to develop NBS around them. The added complexity is that it is increasingly difficult to define or even identify 'natural' ecosystems. Most of the ecosystem services in play in DRR processes are coming from managed landscapes – which may or may not include 'natural' elements.

> Restoring the floodplains and constructing new wetlands could help manage hydroclimatic variability and change, and that whas extensive environmental and socio-economic co-benefits

These complexities are illustrated by a recent attempt to evaluate the flow regulating functions of natural ecosystems (i.e. wetlands, floodplains and miombo woodland) in the Zambezi Basin by McCartney et al. (2013). The method developed in this study utilizes observed streamflow records and standard hydrological techniques *"to derive a simulated time series of flow in the absence of an ecosystem. This can then be compared with an observed time series to evaluate the impact of the ecosystem on the flow regime. The method has been applied to 14 locations in the basin. Results indicate that the different ecosystems affect flows in different ways. Broadly: i) floodplains decrease flood flows and increase low flows; ii) headwater wetlands increase flood flows and decrease low flows; iii) miombo forest, when covering more than 70% of the catchment, decreases flood flows and decreases low flows. However, in all cases there were examples which produce contrary results and simple correlations between the extent of an ecosystem type within a catchment and the impact on the flow regime were not found."* (McCartney et al., 2013, p. vii). *"This confirms that effects on flow are a function not just of the presence/absence of different ecosystem types, but also of a range of other biophysical factors, including topography, climate, soil, vegetation and geology. Hence, the hydrological functions of natural ecosystems depend, to a large extent, on location-specific characteristics that make it difficult to generalize"* (McCartney et al., 2013, p. 26). To a large extent, the same applies to grey infrastructure, managed ecosystems/landscapes and to hybrid green–grey infrastructure applications.

Constructed wetlands (see Chapters 3 and 5) – another range of NBS or hybrid solutions – are increasingly used for stormwater treatment, restoration of the natural hydrology of urban catchments, reduction of downstream erosion from stormwater flows and, more recently, as a disaster risk management strategy (Tidball, 2012). It is argued that restoring the floodplains and constructing new wetlands could help manage hydroclimatic variability and change, and that it has extensive environmental and socio-economic co-benefits, as it helps to safeguard against extreme climate events and disasters (Benedict and McMahon, 2001; Beatley, 2011; Haase, 2016). Constructed wetlands are purposely built to perform some specific ecological services like treatment of municipal, industrial and agricultural wastewater, or to provide for recreational spaces and management of urban and rural runoff (TEEB, 2011 and Box 4.1). They therefore have significant relevance to the New Urban Agenda, as they may be applied to moderate the impacts of climate change and climate extremes in urban environments, and protection of low-lying urban areas. Singapore has exemplified this argument to design its climate adaptation and mitigation plan with constructed wetlands and green corridors (Newman, 2010).

BOX 4.1

WATER MANAGEMENT AND FLOOD PREVENTION IN FRANCE – LafargeHolcim

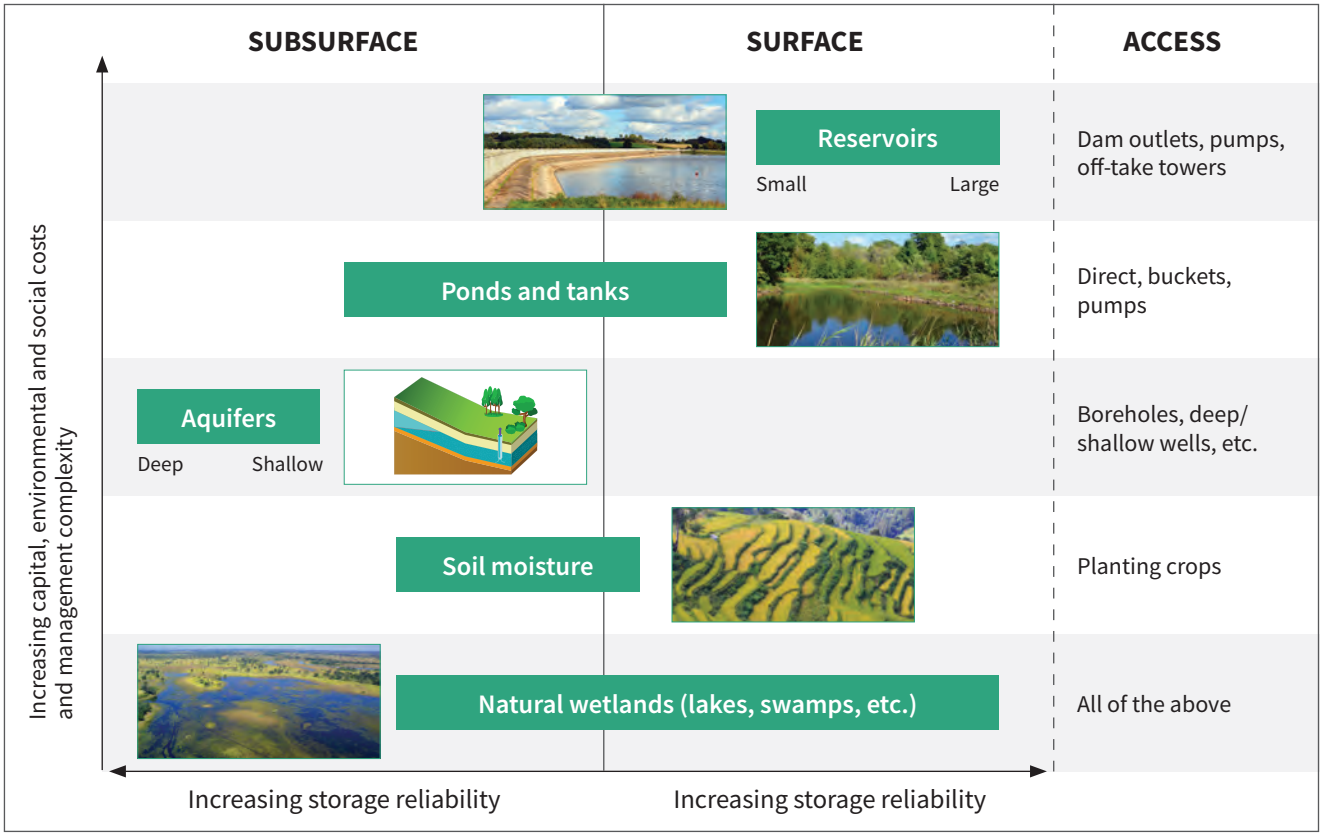
LafargeHolcim – a large building materials company – demonstrated how quarries can be leveraged as water reserves during flood conditions, and that storage capacity in both restored and purposely designed areas in active quarries reduces or prevents flooding. The company worked for over 15 years with the municipality of Bellegarde in the South of France to expand the flood prevention infrastructure and create wetlands that became fully operational in 2015. The extracted quarry areas have been converted into stormwater reservoirs with a total capacity of 2.5 million m³, reducing the risk of flooding in the local communities (see Figure). LafargeHolcim's experience shows that developing quarry rehabilitation schemes with local authorities and communities results in a win-win situation: flood damage is averted, wetland areas that are rich in biodiversity are created, and community recreational areas are developed (WBCSD, 2015c).

Figure | LafargeHolcim quarries in the municipality of Bellegarde, Southern France, converted into stormwater reservoirs



Photo: WBCSD

Figure 4.7 Water storage continuum



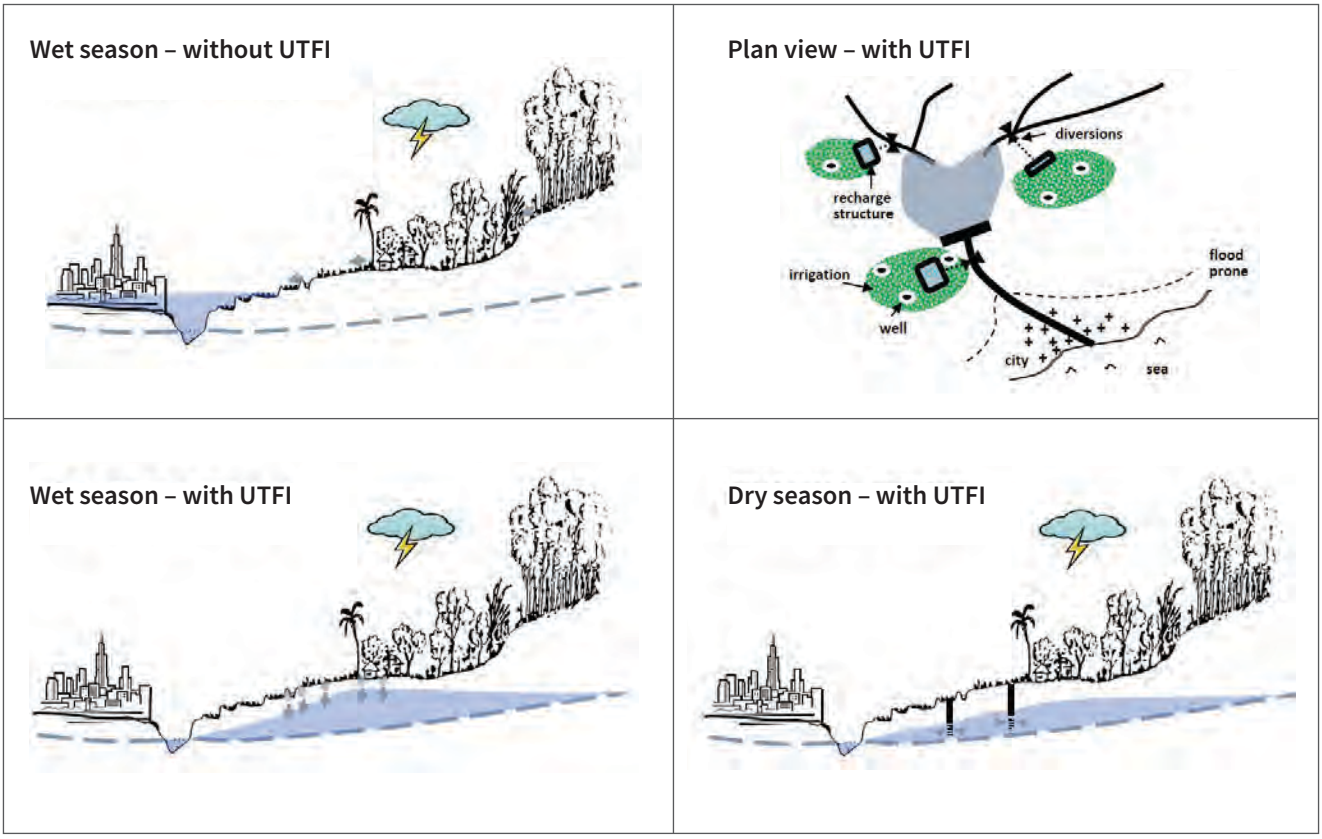
Source: Adapted from McCartney and Smakhtin (2010, fig. 2, p. 5).

The discussions above allude to the need to revisit the overall concept of water storage in the contexts of green and grey infrastructure and DRR. McCartney and Smakhtin (2010) introduced the concept of the water storage continuum (Figure 4.7), suggesting that storage planning at river basin and regional scales should consider a portfolio of surface and subsurface storage options (and their combinations) to arrive at the best environmental and economic outcomes in the face of increasing water resources variability. The NBS concept was an integral component of this approach as the range of storage options considered included various forms of natural storages, such as wetlands and aquifers. Sayers et al. (2014) also recognize that wetlands, dunes, upland storage and infiltration are all legitimate flood management infrastructure and should be used to manage flood waters alongside 'conventional' grey infrastructure, such as embankments and gates. Natural flood management measures will not necessarily provide protection from most extreme events on their own, but can moderate more frequent (and smaller) ones, and reduce the cost of conventional (grey) infrastructure, if used in conjunction with it. At the same time, initial results from a catchment in the UK illustrated that conventional flood defence and natural flood management may deliver comparable benefits, and that benefits attributable to natural flood management interventions increase in more extreme climate futures (Sayers et al., 2014). Overall, a combination of nature-focused, or nature-embedded solutions (such as land use management, wetland storage and floodplain reconnection) and selective "hard path" measures (such as bypass channels, controlled storage, etc.) offers opportunities to simultaneously manage risk and promote ecosystem services.

Groundwater and aquifer-related NBS hold major unrealized potential for alleviating adverse impacts of both floods and droughts in the same region/basin, and impacts of progressive climate change overall. Groundwater has an important environmental role of sustaining river flows and ecosystem services. Groundwater is also becoming an increasingly important resource for human development and economies. Groundwater is more accessible for poor communities than river flow, for example, and less vulnerable to impacts of climate change, such as increasing temperatures. A related aspect is the role of improved soil management (an NBS) for managing infiltration, and therefore both runoff and groundwater recharge, as well as soil moisture retention, which is a particularly important factor regarding water security for crop production.

Aquifers may have a large water storage capacity. This capacity does not only include groundwater already in the aquifers, but also additional water. A groundwater aquifer is a unique buffer to overcome fluctuations of the natural water supply. For example, in areas coping with high seasonal variations, the excess water in wet periods can be stored underground to subsequently improve freshwater availability during dry periods. Underground

Figure 4.8 A schematic summary of the underground taming of floods for irrigation (UTFI) concept



Source: Based on Pavelic et.al. (2012).

storage, enhanced through simple or more technically advanced spreading, recharge or injection methods, provides additional freshwater storage that can increase water security. Such techniques that intentionally enhance natural groundwater recharge by building infrastructure and/or modifying the landscape are collectively known as managed aquifer recharge (MAR). This NBS has the potential to serve various purposes (Dillon et al., 2009; Gale et al., 2006), including maximizing water storage, replenishing depleting aquifers, improving water quality, improving soil quality and providing ecological benefits such as groundwater-dependent plant communities or enhanced downstream river flows.

Aquifer-centric NBS, such as large-scale MAR interventions, may be applied in certain physiographic conditions to alleviate the risks of both floods and droughts in the same river basin. Such sustainable, cost-effective and scalable solutions may be especially relevant in the developing-country context where the vulnerability to water-related disasters and impacts of climate change remains unprecedented. An innovative solution called 'underground taming of floods for irrigation' (UTFI) has been developed specifically for such cases (Pavelic et al., 2012; 2015).

UTFI involves facilitating aquifer recharge to store wet-season high flows in catchments, thus mitigating local and downstream flooding and simultaneously coping with droughts by making additional groundwater available for all human needs, including the intensification of irrigated crop production (Pavelic et al., 2012; 2015). UTFI is a specific application putting the well-established practice of MAR into a much larger-scale perspective, and enabling surface water and groundwater resources within a basin to be managed more holistically. UTFI makes use of natural infrastructure (aquifers) at an unprecedented scale, and hence essentially represents a large-scale 'NBS programme'. Figure 4.8 illustrates this NBS concept by showing the intended transformation from the existing situation (uncontrolled excess runoff during wet periods, which often results in catastrophic downstream flooding – top left), through a range of diversions and MAR structures in a river basin (top right – plan view) that capture this excess water in the aquifers and reduce downstream flooding, avoiding catastrophes (bottom left), and creating a 'flood and drought-free' basin (bottom right), where the excess water captured during wet season and stored in the aquifers is used for irrigation in subsequent drier years.

UTFI aims to transform these risks into societal and environmental benefits in terms of:

- increased water security/drought resilience;
- reduced public/private costs in terms of flood relief and damages;
- increased food security, agricultural production, employment and farmer income; and
- increased dry-season base flows to rivers and wetlands.

BOX 4.2

UTFI CONCEPT ASSESSMENT IN CHAO PHRAYA RIVER BASIN, THAILAND

The Chao Phraya River Basin (160,400 km²) regularly experiences major flooding in the upper and lower reaches as well as El Niño-related droughts. Water resources are heavily allocated across economic sectors, eliminating any possibility of new large-scale reservoirs – grey water storage infrastructure. An analysis of the flow records shows that, on average, 28% of the wet-season flows that discharge into the Gulf of Thailand (3.37 billion m³ per year) could be harvested by peak cutting without significantly impacting the water use from existing large to medium storages, nor the riverine or coastal ecosystem. Field trials with specifically constructed recharge basins revealed that this water could be readily recharged and accommodated within the vast shallow alluvial aquifers in the central plains, situated upstream of the major flood-prone areas. This would also offset the decline in groundwater levels in the agricultural plains due to year-round pumping to irrigate high-water crops. Capturing peak flows would take place largely in the wetter years and requires converting around 200 km² of land for groundwater recharge – the equivalent of about 0.1% of the basin area. This would not only reduce the magnitude and costs of flooding, but also generate around US$200 million of agricultural income per year to boost the livelihoods of thousands of farming households as a result of additional water made available in drier periods. Capital investments could be recouped over time-frames of a decade or less. Careful governance is needed to underpin the system's success. For example, farmers would need to be encouraged to utilize their land for recharge and thereby become 'stewards' who manage infrastructure for the benefit of downstream communities. Water resources managers and flood protection authorities would need to provide overall coordination, capacity building and incentives for effective adoption by farmers. Bringing this study to reality in the Chao Phraya would require detailed investigations to determine the areas where environmental conditions are suitable for aquifer recharge, as well as analyses to identify workable institutional arrangements (Pavelic et al., 2012).

Figure | Maintaining a pond created under UTFI



Photo: Prashanth Vishwanathan/IWMI

Achieving this aim requires careful site selection, system design, setup and operating capital costs, local governance and knowledge of potential environmental impacts to ensure that implementation is responsive to local demand, conditions and constraints. This is exemplified through an examination of UTFI prospects in the Chao Phraya River Basin of Thailand (Box 4.2).

This case study shows that NBS such as UTFI can reduce both flood and drought-related risks, and thus deliver multiple benefits. It is clear also from the above that the socio-ecological benefits of UTFI become most concrete when implemented at large scales, e.g. catchments of thousands of km². To develop evidence that supports UTFI implementation in India, UTFI is currently being piloted in the Ganges. Even though large-scale groundwater recharge programmes have been operating in India for decades, the focus has been on water-scarce areas with no real emphasis on flood risk management. Highly flood-prone basins such as the Ganges are now showing clear signs of groundwater depletion (Shah, 2009). To support the introduction of UTFI in India, a four-step approach is being carried out (Pavelic

et al., 2015). It includes: i) an *opportunity assessment* that already established that almost 70% of the Gangetic plain has high to very high suitability for UTFI; ii) a *pilot trial*, initiated in the Rampur district of Uttar Pradesh State, which involved the renovation of village ponds, the installation of recharge structures and the continuous monitoring of impacts; iii) *stakeholder engagement* from the inception and throughout the pilot trial, including local farming communities and officials from the irrigation and agriculture sectors, the private sector and the media, to ensure community ownership; and iv) *convergence with policy*, registering the pilot trial under the flagship Mahatma Gandhi Rural Employment Scheme (enabling the community to be remunerated to participate in the UTFI pilot) and in the national Pradhan Mantri Krishi Sinchayee Yojana Scheme (which aims at providing each farm with water access), as well as inclusion of UTFI in the District Irrigation Plan for Rampur. Currently, the establishment of a broader set of demonstration sites within the Ganges Basin is being planned, in order to create more diverse experience and stronger guidance on operational modalities to support wider implementation. The UTFI approach, if rolled out in a large-basin scale like the Chao Phraya or Ganges, essentially becomes an NBS alternative to conventional large surface dams.

4.3 Challenges to enabling NBS in the context of variability and risk reduction

There are numerous challenges for wide adoption and implementation of NBS. They are both global and generic, region-specific or place-based, and often applicable to NBS at large, rather than to NBS in the context of just risk reduction and variability management. Challenges include but are not limited to:

- The overwhelming dominance of grey infrastructure solutions for water variability-related risks in the current instruments of governments – from public policy to building codes (WMO, 2007). Similarly, this dominance exists in the orientation of economic markets, expertise of service providers, and consequentially in the minds of policy makers and the general public. These factors collectively result in a general inertia against the development and use of NBS and a bias against NBS, which are often perceived as being less efficient than anthropogenic/built systems. In other words, as an example, an image of a concrete wall or levee that precludes water from coming in dominates the minds and current practices. This leads to a lack of incentives, financial resources and other enabling requirements for NBS that can be developed and applied in the context of variability management, water-related disaster risks and change. Related to this inertia and contributing to it is the lack of documentation, communication and recognition of the costs saved when NBS helped reduce extreme event damage to grey infrastructure, people and the economy. Also, all too often, the value of NBS and the increased costs of extreme water events only become clearer when ecosystems (and the services they provide) have been significantly deteriorated and when conventional practices turn out to be insufficient.
- A lack of awareness, communication and knowledge of what NBS can really offer to reduce water variability risks compared to 'conventional' grey solutions at all levels, from communities to regional planners and national policy makers (WMO, 2006). This is also partially caused by the insufficient level of research and development in DRR-related NBS, especially in terms of cost–benefit analyses of NBS performance in comparison or conjunction with grey solutions.
- A lack of understanding of how to integrate natural and built infrastructure for mitigating risks of floods, droughts and water variability at large, and an overall lack of capacity on how to implement NBS in the context of water-related risk reduction, even in those cases where there is willingness to implement NBS. For example, large-scale basin-wide NBS like UTFI, described above, have not reached the stage of documented manuals, and are only being piloted. This issue is possibly typical to all new/emerging technologies, if NBS can be seen as a 'technology'. Also, disincentives occur when a poorly designed NBS fails, and they contribute to the bias mentioned above.
- Myths and/or uncertainty about how natural infrastructure functions (e.g. in relation to forests, wetlands and aquifers), what ecosystem services mean in practical terms (and in particular how flow-regulating services – the most relevant ecosystem service in the context of risk and variability management – manifest themselves). The above translates into a lack of quantitative knowledge on what positive impact can be achieved – reducing flood peaks or drought severity, for example.
- Difficulties in providing clear evaluations of the performance of NBS-related projects in the context of risk reduction. It is also not entirely clear, at times, what constitutes an NBS and what is a hybrid solution. There is a lack of technical guidelines, tools and approaches to determine the right mix of NBS and grey infrastructure options.
- The use of land for NBS can create tension and possible conflict with alternative land uses. However, in fairness, it needs to be noted that grey infrastructure is also often directly land-consuming or has indirect adverse impacts on land. At the same time, some NBS (e.g. UTFI) only require a small proportion of a river basin area to achieve the basin-wide effect of reducing the impacts of both floods and droughts.
- A more implicit but real challenge is the remaining dominance of a reactive rather than proactive approach to water-related disaster management. A reactive approach deals with the consequences of disasters, and in such context the use of NBS is limited. NBS may have a much greater potential if 'switched on' in the planning and implementation of risk reduction measures – before disaster strikes.

5 NATIONAL AND REGIONAL EXPERIENCES WITH IMPLEMENTATION



WWAP | Richard Connor and David Coates

With contributions from[12] : Andrei Jouravlev (UNECLAC); Aida Karazhanova and Stefanos Fotiou (UNESCAP); Simone Grego (UNESCO Multisectoral Regional Office in Abuja); Carol Chouchani Cherfane and Dima Kharbotli (UNESCWA); Chris Zevenbergen (IHE Delft); Rebecca Welling (IUCN); Chris Spray (University of Dundee, Centre for Water Law Policy and Science (under the auspices of UNESCO)); Tamara Avellán (UNU-FLORES)[13] ; Dragana Milovanović (ISRBC); Franco A. Montalto (Drexel University); Anne Schulte-Wülwer-Leidig (ICPR); Marta Echavarria (EcoDecision); Shreya Kumra (UNESCAP); and Pablo Lloret (EPMAPS)

Wooden bridge in Wuyuanwan Wetland Park in Xiamen (China)



5.1 Introduction

Whereas the previous chapters examined opportunities for the implementation of NBS in the context of the three critical water management objectives – improving water availability, enhancing water quality, and disaster risk reduction – this chapter takes a broader view of assessing relevant aspects of implementation of NBS for multiple water-related benefits and co-benefits across different countries and regions, showcasing good examples and lessons learned.

Different regions (and sub-regions) can face similar or different water-related challenges at varying intensities, which stem from a combination of physical hydrological conditions as well as the state of overall water resource management, including governance, capacity, economics and finance. Although this may result in a different mix – and level of implementation – of NBS, certain similarities can emerge and thus lessons learned in one country or region can help inform the implementation of NBS in another.

5.2 Implementing NBS at the basin scale

5.2.1 Watershed management

As described in Section 1.3, the biological and geophysical characteristics of a river basin directly affect the quantity and quality of water flowing downstream over time and space. Any significant changes in these characteristics (i.e. LULUC) can alter these hydrological features. Improved land management can therefore be seen to include an ensemble of NBS that can collectively enhance water security. There are examples of such practices across all regions.

[12] Authors would like to thank Alexander Belokurov, Sonja Köeppel and Annukka Lipponen of UNECE for the input.

[13] The views expressed in this chapter are those of the author(s). Their inclusion does not imply endorsement by the United Nations University.

> Improved land management can be seen to include an ensemble of NBS that can collectively enhance water security

In Saudi Arabia, the *hima* practice dates back 1,500 years as an organized approach to protect land and water resources. Under this scheme, stakeholders collectively control the use of rangeland and are responsible for preserving the land, seed stocks and water resources. The weakening of the tribal structures accompanied with land use changes in the region resulted in the phasing out of the *hima* management scheme over time. However, initiatives have been undertaken to revive *hima* as a management scheme to support land and natural resources conservation (AEDSAW, 2002). Similar initiatives to revive these ancient land management practices and the traditional/cultural knowledge that comes with them are also underway in other countries of the Arab region, including Jordan (Box 5.1).

Watershed restoration and protection becomes increasingly important in the context of sustaining water supplies to rapidly growing cities. Many watersheds are increasingly affected by deforestation, land use change, intensive agriculture, mining, population growth and climate change. Watershed degradation negatively impacts water supply, particularly for the urban population, reducing water availability at least in certain seasons, aggravating urban flooding in others, impairing water quality, and hence increasing the costs of urban water supply and treatment.

The impacts of watershed degradation are exemplified by the situation in Kenya's Upper Tana Basin (see Boxes 2.5 and 5.4), which provides 95% of Nairobi's drinking water and 50% of Kenya's hydropower. Over the past 45 years, some of the forests in the basin have been replaced with agricultural fields, and demand for water to support horticulture production has increased. Encroachment on natural wetlands that once stored runoff water and recharged aquifers has reduced dry-season flows. Agricultural expansion along with soil erosion and landslides has increased sediments in local rivers. These factors have decreased the water yields during dry periods and increased sediment in streams. The resilience of the system to cope with droughts decreased and equipment disruptions due to sediment-laden runoff during the wet season increased water treatment costs, in some cases by more than 33% (Hunink and Droogers, 2011; TNC, 2015).

BOX 5.1

RESTORING *HIMA* SYSTEMS IN JORDAN

A project to revive traditional *hima* land management practices was implemented in the Zarqa River basin, which is home to half of Jordan's population. Inappropriate land and resource management and unsustainable development has resulted in land degradation and the overexploitation of groundwater resources. Traditionally, *hima* land management practices were followed, which basically consisted of setting land aside to allow for the land to naturally regenerate itself. In tandem, this would reduce stress on groundwater resources from both a water quality and water quantity perspective. However, as a result of growing population and the demarcation of inter-state borders that constrained mobility, the practice was replaced by continuous intensive agriculture.

Research has also shown that the shift from *hima* to these unsustainable land management practices was further exacerbated by changes in the land tenure from tribal to private land ownership and the issuance of government subsidies for dry-season cropping. Under the framework of the project of reviving *hima* land management practices, efforts were pursued to empower local communities by transferring management rights to them. Results also demonstrated an increase in economic growth (e.g. through the cultivation of indigenous plants of economic value) and conservation of natural resources in the Zarqa River Basin.

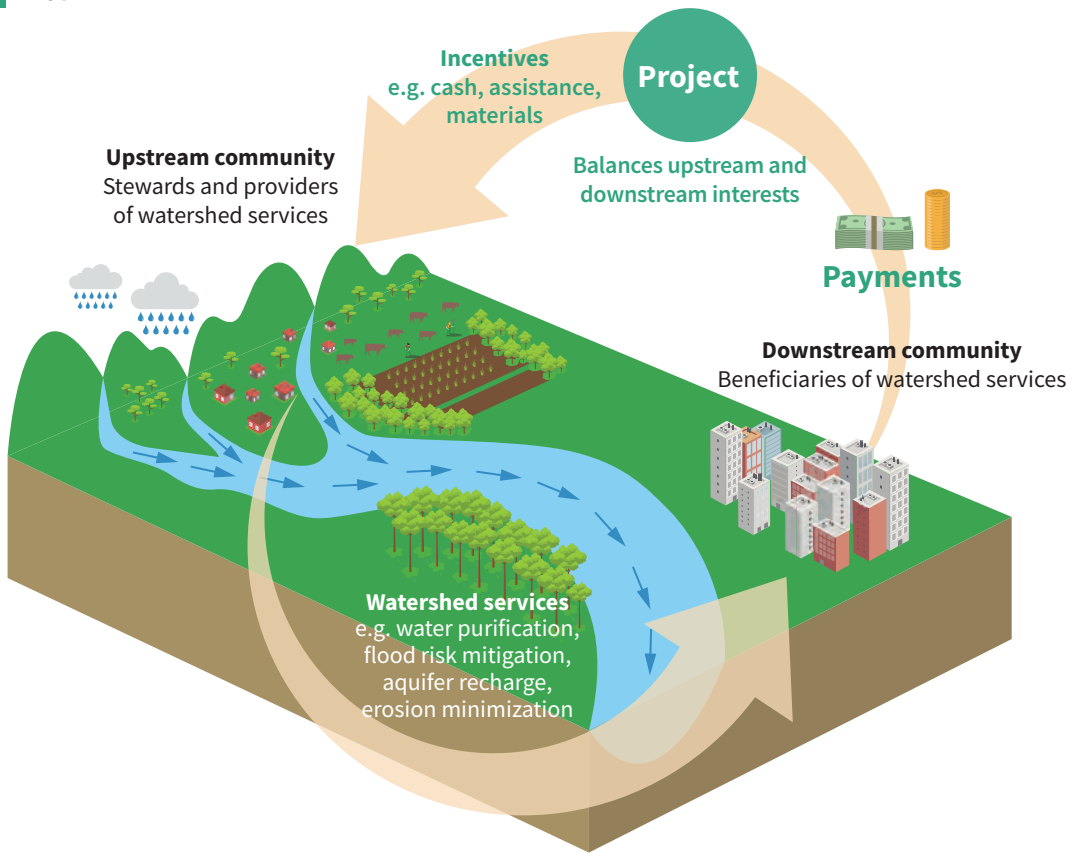
Within the framework of the project implementation, government and community partnerships were also established. Capacity-building workshops were conducted to exchange information on lessons learned and challenges, as well as awareness campaigns to promote the issues at stake. Based on the success of this initiative, the National Rangeland Strategy of Jordan (2014) incorporated the *hima* approach as an effective means to address governance of national rangelands.

Sources: Cohen-Shacham et al. (2016) and Ministry of Agriculture of Jordan (2014).

Contributed by Carol Chouchani Cherfane (UNESCWA).

This situation explains the growing interest of water supply and sanitation sector authorities, local governments and water utilities in the application of NBS, particularly watershed management, for the protection of urban water supply sources, especially regarding water quality (mainly non-point source pollution by fertilizers, herbicides and insecticides from intensive agriculture, bacteria and nutrients from livestock production, and sediments from deforestation). Increased attention to watershed management – particularly, land protection, reforestation

Figure 5.1 A typical watershed PES scheme



Source: Adapted from Bennett et al. (2013, fig. 7, p. 1).

and riparian restoration – is expected to help reduce operation and maintenance costs of urban water utilities, improve service quality and delay the need for expensive capital investment in capacity expansion (Echavarria et al., 2015). Watershed management is not only seen as a cost-effective complement to built or 'grey' infrastructure, but also as a way to generate other important benefits, namely local economic development, job creation, biodiversity protection and climate resilience (LACC/TNC, 2015).

5.2.2 Payments for environmental services

The case of maintaining the water supply system for New York City, initiated in 1997, is one of the best known and documented examples of the implementation of NBS for watershed protection. This was also one of the first recognized successful payment for environmental services (PES) schemes. Today, three protected watersheds provide New York City with the largest unfiltered water supply in the USA, saving the city more than US$300 million per year on water treatment operation and maintenance costs. The programme also serves as an alternative to building a water treatment plant which would have cost between an estimated US$8 and 10 billion (Abell et al., 2017).

PES schemes provide incentives (monetary or otherwise) to landowners or farmers in exchange for sustainable land use practices (agriculture, forestry, etc.). The objective is that those who benefit (e.g. a water utility) from environmental services (e.g. better water quality in a river) should pay for their provision (e.g. for better pesticide and fertilizer use management or for preservation of the forest cover) to those, usually upstream, who can provide them (e.g. farmers or landowners), in order to ensure their continued production (Figure 5.1).

The Latin American and Caribbean (LAC) region has a wealth of experience in implementing watershed PES schemes – also known as 'investment in watershed services schemes' (Bennett et al., 2013). In 2013, the Association of Water and Sanitation Regulatory Entities of the Americas (ADERASA) created a working group devoted specifically to green infrastructure (Herrera Amighetti, 2015). Its mission is to systematize and analyse experiences of the countries of Latin America in investment in green infrastructure as a means to improve water availability and prevent water quality deterioration. These investments can take various institutional forms, but usually are implemented as PES. This interest in PES is in large part explained by the fact that governments across the LAC region, as elsewhere, often have limited and weak control, monitoring and enforcement capacities (Stanton et al., 2010; Embid and Martín, 2015) – especially for water resources management, land use, and pollution control and solid waste disposal – particularly outside of the larger cities. Also, in countries where the provision of water supply and sanitation services has been decentralized to the municipal level, it is not uncommon that the water sources of one municipality are located in the jurisdiction of another, further complicating water source protection (Jouravlev, 2003).

Successful examples of PES schemes have also been documented in other regions of the world, including Asia-Pacific (Box 5.2) and Africa (Box 5.3). In the Mekong River Basin alone, PES schemes with watershed protection components have been documented in Cambodia, Laos, Thailand and Vietnam, although Vietnam is the only country in South-East Asia to have a formal national PES plan (Tacconi, 2015). The Asian Development Bank (ADB) estimates that, at the very least, US$59 billion in investments for water supply and US$71 billion for improved sanitation are needed to cover basic needs in the region. It is also estimated that as much as 70–90% of household and industrial wastewater is released without any prior treatment (ADB, 2013), leading to further ecosystem degradation. Spending a proportion of this required investment on watershed protection and other relevant NBS is increasingly accepted as an appropriate way forward in addressing these challenges.

PES schemes are often implemented through conservation and water funds, financed through government subsidies and contributions paid by large water users (such as urban

BOX 5.2

EXPERIENCE WITH PES IN THE ASIA-PACIFIC REGION

Financial deficiencies and other challenges related to watershed protection are being addressed in Vietnam through a 2008 pilot policy framework on payment for forest environmental services (Forest PFES, Decision 380), which has focused on water supply and landscape conservation for tourism purposes through local contracts. In 2009, the local revenue derived from service buyers, mostly hydropower and water supply companies, was about US$4 million. Due to this instrumental active policy, in 2013 water users, operators and utilities had collectively paid US$54 million to forest-based communities for the watershed services they were providing (To et al., 2012).

Contributed by Aida Karazhanova and Stefanos Fotiou (UNESCAP).

BOX 5.3

PES SCHEME AT LAKE NAIVASHA, KENYA

Lake Naivasha in Kenya has been recognized as a 'wetland of international importance' under the Ramsar Convention on Wetlands. Both small-scale agriculture and intensive commercial horticulture, including flower farming, have poor land use practices within the watershed, resulting in the degradation of ecosystem services, economic losses, worsening poverty and reduction of biodiversity.

A water-centred PES scheme has gathered partners such as ecosystem service 'sellers/providers' (mainly smaller upstream farmers) and 'buyers/users' (including the major horticultural industry around the lake), as well as the principal national and local agencies involved in the regulation of these services through contractual agreements negotiated between ecosystem stewards and beneficiaries.

Intensive information and awareness-raising activities were conducted at highly localized levels (e.g. workshops and seminars, both on- and off-farm) to enhance understanding and buy-in by the community and all stakeholders.

Changes to land management practices aimed at improving downstream water quality and quantity included:

- rehabilitation and maintenance of riparian zones;
- establishment of grass strips/terraces to reduce runoff and erosion on steep slopes;
- reduced use of fertilizers and pesticides; and
- agroforestry and the planting of native trees and high-yielding fruit trees and cover crops for improved farm productivity, reduced runoff/erosion and increased biodiversity.

The project also included training to farmers by the Ministry of Agriculture and Horticultural Crops Development Authority on issues such as soil and water conservation techniques to boost farm productivity, improve fodder storage techniques and the use of more productive/high-value crop varieties.

The use of economic incentives for both ecosystem service buyers and sellers helped achieve significant land and water management improvements, while delivering tangible livelihood benefits.

Source: Chiramba et al. (2011).

More information is available at: www.gwp.org/en/learn/KNOWLEDGE_RESOURCES/Case_Studies/Africa/Kenya-Shared-risks-and-opportunities-in-water-resources-Seeking-a-sustainable-future-for-Lake-Naivasha/

BOX 5.4

UPPER TANA-NAIROBI WATER FUND

The Upper Tana-Nairobi Water Fund was launched in March 2015 to provide residents in the basin with the opportunity to mitigate the threats associated with watershed degradation. In addition, the fund aims to secure Nairobi's water supplies while improving agricultural livelihoods, maintaining dry-season flow in selected watersheds, and thus contributing to resilience to droughts.

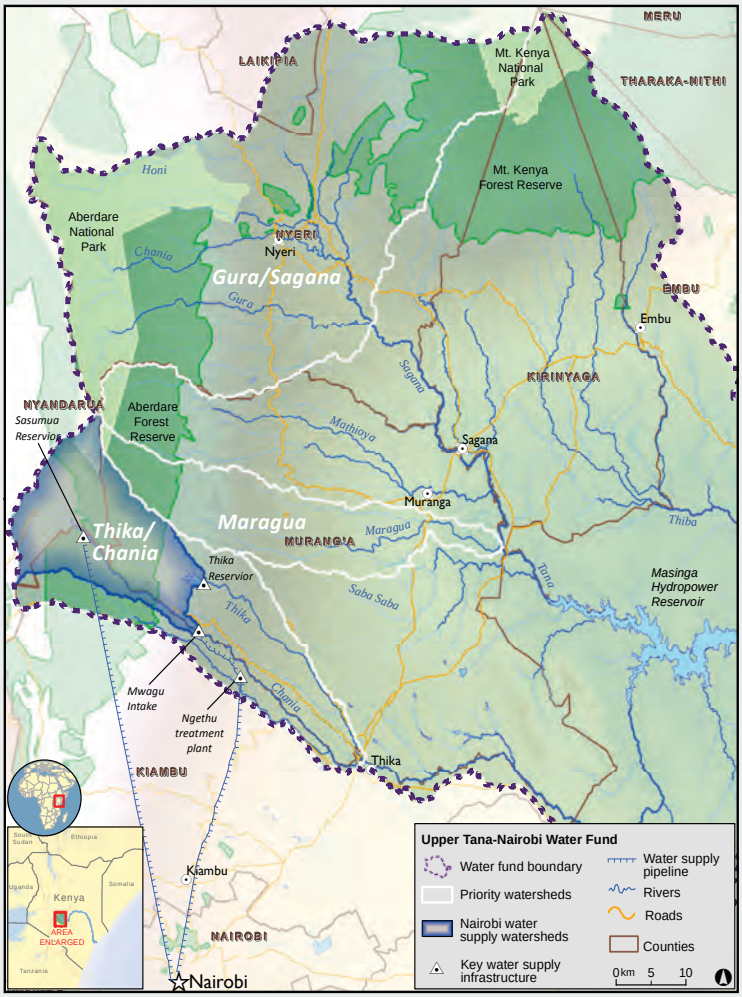
The fund is a public–private partnership and, in the first four years of development, it was able to mobilize US$4 million through voluntary contributions. There are important multilateral funders, including the Global Environment Facility (GEF), which aims to contribute US$7 million during the course of the fund validity. It brings together multiple stakeholders, such as county government, the water resource authority, the forest service, the regional council of governors, the Nairobi water utility and private sector actors.

The Water Fund uses in-kind compensation mechanisms to encourage farmers to adopt agricultural best management practices, restore riparian buffers, install efficient irrigation and reforest. These in-kind compensation packages include water pans, capacity building and training around agricultural production, seeds, equipment, and livestock such as dairy goats. The water fund also focuses on reducing sediment from unpaved rural roads. To date, the water fund has worked with over 15,000 farmers by collaborating with local partners, including the Green Belt Movement and the Kenya National Farmers Federation (Abell et al., 2017).

The Water Fund's business case indicated that a US$10 million investment in Water Fund-led conservation interventions would likely return US$21.5 million in economic benefits over a 30-year timeframe from increases in power generation, in agricultural crop yields for smallholders and larger producers, and from savings in water and wastewater treatment (TNC, 2015).

Contributed by Simone Grego (UNESCO Multisectoral Regional Office in Abuja) and Rebecca Welling (IUCN).

Figure | Location of the proposed Upper Tana-Nairobi Water Fund



Source: TNC.

water utilities, hydropower generation plants, and bottled water or soft drink companies) located in the lower areas of a river basin, to support watershed management activities in the high- and medium- altitude zones of the basin (Calvache et al., 2012; Jouravlev, 2003). They are essentially private–public partnerships in many cases.

Water funds are used to provide monetary and non-monetary incentives to the communities, farmers and private landowners located upstream (Box 5.4) to protect, restore and conserve natural ecosystems (forests, wetlands, etc.) that provide benefits to downstream water users in the form of water regulation, flood control, and erosion and sediment control, among others, thus ensuring a constant, high-quality water supply, and helping reduce water treatment and equipment maintenance costs (Box 5.5). The funds are usually governed by a contract among founding members, which designates an independent institution to manage the financial resources and to ensure that they are spent on watershed protection activities in

> PES schemes provide incentives (monetary or otherwise) to landowners or farmers in exchange for sustainable land use practices (agriculture, forestry, etc.)

compliance with the objectives of the fund (Stanton et al., 2010). There are already more than 20 of such water funds in operation in the LAC region alone (Echavarria et al., 2015).

According to Ecosystem Marketplace by Forest Trends, governments, water utilities, companies and communities spent nearly US$25 billion in payments for green infrastructure for water in 2015, positively affecting 487 million ha of land (Bennett and Ruef, 2016). Transactions grew by about 12% per year between 2013 and 2015, suggesting a rapid increase in the level of uptake. Funding for the vast majority of these PES schemes (US$23.7 billion) is derived from national governments (Figure 5.2), and in Europe from the European Commission. Much of the remaining investment (about US$650 million) was categorized as *'user-driven watershed investments'* led by large programmes in China and Vietnam, whereby cities, companies or water utilities acting on behalf of their customers paid landholders for stewardship of water-critical landscapes (Bennett and Ruef, 2016).

In the drinking water supply and sanitation sector as a whole, NBS appear to be severely underfunded in comparison with grey infrastructure. In the countries of the LAC region, water utilities are investing less than 5% of their budgets in green infrastructure (with the possible exception of some cities in Peru), although these allocations appear to be on the rise (Echavarria et al., 2015; Bennett and Ruef, 2016). In England, watershed management activities generally account for less than 1% of water company expenditure. A recent report estimated that £100 billion will be spent in English catchments between 2015 and 2030 *"to address issues including the continued provision of water and waste water services, water quality, farming and on flood protection and maintenance"* of which *"over £30 billion will be spent in England in meeting the requirements of the EU Water Framework Directive (WFD) and in maintaining current standards of water and waste water treatment"*. Of this £30 billion for the WFD, the report estimates that *"between £300 million to £1 billion of cost would be avoided by the adoption, by the water sector, of wider catchment approaches"* (Indepen, 2014, p.1). Taking account of the

BOX 5.5

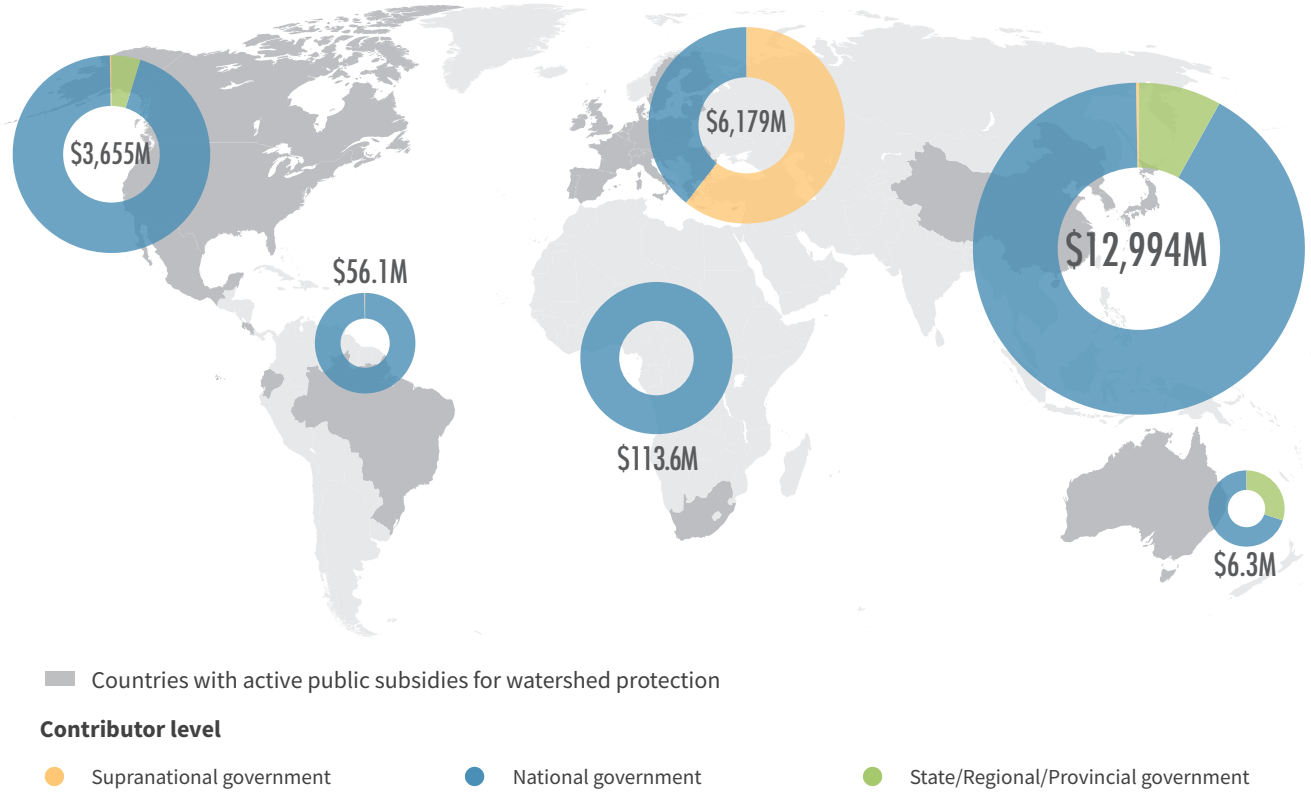
THE QUITO WATER CONSERVATION FUND (FONDO PARA LA CONSERVACIÓN DEL AGUA – FONAG)

The Water Conservation Fund (FONAG) in Ecuador is the first and perhaps one of the most successful water funds in the LAC region. The watersheds that supply water to the capital city of Quito are threatened by inadequate agricultural, livestock and forestry practices. In response to this situation, in 2000, the Municipality of Quito, through its water utility (EPMAPS) and with the cooperation of The Nature Conservancy (TNC), created FONAG (Lloret, 2009). FONAG is a trust fund designed to operate for a period of 80 years. It is financed by contributions from its members which include most of the large water users of the area (water and electric utilities, a brewery, a bottled water company, etc.). The objectives of FONAG are to support the conservation, restoration and preservation of the watersheds that provide water to Quito and surrounding areas (FONAG, n.d.). Its intervention is in the form of both long-term programmes (communication, recovery of vegetation cover, water management, environmental education, and surveillance and monitoring of priority areas) and short-term projects, which range from support for production activities with an environmental focus, to applied research. FONAG works with the active participation of different community stakeholders, local authorities, governmental and non-governmental organizations, and educational institutions.

"FONAG has an endowment of more than US$10 million and an annual budget of more than US$1.5 million. As the oldest official water fund, FONAG has been successful in protecting and restoring over 40,000 hectares of páramo and Andean forests through a variety of strategies, including working with more than 400 local families. … Rather than make direct payments for conservation, restoration and sustainable agriculture, the water fund utilizes in-kind compensation like home gardens and support for community projects. In addition to direct source water protection activities, FONAG focuses on strengthening watershed alliances, environmental education and communication to mobilize additional watershed actors in watershed protection. FONAG has also established a rigorous hydrologic monitoring program to communicate and improve outcomes of investments in collaboration with several academic institutions" (Abell et al., 2017, p. 115).

Contributed by Andrei Jouravlev (UNECLAC).

Figure 5.2 **Public subsidies for watershed protection in 2015: Countries with public subsidies programmes and the total share of each contributor, by region**



Note: Based on US$23 billion in transactions in 2015. For another US$727 million in public subsidies in 2015, it was not possible to determine the relative contributions of national and subnational governments.

Source: Adapted from Bennett and Ruef (2016, Map 2, p. 14).

wider co-benefits to biodiversity, flood risk reduction and carbon management, which were not accounted for in the report, would further enhance the financial argument for watershed management.

Both the cases of the UK and the LAC countries suggest that cities, companies and water utilities could invest much more in NBS. There is mounting evidence that such investments are cost-effective and make good business sense, while at the same time generating co-benefits such as biodiversity conservation, community benefits, climate change adaptation, and jobs and training. Obviously, there will usually be a threshold beyond which further expenditure in watershed management and NBS ceases to provide adequate returns on investments, even if the co-benefits from green infrastructure are included. However, the same can also be said for grey infrastructure. Therefore, identifying these thresholds, and the optimum mix of green–grey approaches, requires a common analytical framework (i.e. common performance indicators) for assessing the cost–benefits of both grey and green infrastructure in terms of the relevant water management and other objectives in question.

Designing and implementing PES for watershed-scale land management schemes requires clearly establishing the cause-and-effect relationships between upstream land and water use practices and the provision of watershed services for downstream users, identifying and organizing the stakeholders who have effective control of these practices, and reaching a sustainable agreement under the constantly changing market as well as the political and social conditions. There is always the question of whether, and to what extent, it is appropriate to reward compliance with the law and good practices.

This in turn requires a common conceptual framework for assessing the value and benefits of investments in both green and grey infrastructure, which can be difficult, especially for water utilities and service providers – particularly in small and medium cities – that still do not fully recover the costs of service provision and therefore depend on governmental budgets for investments, and in some cases, even for operation and maintenance. Limited experience with and knowledge of NBS (and their long-term sustainability), coupled with the preference for built or 'grey' infrastructure on the part of many engineers and politicians, can pose an additional challenge. With extremely limited control, monitoring and enforcement capacities for water resources management and land use control, it is not surprising that the expenditure of water utilities for watershed activities is generally low – when it even exists. Acceptance of, support for, and participation in NBS and PES schemes among a broader range of

> In the drinking water supply and sanitation sector as a whole, NBS appear to be severely underfunded in comparison with grey infrastructure

stakeholders is therefore imperative, but still not enough. Landowners, for example, require insurances of long-term financial support. Strong legal backing to assess, integrate and implement NBS across multiple policy objectives (agriculture, climate change, green energy, etc.) can be equally critical (e.g. Box 5.6).

In terms of overseas investments, financial institutions and enterprises can play an important and influential role in supporting and financing NBS and PES schemes. Entities engaged in overseas investment do not only have the responsibility to adhere to the environmental laws, regulations and standards of host countries, they should also adhere to the UN Principles for Responsible Investment, which include taking full account of environmental, social and governance factors (PRI, 2006). The Environmental Risk Management Initiative for China's Overseas Management Initiative, which also supports 'green' trade financing across the supply chain, takes these principles one step further by encouraging financial institutions and enterprises *"to quantify the environmental costs and benefits of overseas investment projects, including different types of pollutant discharge, energy consumption and water use, as a basis for decision-making. ... To ensure the applicability of the quantitative analysis, the calculation of environmental costs and benefits should take into consideration such factors as the host country's level of technology development and environmental situation, while international standards should be used as benchmarks where appropriate"* (GFC/IAC/CBA/AMAC/IAMAC/CTA/FECO, 2017, p. 3).

5.3 Implementing NBS within urban areas

Accelerating urbanization is exacerbating water management challenges for a large number of cities across most regions. In the LAC region, the most urbanized region in the developing world, nearly 80% (2014) of the population lives in urban areas, a ratio that is projected to grow to 86% by 2050. Although Asia and Africa remain mostly rural, these regions are experiencing the most rapid urbanization rates, evaluated at 1.5% and 1.1% per year, respectively (UNDESA, 2015).

Watershed management, as described above, offers a wide range of potential benefits for these growing urban settlements. The implementation of localized NBS within the cities themselves offer additional opportunities for meeting multiple water management objectives. In the case of New York City, for example, measures taken to enhance grey infrastructure with green infrastructure were shown to have been cost-effective while providing substantial co-benefits (Box 5.6).

Urban green infrastructure, from the revegetation of impermeable surfaces to green roofs and constructed wetlands, can yield positive results in terms of water availability, water quality and flood reduction, as exemplified by China's 'sponge city' project (see Box 2.6).

In the context of water and sanitation, constructed wetlands for wastewater treatment can be a cost-effective NBS that provides effluent of adequate quality for several non-potable uses, including irrigation, as well as offering additional benefits, including energy production (Box 5.7). With over 80% of all wastewater released to the environment without any prior treatment globally, and over 95% in some developing countries (WWAP, 2017), constructed wetlands can provide great opportunities for communities of all sizes. Such systems already exist in nearly every region of the world, including the Arab region (Box 5.8) and Africa – they are relatively common in East Africa.

5.4 Regional and national frameworks of NBS

Although most often driven by local stakeholders, such as large water users and municipalities, to achieve specific water management outcomes, broader frameworks and partnerships at national and regional levels play a critical role in fostering implementation of NBS. National legislation to facilitate and oversee implementation of NBS is particularly critical.

The European Commission's Water Framework Directive (WFD) (Directive 2000/60/EC) provides an overarching framework for many other legislative, governance and even NGO-focused activities to take a lead. Europe has been moving towards a holistic, sustainable, risk-based, whole-catchment approach. Increasingly, this has also been characterized by consideration of the value of and impact on a wide range of ecosystem services, with recognition of the importance of delivering multiple benefits and engaging with stakeholders at national, regional and local levels (Box 5.9). Water quality, and in

BOX 5.6

NBS IN URBAN SETTINGS: NEW YORK CITY

In New York City (NYC), a variety of nature-based approaches deploying green infrastructure have been implemented since the 1990s, in response to regulations regarding water quality, public interest in sustainability, and evolving paradigms in urban land management. Formalized in 1972, the Clean Water Act (CWA) establishes regulations regarding the discharge of pollutants into surface water bodies of the USA. Under the CWA, it became unlawful to discharge pollutants without obtaining a permit through the National Pollutant Discharge Elimination System programme. Amendments to the original CWA require cities like New York to develop long-term plans to control combined sewer overflows (CSO), triggered when urban runoff enters the city's sewer system (US EPA, n.d.).

Building upon new strategies in natural resource, land and infrastructure management made in PlaNYC, the City's first comprehensive sustainability plan, the NYC Department of Environmental Protection (DEP) released its Green Infrastructure Plan in 2010. This plan integrates nature-based and traditional 'grey' approaches to the capture and treatment of urban runoff (DEP, 2010). The plan was based on cost-effectiveness calculations, performed in 2008 during the development of the City's Sustainable Stormwater Management Plan. These calculations compared green and grey approaches to stormwater management in terms of construction cost per volumetric unit of stormwater detained or retained in the facility. The lower costs of green infrastructure compared to conventional CSO retention facilities ultimately lead the City to propose the capture of the first 25 mm of runoff generated over 10% of the impervious areas served by combined sewers with rain gardens, bioswales, green roofs, constructed wetlands and other nature-based approaches (The City of New York, 2008).

The Green Infrastructure Plan is implemented principally by DEP, with funds generated by water rate payers, but also leverages other capital infrastructure investments made by other city agencies and makes grants to private property owners so as to maximize application of green infrastructure on different urban land uses. The principal challenges to implementation have been associated with appropriately siting facilities away from low-permeability soils, underground infrastructure and street furniture, and in maintaining system performance through time.

Publicly funded stormwater green infrastructure systems such as Bioswales and Stormwater Capture Greenstreets are typically sized to accommodate all runoff generated within their tributary areas during approximately 90% of all wet weather events occurring annually (e.g. 25–30 mm of daily precipitation). However, ongoing field-based monitoring suggests that these systems may provide significant co-benefits. Green infrastructure are believed to enhance biodiversity, reduce air temperature through shading, beautify communities and create opportunities for ecological stewardship. Under certain conditions, these same systems may also reduce flood risks. Utilizing four years of field data, De Sousa et al. (2016), for example, found that a 125 m^2 bioretention facility located in a flood-prone Section of Queens, NYC, captures 70, 77 and 60% of all runoff generated within a tributary area four times its own size during all events (n = 92), just the non-extreme events (n = 78) and just the extreme events (n = 14), respectively.

Green infrastructure systems designed for stormwater capture may also provide thermal benefits due to the latent heat of vaporization of evaporated water. The 2.7-ha Jacob K. Javits Convention Center Green Roof (photo) in Manhattan, NYC, the second largest in the USA, retains more than half of event precipitation that occurs during the growing season, and evaporates, on average, 3.2 mm of water per day (over the same period), reducing the urban heat island intensity and considerably lowering its exterior surface temperature compared to a conventional black membrane roof (Alvizuri et al., 2017; Smalls-Mantey, 2017).

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Photo: © Felix Lipov/Shutterstock.com

> Urban green infrastructure, from the revegetation of impermeable surfaces to green roofs and constructed wetlands, can yield positive results in terms of water availability, water quality and flood reduction

particular diffuse pollution, is a key target often linked to the need to improve drinking water catchments. The second main focus area is flooding.The EU Floods Directive (Directive 2007/60/EC) promotes the potential of NBS to help reduce flood risk through coastal defences (saltmarshes, beach renourishment, managed retreat, etc.) as well as rural catchment 'natural flood management' and sustainable urban drainage systems (SUDS). Another major focus area concerns countering the loss of biodiversity. The EU Biodiversity Strategy to 2020 recognizes this and calls for *"integrating ecosystems services into decision-making"* (EC, 2017b, p. 6).

Ecosystem-based interventions can be especially advantageous from a transboundary perspective. They rarely have negative transboundary impacts, but instead can have numerous co-benefits for the entire basin, for example through the maintenance and enhancement of ecosystem services crucial for livelihoods and human well-being, such as clean water, water regulation and habitat, recreational opportunities, and food. The UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (the 'Water Convention') provides a global legal and intergovernmental framework for supporting transboundary cooperation in promoting NBS. All UN Member States have been able to accede to the Convention since March 2016. The Water Convention itself promotes an ecosystem approach since it obliges Parties to prevent, control and reduce transboundary impacts, ensure conservation and, where appropriate, restore ecosystems. Several ecosystem-based activities have been implemented under the Convention.

Transboundary basin organizations can also provide pragmatic opportunities for promoting the uptake of NBS among riparian countries. For example, the International Commission for the Protection of the Rhine (ICPR), which pre-dated the WFD by decades, already had NBS at the core of the activities and programmes that have been implemented by its member states (Box 5.10).

Since its inception, the WFD has stimulated the establishment of more recent transboundary basin organizations within which NBS play a central role. The Sava River Basin in South-Eastern Europe is one such

BOX 5.7

MOVING BEYOND WASTEWATER TREATMENT – MULTIFUNCTIONALITY OF CONSTRUCTED WETLANDS

Domestic wastewater is made up of three basic components: water, carbon and nutrients. These are useful components for various purposes such as growing food or producing bio-energy (WWAP, 2017).

One NBS to domestic wastewater treatment is the use of constructed or man-made wetlands. As most treatment systems, they are intended to reduce organic matter and pathogens to a minimum, but are of varying efficiency when it comes to nitrogen and phosphorus reduction. Since humans produce about 4.5 kg of nitrogen and 0.6 kg of phosphorus per person per year (Mateo-Sagasta et al., 2015), the effluent leaving constructed wetlands can have relatively high levels of these nutrients, making it a highly suitable source of water for irrigation.

Constructed wetlands are also among the world's most productive ecosystems, capable of producing relatively large quantities of biomass, depending on the type of plant used (most commonly either *Phragmites australis* or *Typha spp*.) and the climate of the location (Vymazal, 2013; Zhang et al., 2014; Mekonnen et al., 2015). This biomass can be harvested at regular intervals to be used as biofuel. The caloric value of most of these plants is also similar to traditional combustion fuels such as *Acacia spp*. (Morrison et al., 2014). Even less explored is their potential for biogas production, which shows some promising initial research results. In particular, when using *A. donax*, also known as giant reed, methane yields surpass that of corn or sorghum in some cases (Corno et al., 2016). It is estimated that about 12% of the cooking fuel needs of a 60-person village in sub-Saharan Africa can be supplied from the biomass of a constructed wetland (Avellán et al., 2017).

Using these NBS can thus serve multiple purposes and indirectly impact other aspects, such as increased forest conservation through a reduced reliance on wood fuels and enhanced energy security.

Contributed by Tamara Avellán (UNU-FLORES).

BOX 5.8

CONSTRUCTED WETLANDS IN EGYPT AND LEBANON

Egypt has a history of using constructed wetlands for wastewater treatment. A pilot project tested the feasibility of building constructed wetlands in Bilbeis, 55 km north of Cairo. The constructed wetlands resulted in a secondary-level treated wastewater effluent, which was used to irrigate Eucalyptus trees for the manufacture of packaging boxes. Hence, the project has contributed to water conservation and the preservation of groundwater resources.

This nature-based system has also proven to be cost-effective over extended periods of time since both the construction and operating costs were lower than the conventional wastewater treatment systems. As a result, it was decided to extend the scheme to other areas within the municipality.

The Litani River in Lebanon is highly polluted due to the discharge of untreated agricultural, industrial and domestic wastewater discharges. Wastewater treatment plants in the region are either non-functional or only partially operated. This has resulted in soaring concentrations of nutrients and pathogens in the river. A constructed wetland system has been designed to treat water flows in the Litani River and removed between 30% and 90% of the pollutant mass, resulting in wetland effluent quality that falls within the range permitted by international environmental standards. The treated water effluents are directed through a discharge channel back to the Litani River.*

Contributed by Carol Chouchani Cherfane (UNESCWA).

* Evidence provided by Difaf (Lebanon), based on a project supported by USAID.

BOX 5.9

NBS AND THE EU WFD: EXPERIENCES FROM PILOT PROJECTS IN THE NORTH SEA REGION

The EU WFD aims to promote sustainable water use through the protection and enhancement of aquatic ecosystems. Since 2013, NBS have been actively promoted by the European Commission to restore degraded ecosystems in order to secure long-term availability of water resources and safeguard benefits from aquatic ecosystems. Although the WFD supports the application of NBS, its practical application is hampered by a lack of evidence, methodologies and guidelines. A common transnational evidence base is needed to justify investments and optimize the effectiveness of NBS solutions (EC, 2015). In 2016 and 2017, the Commission launched a targeted research and innovation agenda and published calls for proposals for large-scale NBS demonstration projects to develop this base.

NBS have gained momentum in several member states. Emphasis has been laid on the uptake of NBS in cities and specifically for urban regeneration to improve the quality of life of EU citizens and to reduce the risk of disasters in EU cities. The Horizon 2020 Framework Programme has been particularly relevant in promoting the wider adoption of NBS in the urban domain (Faivre et al., 2017). The WFD provides member countries with a shared overarching legislative framework for sustainable water use. Despite the efforts of policy-makers and practitioners to communicate on their purpose and use, NBS are still unknown to the larger public and often remain in experimental stages (Voulvoulis, et al., 2017). In addition, it differs from country to country to what extent and in what manner NBS have been incorporated into legislation, and what roles and responsibilities have been given to different organizations for their promotion and delivery.

The project Building with Nature, which is part of the Interreg Vb Programme 2014–2020 for a 'Sustainable North Sea Region',* aims to support the practical implementation of NBS in natural catchments and coastal areas of the EU through the exchange of pilot test results and the development of guidelines or tools. Some first conclusions drawn from these pilots are: (i) as opposed to traditional infrastructural systems, the performance of NBS changes over time and is dependent on local physical and ecological conditions – hence, NBS call for a tailor-made approach requiring a detailed understanding of local conditions, (ii) the continuous involvement of local communities and stakeholders in the planning, design and maintenance phases has demonstrated to be conditional for the successful initiation and implementation of the pilots, and (iii) the monitoring of NBS performance and the evaluation of ongoing pilots are crucial to build the evidence base to support wider uptake. However, a practical and meaningful set of performance indictors is still lacking (Di Giovanni and Zevenbergen, 2017).

Contributed by Chris Zevenbergen (IHE Delft).

* For more information, please see archive.northsearegion.eu/ivb/project-ideas/ and www.northsearegion.eu/sustainable-nsr/

example, where the implementation of NBS is also generating several co-benefits through ecosystem services, from flood mitigation and the protection of biodiversity to economic growth related to ecotourism and improved navigation (Box 5.11).

There are also examples of regulatory frameworks promoting NBS at the national level, as exemplified by the experience in Peru (Box 5.12), where a national legal framework was adopted to regulate and monitor investment in green infrastructure.

A key advantage of NBS is also the way in which they contribute to building overall system resilience. Assessments of the returns on investments in NBS often do not factor in these positive externalities, just as those for grey infrastructure rarely take negative environmental and social externalities into account. Indeed, single-purpose, built infrastructure for water supply in one location can even result in a loss of supply or quality in other hydrologically linked locations, as has been witnessed with China's Three Gorges Dam (Zhang et al., 2014).

Large-scale national-level implementation of NBS as part of a broader policy framework for achieving a specific water management objective – in this case flood management – with complementary objectives such as spatial planning and environmental protection is exemplified by the Netherlands' 'Room for the River' programme. Initiated in 2009 with a budget of €2.5 billion, the programme was designed to restore the natural floodplains of rivers (an NBS) along certain non-vulnerable stretches, diverting rivers and creating water storage areas, in order to protect the most developed riparian areas. The restored wetlands both provided additional storage and safeguarded biodiversity, while enhancing aesthetic and recreational opportunities. The programme also serves as an example of 'multi-level governance', which is based on close collaboration between national and local authorities during both the planning and implementation stages of projects (Room for the River, n.d.a., n.d.b.).

NBS provide a mechanism for realizing participatory approaches to water and land use management, facilitating the exchange of information and in some cases drawing upon traditional knowledge and historically tested natural resource management approaches (e.g. Boxes 5.1 and 5.5). They can assist in formalizing and activating partnerships among disparate groups at the community level, including national and local government, local stakeholders and community-based organizations, the private sector, and donor agencies, thus empowering community members to implement, monitor and report on investments, successes and lessons learned.

BOX 5.10

NBS IN WATER MANAGEMENT AND WATER SERVICES IN THE CONTEXT OF THE IMPLEMENTATION OF THE EU WFD: THE RHINE RIVER BASIN

The Rhine, one of the largest rivers in Europe, has undergone a history of tremendous pollution in the period 1950–1970 and impressive restoration in the last four decades. What started with the development of a joint monitoring strategy in the 1950s and 60s under the International Commission for the Protection of the Rhine (ICPR) has developed into a comprehensive integrated management strategy for achieving sustainable development, comprising aspects of water quality, emissions reduction, ecological restoration and flood prevention and mitigation.

Since the beginning of the 1990s, the work of the ICPR has triggered the integrated water policy in the EU. Integrated river basin management was developed within the ICPR step by step: The ICPR has been dealing with the reduction of water pollution since 1950, with ecosystem improvement since 1987, with water quantity issues since 1995 (Action Plan on Floods) and with groundwater issues since 1999. Today, basin-wide and transboundary approaches in water management and the required cooperation between all countries in a catchment is a European obligation.

The EU WFD has set new standards in water policy for EU Member States. Running waters, lakes, and coastal and transitional waters within a river catchment (river basin district) are to be considered as an ecosystem, and aspects of protection and use are to be harmonized as far as possible. The WFD and the Floods Directive (Directive 2007/60/EC) provide for a revised management plan every six years.

Key elements of the Floods Directive for NBS are illustrated by the implementation of several measures convened in 1998 within the Action Plan on Floods of the Rhine that are considered as win-win and no-regret measures that not only have a positive effect on flood prevention, but also on water quality and ecology. Among them are measures such as water retention in the entire catchment, maintaining and/or extending floodplains, dyke relocations, restauration measures, less intensive agricultural soil use, creation of retention areas, etc.

"Based on the experiences and achievements of the ICPR, it could be argued that a process driven by political commitments is more effective and flexible than an approach using legally binding measures. ... However, both elements are required and finding a good balance between political commitment and legal enforceability is a continuous and iterative process." (Schulte-Wülwer-Leidig, n.d., p. 9).

Contributed by Anne Schulte-Wülwer-Leidig (ICPR).

BOX 5.11

THE VALUE OF NATURAL ASSETS AND THE IMPORTANCE OF TRANSBOUNDARY COOPERATION IN THE SAVA RIVER BASIN

The Framework Agreement on the Sava River Basin, ratified by Bosnia and Herzegovina, Croatia, Serbia and Slovenia entered into force in 2004. The key objective of the Agreement is to promote the sustainable development of the region through transboundary water cooperation, with particular objectives regarding the establishment of an international navigation regime and the sustainable management of water and hazards, thus linking the development of navigation and environmental protection.

The Sava River Basin is of significance due to its outstanding biological and landscape diversity. It hosts the largest complexes of alluvial riparian hardwood forests in Europe. A large portion of these floodplains are still intact and support flood alleviation and biodiversity, performing a variety of ecosystem services. The large retention areas of the Sava are among the most effective flood control systems in Europe.

The seven Ramsar sites in the Sava River Basin are recognized as focal points for ecotourism development. Suitably managed, they can boost local and regional economies while protecting ecologically sensitive areas. Protected areas and ecosystem services of the Sava River Basin were integrated into the first Sava River Basin Management Plan (2014), the main strength of which it is that it closely matches the requirements of the WFD, including full recognition of NBS in addressing all major water management issues.

The Sava River Basin is rich in valuable water-dependent ecosystems both within and beyond borders of the protected areas. The vast lowland and alluvial forests serve multiple functions and are of economic significance: they provide valuable timber, store a significant amount of climate-relevant carbon and prevent soil erosion. However, if the groundwater level drops, these forests and their ecosystem services deteriorate. Similarly, the outstanding retention capacity of floodplain wetlands provides a host of benefits to people as long as they enjoy a proper water regime. The retention volume of the Sava wetlands is outstanding and lowers flood peaks when water levels are high, with large positive transboundary impacts on the flood regime. These wetlands are also a source of water during droughts, which is of growing importance as a result of climate change. The Sava wetlands also purify water, a benefit that should not be underestimated as effective treatment plants are in short supply. These functions would be very costly to replace with 'grey' infrastructure. Effective management of these areas provide a win-win solution by achieving the WFD environmental objectives as well as multiple water management objectives.

Contributed by Dragana Milovanović (ISRBC).

BOX 5.12

COMPENSATION MECHANISMS FOR ECOSYSTEM SERVICES LAW (PERU)

Peru's Compensation Mechanisms for Ecosystem Services Law of 2014 is the first national-level regulatory framework specific for green infrastructure investment in the drinking water supply and sanitation sector in Latin America. The main objective of this law is to promote, regulate and monitor remuneration mechanisms for ecosystem services, which are defined as systems, instruments and incentives for generating, channelling, transferring and investing economic resources, when the stewards of ecosystems enter into an agreement with those paying for their services, or for the conservation, rehabilitation and sustainable use of the sources of these services (UNECLAC, 2015). The purpose of remuneration mechanisms is to ensure that the benefits generated by ecosystems endure into the future. Under this law, the stewards of ecosystem services can receive remuneration that is contingent on the implementation of measures for the conservation, rehabilitation and sustainable use of sources of ecosystem services. This may be the conservation of natural areas, the rehabilitation of an area that has suffered environmental harm or degradation, or measures to switch the sources of ecosystem services to a sustainable use. At present, 12 cities have already approved tariffs that include watershed investments (Bennett and Ruef, 2016).

Although many relevant frameworks either mandate or enable NBS to be considered, the final decisions will often depend on a more detailed consideration of the costs and benefits of various options. A notable feature of recent legal/regulatory/framework development is their emphasis (whether legally mandated or not) that all benefits, and not just a narrow set of hydrological outcomes, need to be factored into assessment of investment options. This requires a detailed systematic approach to evaluating costs and benefits, which is possible and will lead to improved decision making and overall system performance (Box 5.13).

> A key advantage of NBS is also the way in which they contribute to building overall system resilience

BOX 5.13

HOLISTIC AND QUANTITATIVE ASSESSMENTS THAT ENABLE COMPARABLE INFRASTRUCTURE INVESTMENT OPTIONS CAN FAVOUR NBS

The South Africa 2013 National Water Resources Strategy explicitly considers ecological and built infrastructure as mutually supportive elements of an integrated approach to managing water. However, investing in ecological infrastructure requires a thorough understanding of how, when and where society gains the greatest benefits from the hydrological cycle and the services provided by catchment areas. In order to obtain better quantitative information on the performance of various options, two ecological infrastructure options (removing large stands of invasive alien plants, planting trees and rehabilitating indigenous grassland and woodland) were compared to grey-infrastructure performance in and between two catchments in South Africa.

Previous investment had targeted rehabilitation of indigenous sub-tropical thicket on hillslopes that had been denuded by livestock grazing. Increasing vegetation cover in a catchment can reduce the annual average water supply due to increased evaporation. However, plot-scale observations demonstrated that rehabilitating thicket increases canopy interception, soil infiltration and conductivity, and soil moisture retention, and can also have significant desirable downstream impacts, such as decreased flood intensities, potentially increased baseflow and thus more sustained, reliable, valuable flows during the dry season. Rehabilitating thicket on degraded hillslopes can reduce surface runoff by half and hill-slope sediment loss six-fold, indicating that there are significant hydrological gains to be made through specific interventions to rehabilitate, maintain and protect priority ecological infrastructure.

The methodology to try to obtain quantitative information to compare options used unit reference values for the economic costs of quantified increased water supply. These ranged from ZAR1.17 to ZAR2.50 for ecological infrastructure, depending on the rehabilitation measures chosen and their location, compared to ZAR0.46–ZAR3.79 costs for existing dams but ZAR4.56–ZAR9.01 for new alternative grey infrastructure to increase supply. Significant gains in water supply were achieved through ecological infrastructure and, importantly, the increases in baseflow contributed to more valuable dry-season supply.

The above only assessed the benefits of investing in ecological infrastructure in terms of water supply (quantity) and reduced sediment loads. A significant advantage of rehabilitating and protecting functioning ecosystems is the multiple additional benefits that ecosystems provide when compared to single-purpose built infrastructure installations. Improving ecological infrastructure can also improve water quality, pollination services to adjacent cropland, grazing values, and access to medicinal plants, while reducing flood intensities and damages, removing carbon dioxide from the atmosphere, increasing game and livestock productivity, and providing ecotourism opportunities and improved recreational and cultural spaces.

The detailed assessments undertaken, using consistent hydrological and economic comparisons between water resources infrastructure investment options, show that rehabilitating ecological infrastructure could result in improved water security, support built infrastructure and simultaneously provide other benefits, including job creation potential that has not yet been realized and is financially viable and cost-effective.

Source: Mander et al. (2017).



Vertical forest building in Milan (Italy)



6 ENABLING ACCELERATED UPTAKE OF NBS



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Collecting rainwater data in the Tana River watershed (Kenya)



6.1 Introduction

This chapter assesses challenges to implementing NBS that constrain them reaching their full potential to contribute to the sustainable management of water. These challenges were considered when preparing Chapters 2 to 5 of this report and were fairly consistent among them. Consequently, information from Chapters 2 to 5 is amalgamated in this chapter together with information from other reviews of the topic, including Davis et al. (2015), Bennett and Ruef (2016) and other sources as referenced below. These challenges are global/generic, region-specific and place-based, and often applicable to NBS at large. They include:

- Overwhelming dominance of grey-infrastructure solutions for water management in the current instruments of governance. This dominance also exists in the orientation of economic markets, expertise of service providers, and consequentially in the minds of policy makers and the general public. These factors collectively result in a general inertia against the development and use of NBS and in bias against NBS, which are often perceived to be less efficient than built (grey) systems. The imbalance is significant. For example, although accurate figures are unavailable, data presented in Chapter 5 suggest that, despite increasing allocations to NBS in certain countries and regions, current direct investments in NBS appear to be less than 1% (globally), and probably closer to the order of only 0.1%, of the total investment in water resources infrastructure and management.
- A lack of awareness, communication and knowledge of what NBS can really offer to reduce water variability risks and to improve water quality and availability, compared to 'conventional' grey solutions – at all levels from communities to regional planners and national policy makers.

[14] Authors would also like to thank Penny Stock, Lisa Farroway and Saskia Marijnissen of UNDP, and Neil Coles of the University of Leeds for their precious comments.

> NBS do not necessarily require additional financial resources but usually involve redirecting and making more effective use of existing financing

- A lack of understanding of the ways to integrate green and grey infrastructure at scale, and an overall lack of capacity to implement NBS in the context of water.
- Myths and/or uncertainty about how natural infrastructure functions, and what ecosystem services mean in practical terms.
- Difficulties in providing clear evaluations of the performance of NBS-related projects. It is also not entirely clear, at times, what constitutes an NBS and what is a hybrid solution. There is a lack of technical guidelines, tools and approaches to determine the right mix of NBS and grey-infrastructure options.
- There is also an issue of land used by some NBS and the likelihood of tension and possible conflict with alternative land uses, even though grey infrastructure is also often directly land-consuming or can have indirect adverse impacts on land, and some NBS require (estimated) negligible proportions of a river basin area to achieve basin-wide effects. This also requires the involvement of many stakeholders, such as independent landowners, which can add to the complexity of implementation.

The required responses to the challenges identified essentially involve creating the right enabling conditions for NBS to be considered equitably alongside other options for water resources management. Interrelated areas where enabling conditions need to be improved include financing, the regulatory and legal environment, intersectoral collaboration including harmonizing policies across development areas, and the knowledge base underpinning NBS. The implementation of NBS will have to fit within the existing (or newly adapted) governance structures of the locations where they are being implemented. Strong enabling environments are needed, with supporting policies, plans and financing. Legal and regulatory frameworks should be supportive or at least neutral to enable promising NBS to be adopted. National frameworks can already have provisions encouraging ecosystem-based approaches or sustainable actions that can support increased implementation of NBS. Cross-sectoral cooperation (e.g. between ministries) is essential for implementation of most NBS at any scale.

An improved knowledge base, and in some cases a more robust science base, is an important requirement in most areas. Knowledge needs to be translated and disseminated into a user-appropriate form: for example, guidelines that enable specific NBS interpretations in the application of existing regulations. The development of new or the reform of existing policies, regulations and plans can help advance this process.

6.2 Leveraging financing

NBS do not necessarily require additional financial resources but usually involve redirecting and making more effective use of existing financing. It is estimated that approximately US$10 trillion will be required in water resources infrastructure between 2013 and 2030 (Dobbs et al., 2013). A key issue, therefore, is how NBS can contribute to reducing this investment burden through improved economic, environmental and social efficiencies in investment outcomes. However, there are indications of increasing investments in NBS (see Section 5.2.2). For example, an estimated US$25 billion was invested in green infrastructure for water worldwide in 2015, with an estimated annual increase in investment of more than 11% over the previous year (Bennett and Ruef, 2016). A trigger for this progress is the increasing recognition that deploying nature-based approaches can create system-wide solutions by optimizing the generation of ecosystem services to make investments more sustainable and cost-effective over time. Hence, as evidenced in previous chapters, there is growing interest from the science, political and financing communities to refine knowledge on how to design NBS and scale up investment capital to put them into place. An essential ingredient in achieving this outcome will be improved, more holistic and innovative approaches to financing.

Davis et al. (2015) noted a lack of specific financing mechanisms for investment in NBS. However, a diversity of financing instruments and approaches is being created to make investments in NBS that provide value to society. Several examples of financing approaches based on payments for watershed services were presented in Chapter 5. Bennett and Ruef (2016) found that investment in watersheds is predominantly done locally, with nearly 90% of those investments coming via government programmes to subsidize landholders directly with payments to take actions for watershed protection. An emerging 'green bond' market shows promising potential for mobilizing NBS financing and, notably, demonstrates that NBS can perform well when assessed against rigorous standardized investment performance criteria (Box 6.1). In this field, the Climate Bonds Initiative (CBI)[15] has noted that the global green and climate bonds markets could have an expanded role in influencing, capacitating and helping to leverage private capital to invest in NBS and green infrastructure.

[15] The CBI is an international, investor-focused not-for-profit organization. See www.climatebonds.net/about.

BOX 6.1

FINANCING WATER RESILIENCE: THE EMERGENCE OF GREEN AND CLIMATE BONDS FOR WATER

In 2007, the European Investment Bank and the World Bank began issuing 'green bonds' (which have also come to be known as 'climate bonds') as a loan mechanism to demonstrate the economic advantages of environment-positive investments and assets. A 'green bond' is different from a regular bond in that it signifies a commitment to use the funds raised exclusively to finance or refinance environmentally beneficial projects, assets or business activities (ICMA, 2015), while a climate bond more specifically refers to an asset or project that has a climate mitigation or adaptation focus. Many water infrastructure projects at national and subnational levels are financed through bonds. In the developed world, single bonds for entities such as city water utilities can easily amount to several hundreds of millions of US dollars.

As an investment category, green and climate bonds remained relatively niche markets with limited impact until about 2013. That year, issuances tripled to about US$10 billion after commercial finance and corporate institutions began promoting the market. These trends accelerated in 2014 (US$35 billion) and passed US$80 billion in 2016, which looks favourable in the light of the Paris Agreement's UNFCCC call for reaching US$100 billion for climate finance by 2020 (CBI, 2017). While the market pool has grown rapidly, most bonds were initially offered with limited evidence of safeguards. Moreover, the sensitivity of water-related investments to climate impacts highlighted the need for these investments to demonstrate robustness and climate adaptation efficacy. In 2014, a consortium of NGOs – Ceres, the CBI, the World Resources Institute, the CDP*, the Stockholm International Water Institute (SIWI) and the Alliance for Global Water Adaptation (AGWA) organized a series of technical and industry working groups that defined scoring criteria for issuers and verifiers to provide investor confidence in the climate and green bonds market, making use of more than one hundred experts in aquatic ecosystems, engineering, governance, environmental economics and hydrology. These criteria score the climate-adaptive potential of the bonds in addition to their environmental impact based on the most recent evidence and science for evaluating robust and flexible water management solutions (Walton, 2016).

Phase one of the work targeted traditional 'grey' water infrastructure investments with the exclusion of hydropower, while phase two focused on the use of NBS as well as on hydropower criteria. In many ways, these criteria serve to bridge knowledge and awareness gaps between the technical water management community and finance and investor audiences. As such, the criteria serve as a powerful communication tool about the issues surrounding resilience and water assets (Michell, 2016). The successful issuance in 2016 of the first bond scored against the standard represents a vivid shift in investor awareness,** with dramatic reactions from the development finance, investor and water management press (Lubber, 2016), as well as major public institutions (e.g. the USA's promotion of the CBI standard for 2016 World Water Day***). Within a year of finalizing the phase-1 criteria, more than US$1 billion had been issued against the standard, including the first African issuance from Cape Town, with scoring supported by KPMG. The standard has gone some distance towards filling gaps between the climate change, water and finance communities.

Contributed by John H. Matthews (AGWA).

* Formerly known as the Carbon Disclosure Project

** www.waterworld.com/articles/2016/05/san-francisco-public-utilities-commission-issues-world-s-first-certified-ggeen-bond-for-water-infrastructure.html

*** www.ooskanews.com/story/2016/03/agwa-presents-two-new-initiatives-white-house-water-summit_170615

Improving the understanding within the financial sector of the ways to execute this remains a critical challenge, but there is evidence that a shift is taking place in this regard.

The private sector can also be further stimulated and guided to advance NBS in the areas in which it operates. Businesses are increasingly interested in investing in natural capital and NBS driven by a convincing business case. Business drivers for NBS include resource limitations, regulatory requirements, changing climate and severe weather events, stakeholder concerns, direct financial benefits, and operational, financial and reputational gains from environmental and social co-benefits (WBCSD, 2015a). NBS recognize ecosystems as natural capital, which the Natural Capital Protocol[16] defines as the stock of renewable and non-renewable natural resources (e.g. plants, animals, air, water, soils and minerals) that combine to yield a flow of benefits to people. The Natural Capital Protocol provides a standardized but fit-for-purpose method, used by numerous firms worldwide, to measure, value and integrate natural capital into business processes in order to support them to develop strategies and investment and action plans. However, companies often lack in-house expertise and sometimes may not even be aware of NBS

[16] For more information on Natural Capital and the Natural Capital Protocol, see naturalcapitalcoalition.org/protocol/.

> An emerging 'green bond' market shows promising potential for mobilizing NBS financing and, notably, demonstrates that NBS can perform well when assessed against rigorous standardized investment performance criteria

and the effectiveness of those solutions. To overcome such barriers, companies can train staff, either together with an independent organization or using guides targeted for corporations. For example, the *Natural Infrastructure for Business* training course,[17] developed by the World Business Council for Sustainable Development (WBCSD) in collaboration with UN Environment and with support from Wetlands International, Arcadis and Shell, is a useful, freely available resource derived from concrete business experience in working with NBS. Companies can also develop an organizational framework for NBS that can be applied across different business functions (e.g. operations, finance, investor relations, etc.) to identify how they can contribute to NBS. This can help facilitate understanding of NBS across functions and its potential added value, including direct financial benefits. Business can also expand partnerships to co-develop NBS. Collaboration with neighbouring communities and NGOs can help companies secure their social license to operate and multiply the social and environmental co-benefits that can be derived from NBS.

The Natural Capital Financing Facility is a financial instrument that combines European Investment Bank financing and European Commission funding under the LIFE Programme, the EU's funding instrument for the environment and climate action.[18] The Facility provides financial support to projects focused on biodiversity and ecosystem services that generate revenue or save costs. In doing so, the Facility aims to convince the market and potential investors of the attractiveness of biodiversity and climate adaptation operations in order to promote sustainable investments from the private sector.

[17] For more information on the Natural Infrastructure for Business training course, see www.naturalinfrastructureforbusiness.org/resources/#training.

[18] For more information on the Natural Capital Financing Facility, see www.eib.org/products/blending/ncff/index.htm

Improving ecosystem and natural resource valuation methods are providing the necessary tools to mainstream NBS in decision making. For example, the wealth accounting and valuation of ecosystem services (WAVES) approach provides better-informed decisions regarding infrastructure and the regulation of water quality and quantity in national accounting systems (World Bank, n.d.).

Agriculture represents a significant area for financing further uptake of NBS. However, it is difficult to assess current and potential investments, because they are usually part and parcel of broader investments in improving agricultural sustainability. Collectively, the OECD countries alone transferred an annual average of US$601 billion to agricultural producers in the years 2012–14 and they spent an additional US$135 billion on general services that support the overall functioning of the sector. Some large emerging economies have begun to reach the average level of support provided by OECD countries (OECD, 2015b). However, the vast majority of agricultural subsidies, and probably the majority of public funding and almost all investment by the private sector for agricultural research and development, support conventional agricultural intensification that increases water insecurity (FAO, 2011b). Mainstreaming the concept of sustainable ecological intensification of agricultural production, which essentially involves deploying NBS (improved soil and landscape management techniques), is not only the recognized way forward in order to achieve food security (FAO, 2014a), but would also be a major advance in NBS financing.

Finance can do more than just channel investments. It can also guide project development towards bankable and suitable NBS. Governments regularly provide guidance to state investment funds, sovereign wealth funds and similar instruments to create investment filters that will support a sustainable economy. The same can apply to green investments. By putting green mandates in place, policy makers signal to bond issuers that there is robust demand for their green bond issuance (CBI, n.d.). The experiences from market and blended instruments with green bonds can be useful for other financial sector actors to join or replicate worldwide so they become pilots themselves, testing different options for investment tools that can effectively support NBS in different settings. The further coordination, knowledge sharing and co-development of similar standards among green and other bonds or instruments would have a profound positive impact in accelerating flows of available financial capital into NBS and likely make those investments provide better returns and greater value to society.

Assessing co-benefits of NBS (through a more holistic cost–benefit analysis) is an essential step in achieving efficient investments and tapping into financial resources across multiple sectors. For example, NBS are a key solution to meeting shortfalls in the projected needs for financing biodiversity conservation through redirecting existing investments, particularly in water management infrastructure and agricultural development (UNDP/BIOFIN, 2016). All benefits, not just a narrow set of hydrological

outcomes, need to be factored into assessments of investment options. This requires a detailed systematic approach, but will lead to significant improvements in decision making and overall system performance. For example, Mander et al. (2017) provide a useful tool or methodology for more holistic valuations of hydrological and other outcomes of investment options that can greatly benefit investment choices, showing that the co-benefits of NBS can often swing investments decisions in their favour (see Box 5.13).

Nonetheless, there is still a considerable gap between how the business and finance communities assess the importance of support to wise investment in NBS, and their current ability to mobilize investment into concrete projects and development planning (CBI, 2017). An enormous challenge, seen at all scales (national, regional and global), is the gap between available potential capital for investment and bankable projects supported by capable implementation bodies to perform them. This is often partially a result of a mismatch in knowledge and capacity between stakeholder groups – those with technical knowledge of NBS often do not themselves have the knowledge about available financing and the requirements to access it, and vice versa, finance specialists often do not recognize or appreciate NBS. Clearly, improved communication between these two groups will be key to accelerated progress.

6.3 Enabling the regulatory and legal environment

6.3.1 National and regional regulations and frameworks

Davis et al. (2015) noted that current regulatory and legal environments for water were developed largely with grey-infrastructure approaches in mind. Consequently, it can often be challenging to retrofit NBS into this framework. Achieving progress in the full deployment of NBS, therefore, requires that governments assess, and where necessary modify, their legal and regulatory regimes to remove barriers to NBS uptake. For example, the city of Basel in Switzerland has developed the largest area of green roofs per capita in the world, through investment in incentive programmes to provide subsidies for their installation, and extended this by passing a Building and Construction Law requiring green roofs on all new developments with flat roofs, including an amendment that stipulates associated design guidelines to maximize their contribution to biodiversity (Kazmierczak and Carter, 2010; EEA, 2016).

Drastic changes in regulatory regimes may not necessarily be required and much can be achieved by promoting NBS more effectively through existing frameworks. For example, the European Commission in 2013 adopted the *Green Infrastructure Strategy* (EC, 2013b) to promote the development of green infrastructure in rural and urban areas in the EU.

In places where enabling legislation does not yet exist, identifying where and how NBS can support existing planning approaches at different levels can be a useful first step in this process. For example, the European Commission produced a policy document on 'natural water retention measures' (EC, 2014), highlighting both their potential contribution to the implementation of multiple directives (water, floods, habitat, etc.) as well as to river basin management plans. While it does not mandate their use, it has been followed by the creation of regional support networks and new communities of practice in major river basins.

In some cases, direct policy levers can enable easier uptake of NBS or remove direct barriers. Bennett and Ruef (2016) provide several examples: in California, a new law was introduced in 2016 that allows forests and meadows to qualify as water infrastructure, which in turn enables available water infrastructure financing to be used to protect or restore landscapes that are used for water supply; Peru directly mandates utilities to allocate revenues from water tariffs to invest in green infrastructure and NBS for climate adaptation; and in the EU, the Common Agricultural Policy includes a target for spending 30% of the direct payments provided through EU farm subsidies for the improved use of natural resources (i.e. 'greening' measures, which include multiple possible farm-level NBS). These policies provide public authorities with a vehicle to access new or existing processes that allow them to select, fund and implement NBS.

For cities to be able to adopt a wide range of NBS, they generally need to fall under a specific plan or strategy, or NBS need to be integrated into the overarching development plan (Kremer et al., 2016). Each city, region or country will find different options that make sense within their existing plans and financing mechanisms. In Barcelona, for example, a 'Green Infrastructure and Biodiversity Plan' was adopted, which suggested programmes for implementation and a 'catalogue of potential actions' that included a range of NBS (Oppla, n.d.). In China, large national investments to support demonstration cities to create 'sponge city' (see Box 2.6) planning and design is a similar avenue to test and expand NBS within SUDS schemes (Horn and Xu, 2017).

6.3.2 Leveraging international and global frameworks

At the global level, NBS offer Member States a means to respond to and use various multilateral environmental agreements, such as the Convention on Biological Diversity, the UNFCCC and the Ramsar Convention on Wetlands, as well as the Sendai Framework on Disaster Risk Reduction, which includes food security (see Chapter 1 for further details), and the Paris Agreement on Climate Change, whilst also addressing economic and social imperatives. Each of these should be incorporated into relevant national regulations and policies that influence decision making at provincial and local scales and involve mainstreaming NBS. Since many NBS are implemented at the local level, Member States can review their overall policy framework,

ensuring that at the appropriate decision-making level the correct incentives and supporting policy-making environment are in place enabling the adoption of NBS where justified. An overarching framework for promoting NBS is the 2030 Agenda for Sustainable Development and the SDGs (discussed further in Chapter 7).

6.4 Enhancing intersectoral collaboration and harmonizing policies

6.4.1 Intersectoral collaboration

A well-documented challenge is that NBS can require much greater levels of intersectoral collaboration than grey-infrastructure approaches, particularly when applied at landscape scale. NBS often cross many sectoral areas of interest (for example between those working with water management, agriculture, forestry, urban planning, ecological protection, etc.) and stakeholders have different perspectives and priorities for any proposed NBS (Nesshöver et al., 2017). However, this can also open opportunities to bring those groups together in a common project or agenda.

An NBS can come across as more useful to a planner when the discussion focuses on a clearly identified problem and is presented as an alternative or complement to other options (Barton, 2016). This will help strengthen uptake of NBS within the overall design of policies, measures or actions to address diverse challenges. For an NBS to be brought forward successfully, it should be clear what it will offer, how much it will cost, how it should be managed and who will be able to do it.

A set of 'green infrastructure case studies' involving businesses have been collected and evaluated by participating companies (Dow Chemical Company/ Swiss Re/Shell/Unilever/TNC, 2013). These range from constructed wetlands and stormwater management to treatment, decontamination and erosion control. Key lessons relate to time perspectives, where a long-term view favours NBS over grey solutions, and the need to set boundaries that are sufficiently large to include ecosystem services and, importantly, upper management buy-in along with a champion to push the project.

The agriculture sector has also been making advances: for example, the rapid uptake and spread of croplands under low tillage or conservation agriculture more than tripled from an estimated 45 million ha of croplands in the 1990s to about 157 million ha today (AQUASTAT, n.d.), representing just over 1% of land currently under permanent crops. Moreover, uptake is highly variable between regions and differences appear to have more to do with enabling environments than with economic or biogeological-climatic factors. Notably the existence of an institutional, political and commercial interest bias that works contrary to sustainable solutions seems to be a decisive factor (Derpsch and Friedrich, 2009). A key ingredient of the success of conservation agriculture has been the recognition by farmers that the approach delivers improved farm productivity and sustainability, in addition to off-farm environment benefits. This illustrates that win-win outcomes of NBS need to be better identified and promoted to encourage broader stakeholder engagement and to promote improved coordination. Where there are losers, these need to be identified and where necessary compensated.

6.4.2 Harmonizing policies across multiple agendas

Harmonizing multiple policy areas at global, international, national, provincial and local scales is a key need for sustainable development. NBS offer a means to operationalize policy across scales and economic, environment and social dimensions. This is also, in a sense, a key means of promoting intersectoral collaboration through the development of consensus on policy objectives in a particular situation.

In many countries, the policy landscape remains highly fragmented. Better harmonization of policies across economic, environment and social agendas is a general requirement in its own right, but particularly important regarding NBS because of their ability to deliver multiple, and often significant, co-benefits beyond just hydrological outcomes. The social impacts of green-space management strategies, for example, contribute to a range of public health and well-being outcomes that can also drive public interest or bolster political support for their implementation. These include positive effects of green spaces on residents through psychological relaxation, stress relief, enhanced opportunities for physical activity, reduced depression and improved mental and physical health (Raymond et al., 2017). The European Commission's NWRM (EC, 2014) also provide recommendations to coordinate planning and financing within other policy arenas such as the WFD and the Floods Directive. In Germany, an assessment identified the precise policy targets set out by the government where investments in NBS could be directed to help achieve them, including its climate change mitigation goal, as well as its national strategies for adaptation, biodiversity and forest protection (Naumann et al., 2014). Four different ministries with a different thematic emphasis collaborate closely to ensure an integrated approach for the successful implementation of China's 'sponge city' approach (see Box 2.6). The National Development and Reform Commission provides specially allocated funds on sponge city construction, the Ministry of Finance promotes private–public partnerships and direct financial support, the Ministry of Urban and Housing provides systemic guidance on objectives, technological standards and evaluation, and the Ministry of Water Resources provides functional guidance and supervision on water conservation aspects (Embassy of the Kingdom of the Netherlands in China, 2016; Xu and Horn, 2017).

Clear mandates from the highest policy level can significantly accelerate NBS uptake and foster improved intersectoral coordination. In the USA, for example, a 2015 Presidential Memorandum (The White House,

2015) mandated federal agencies to consider green infrastructure in their decision making and launched a natural resource investment centre. In response, the Department of Energy and the Environment in Washington DC provides training and guidance on the use of green infrastructure for stormwater reduction, including training on General Compliance, Generation and Certification of Storm-water Retention Credits and Discounts on Storm-water Impervious Fees, Green Area Ratio and Best Management Practices for Green Infrastructure Construction and Inspection.[19] The United States Environmental Protection Agency (US EPA) has a series of factsheets that describe *"how EPA and state permitting and enforcement professionals can incorporate green infrastructure practices and approaches into National Pollutant Discharge Elimination System wet weather programs, including storm water permits, Total Maximum Daily Loads, combined sewer overflow long-term control plans and enforcement actions."* (US EPA, 2015, p. 2).

Two commonly used key tools to assist more integrated approaches to water resources management, including addressing multiple stakeholder groups, are integrated land use planning and IWRM. However, in practice, both often fail to adequately include the water–ecosystem dimension: land use planning often fails to fully factor in land use implications for water resources and IWRM (in practice) is often over-focused on managing surface and groundwater allocations and neglects ecosystem influences, including the impacts of land use change. Both tools also too often fail to consider ecosystem services as a framework for assessment, leading to significant omissions of important impacts of management choices. A key response, therefore, is the full integration of ecosystems and ecosystem services into land and water use planning.

6.5 Improving the knowledge base

6.5.1 Improving knowledge and dispelling myths

The subject of the interaction between the natural environment and water is plagued by myths, misinterpretations and too hasty generalizations (Bullock and Acreman, 2003; Andréssian, 2004; Chappell, 2005; Tognetti et al., 2005). This does not help build confidence in NBS applications. Inferences or assumptions are made, often mistakenly, about the hydrological functions operating in ecosystems and thus how effectively they may alter the hydrological cycle and provide benefits to people. As noted in Chapter 1, there is a wide variation in the hydrological and other services delivered by different ecosystem types. This means that NBS applications need to be based less on generalized assumptions, and better assessed and designed specifically for local applications. A contributing factor is often a lack of rigour,

> An NBS can come across as more useful to a planner when the discussion focuses on a clearly identified problem and is presented as an alternative or complement to other options

if not misunderstanding, regarding the precise hydrological pathways in play and how these are influenced, or not, by ecosystem management interventions. Raymond et al. (2017) summarized key knowledge gaps in the assessment of impacts from NBS (focused on urban areas), noting that the impacts of NBS on the environment are well understood, but their cost-effectiveness and the sustained delivery of different benefits is often unclear. An improved knowledge base, including in some cases more rigorous science, is an essential overarching need. Established evidence helps convince decision makers of the viability of NBS. Perceptions of uncertainty around their performance and cost-effectiveness, limited access to information and guidance on their design, implementation, monitoring and assessment, as well as fear of high implementation costs, are all identified constraints to implementing NBS (Davis et al., 2015). The most fundamental requirement is the capacity to instil confidence that an NBS can provide the primary water service objective it is meant to fulfil; although consideration of the non-hydrological co-benefits may still tip decisions in their favour (Mander et al., 2017). Also, disincentives occur when a poorly designed NBS fails. This contributes to the bias towards grey solutions.

However, criticism of the evidence base for NBS is another illustration of how differently green and grey approaches are treated. For example, the hydrological and socio-economic evidence underpinning some grey infrastructure sets a very low bar against which NBS might be judged. The World Commission on Dams (2000), for example, dispelled the perception that mega-infrastructure projects are always built on solid scientific, economic and technical foundations, with large dam projects exhibiting a high degree of variability in projected benefits, often falling short of physical and economic targets, and having significant cost overruns, while their true profitability remains elusive since their environmental and social costs have often been poorly accounted for in economic terms. The Commission was also *"disturbed to find that substantive evaluations of completed projects are few in number, narrow in scope, poorly integrated across impact categories and scales, and inadequately linked to decisions on operations"* (The World Commission on Dams, 2000, p. xxxi). The World Commission on Dams country study on India concluded that a century or more of large-scale water development had resulted in

[19] For more information, see doee.dc.gov/node/619262

> NBS applications need to be based less on generalized assumptions, and better assessed and designed specifically for local applications

major social and ecological impacts, including substantial human displacement, soil erosion and widespread waterlogging while, contrary to stated objectives, achieving only limited food security benefits (Rangachari et al., 2000). Nevertheless, NBS are required to have a strengthened science and knowledge base to support their accelerated uptake. NBS are indeed often not as predictable as conventional grey-infrastructure solutions. While there is a wealth of historical cost-and-benefit data on built infrastructure for water resource management, this is generally not the case for NBS options (UNEP-DHI/IUCN/TNC, 2014). The best way forward is to embrace continual innovation and research during implementation and to adaptively manage NBS in a scientifically rigorous manner, acknowledging that ecosystems are dynamic and complex (Mills et al., 2015).

Another frequently raised concern is that NBS take a long time to achieve their impact, implying that grey infrastructure is quicker. This is not necessarily the case. For example, fitting a local sustainable urban drainage facility or a green roof can be done within days, with immediate impacts. Applying these at scale may indeed take longer, but not necessarily longer than grey alternatives. Shifting cropland management to more sustainable low tillage ('conservation agriculture') can yield benefits in two to three years (Derpsch and Friedrich, 2009). Landscape-scale deployment of NBS, through ecosystem restoration for example, can take longer, but significant impacts can be achieved in about ten years (see Box 2.2). By comparison, large dams on average take 8.6 years to be physically constructed (not including the time required for design, planning and financing) and eight out of ten large dams suffer a schedule overrun (Ansar et al., 2014).

Another often overstated assumption about NBS is that they are 'cost-effective', whereas this should be established during an assessment, including consideration of co-benefits. Also, whilst some small-scale NBS applications can be low- or no-cost, some applications, particularly at scale, can require large investments: for example, ecosystem restoration costs vary widely from a few hundred to several millions of US dollars per hectare (Russi et al., 2012).

While there is little debate that humans receive invaluable services from ecosystems and are highly dependent upon them, the methods to identify and value these services and integrate valuation into planning and decision-making processes is still a large governance challenge (Kremer et al., 2016). Different forms of multi-criteria analysis can be used to better inform decision making on NBS projects (Liquete et al., 2016). These are most useful when they can evaluate a possible NBS against alternative options, which may include grey or hybrid grey–green infrastructure or maintaining a current situation.

NBS, naturally, are closely aligned with traditional and local knowledge, including that held by indigenous and tribal peoples, in the context of water variability and change. Indigenous and tribal peoples care for an estimated 22% of the Earth's surface, and protect nearly 80% of the remaining biodiversity on the planet, while representing only close to 5% of the world's population (ILO, 2017). For NBS to adequately benefit from contributions of indigenous and tribal peoples, and other sources of knowledge, it is imperative that their socio-economic and environmental vulnerabilities are addressed, and their rights are respected. The Indigenous and Tribal Peoples Convention 169 of the International Labour Organization (ILO, 1989) is an international treaty that provides guidance for ensuring indigenous peoples' empowerment and promotes their traditional knowledge, cultures and ways of life. Increasingly, global international processes, such as the Sendai Framework for Disaster Risk Reduction, and the Paris Agreement on Climate Change are recognizing the valuable role that indigenous peoples and their traditional knowledge make towards building resilient societies.

Traditional ecological or local-community knowledge of ecosystem functioning and the nature–society interaction can be invaluable, but there are frequent constraints to its incorporation into assessments and decision making. Traditional knowledge is also threatened by the conflict of commercial uses of natural resources and by the delicate social fabric of some societies (Tinoco et al., 2014). One response to this is to ensure that the holders of knowledge are fully and effectively involved in assessments, decision making, implementation and management. More generally, awarding community-driven NBS is a way to highlight how such solutions can fit into locally sustainable development (Box 6.2).

Equally important to knowledge itself is the means by which it is communicated. Methods to test the capacity of NBS to provide water services, for example, can be translated into manuals, which can be understood by both engineers and ecologists but targeted to provide guidance to policy makers and local managers and contractors who would implement a given NBS in practice (Hulsman, 2011). The knowledge challenge can be even more important in many developing countries where technical capacity for implementing alternative approaches is often lower than in developed countries (Narayan, 2015; Jupiter, 2015). However, there are sources for learning and approaches to emulate. For example, in the Mekong region the ADB and

the International Centre for Environmental Management created a seven-volume toolkit to support city authorities, infrastructure engineers, environmental assessment specialists, decision makers, urban planners, flood and drought specialists, and local community representatives to better understand where and how they can incorporate NBS in sustainable and resilient town planning (ADB, 2015).

More diverse examples of delivery against performance indicators could support a stronger evidence base to make the case for NBS more convincing. Tailored information suited to the needs of stakeholders is needed and may have to encompass the economic value presented, possible risk reduction, benefits generated etc., as well as a broad range of social and cultural values related to ecosystems and their management across different spatial scales (Brown and Fagerholm, 2015; Plieninger et al., 2015; Raymond and Kenter, 2016). In addition to a diagnosis of the potential value proposition and the barriers to investment in, and implementation of, the specific NBS, attention to community engagement in the valuation, design and delivery of NBS are also essential parts of this process.

6.5.2 Information and research gaps

Some clear information gaps and research needs have been identified in preparing this report. These include improving the:

- understanding of the hydrological performance of different ecosystem types and sub-types, including under different management regimes, to enable improved projections of NBS performance in locally specific sites;
- knowledge of the hydrology of LULUC, particularly its impacts at scale;
- understanding of the impacts of ecosystem loss and degradation on hydrology;
- understanding of the links between ecosystems, water and ecosystem services to better underpin predictions of the impacts of (positive or negative) ecosystem change on human well-being;
- assessments of the hydrological and socio-economic performance of NBS applications, and sharing this knowledge, including of NBS failures. Raymond et al. (2017) suggest a potential roadmap for assessing the performance of NBS;
- indicators for the effectiveness and efficiency of NBS and in particular those that enable ecosystems, hydrology, and economic and social outcomes to be linked;
- guidelines for conducting holistic cost–benefit analyses that include non-water-related co-benefits;
- communication tools for NBS;
- integration of ecosystems into land use planning and IWRM; and
- understanding of the socio-political drivers of water resources policy and management to better understand and identify effective triggers to stimulate transformational change.

BOX 6.2

THE EQUATOR INITIATIVE: ADVANCING NBS INVOLVING INDIGENOUS COMMUNITIES

The Equator Initiative is a partnership that brings together the United Nations, governments, academia and civil society organizations ranging from international NGOs to grassroots and indigenous peoples' organizations to build capacity and raise the profile of efforts that advance NBS to local sustainable development in several countries. The related Equator Prize is awarded biennially to recognize outstanding community efforts to reduce poverty through the conservation and sustainable use of biodiversity. The Equator Initiative's Knowledge Center also holds an NBS database and interactive map.

Several projects involve the rediscovery of ancestral water management systems as well as traditional rainwater harvesting techniques to improve the quality of drinking water. Reinstitution of rainwater harvesting may be necessary because of new pressures, such as oil spills and wastewater dumping that inhibited the use of some rivers in the case of Ecuador, or because of saline water intrusion in the case of the coastal city of Barisal in Bangladesh.

Water harvesting at the broader scale can also be important for sustaining livelihoods and habitats. The Centre for Development in India supports community education on ancestral survival systems. For this, a demonstration project with community governance structures involving the regeneration and maintenance of village committees, combined with increased incomes and livelihood security, was developed, with the potential of replication, to improve the balance between humans and nature.

Watershed management also involves the preservation and rehabilitation of the native vegetation cover, as in the River Ethiope in Nigeria, where such initiatives have helped to mitigate the impacts of erosion and channel siltation in headwaters streams, and to reconnect fragmented stream sections and native vegetation reserves.

The community-based projects working particularly with indigenous peoples show feasible ways to address future challenges of increasing unreliability of water sources due to pollution or other changes in water regimes. The community-driven water projects can foster a more diverse and locally adapted set of solutions to water and natural resources management, and taps into existing and increasingly disappearing knowledge about the local environment and how to sustainably make use of its resources through solutions that are inherently nature-based.

Source: Equator Initiative (n.d.).

Contributed by Marianne Kjellén (UNDP).

As noted in all previous editions of the *World Water Development Report*, there are needs for improved data across the board regarding water availability, quality and risks, and no less so as these relate to NBS and their benefits. Better data are required for the status and trends of all water-related ecosystems. However, particular note is made of the very poor data availability for soils in view of their influence on hydrology, their importance to food security and in particular the extended time-frame for their formation and consequently for their replenishment, in comparison to other ecosystem types, which can span centuries (FAO/ITPS, 2015a). However, an improved scientific basis for water management, regulation and policy will not come merely from obtaining more data and information on more indicators but from acknowledging that a perceptual shift to larger temporal, spatial and organizational scales is equally necessary (Bedford and Preston, 1988).

6.6 A common framework and criteria for assessing options

A well-recognized challenge to uptake of NBS is that various water sectors or sub-sectors tend to use their own specific individual methods for assessment, monitoring and evaluation, including for assessing the return on investment over time. The development and implementation of common criteria against which both NBS and other options for water resources management can be assessed is a priority requirement for enabling an equitable consideration of the costs and benefits of options. Cohen-Shacham et al. (2016) provide suggestions for criteria to assess the viability of NBS, whilst Raymond et al. (2017) provide a detailed review of indicators for NBS assessment and monitoring, many of which would also be relevant for other water management options. Ongoing work on developing common criteria and standards for assessing potential NBS investments, compared to grey-infrastructure options, was briefly discussed in Section 6.2 (see also Box 6.1).

Common general criteria for an assessment of water resources management options (e.g. green versus grey solutions) can be developed on a case-by-case basis. The full inclusion of all hydrological benefits and other co-benefits and the full range of the costs and benefits of ecosystem services (for any option) would be a key requirement. However, it is likely that more detailed criteria for applications in key areas (e.g. urban infrastructure, agriculture and DRR) would also be needed. This will require consensus building across the various relevant stakeholder groups and, therefore, further details are not proposed here. A common framework and criteria for assessing any option will form essential contributions to the achievement of sustainability and equity in water resources management outcomes.



Polder landscape in the Netherlands



7 REALIZING THE POTENTIAL OF NBS FOR WATER AND SUSTAINABLE DEVELOPMENT



WWAP | David Coates, Richard Connor, Angela Renata Cordeiro Ortigara, Stefan Uhlenbrook and Engin Koncagül

Green skyscraper building in Sydney (Australia)



This *World Water Development Report* concludes that there is great potential for NBS to make significant, and in many areas unique and essential, contributions to achieving sustainability of water resources and meeting various water management objectives. This fact is currently widely underappreciated.

This chapter draws conclusions regarding the three key questions concerning NBS:

- What is the current status of NBS applications?
- What is the potential for their further application?
- What needs to change to realize that potential?

Drawing upon conclusions and lessons learned from previous chapters, an overview of the current status of how NBS contribute to water resources management is presented, followed by an assessment of their potential contribution to meeting contemporary and future water resources management challenges. This is followed by a description of the key changes required to achieve the full potential of NBS. The chapter concludes by demonstrating how NBS for water also contribute to achieving the 2030 Agenda for Sustainable Development and the SDGs.

Although this report has assessed NBS for improving water availability, quality and risks in separate chapters (2, 3 and 4, respectively), whilst recognizing the linkages between them, a key point is that most NBS deliver benefits in all three areas simultaneously. It is rare for NBS to be deployed for a single purpose and usually they are favoured because they improve overall system performance, including increasing resilience. In addition, all previous chapters have highlighted the significant co-benefits that NBS usually deliver beyond direct water-related outcomes, such as improved biodiversity outcomes, landscape values, social and economic benefits and system sustainability. Such co-benefits often tip individual assessments of options in favour of NBS and certainly argue for their strengthened consideration overall.

7.1 Where are we now?

Although there has been no comprehensive quantitative assessment of the current application of NBS worldwide, two points are well established.

Firstly, there has been considerable application of NBS in water management throughout history, across all three of its dimensions – water availability, water quality and water-related risks. The topic is not new. There are existing knowledgeable, experienced and enthusiastic communities of practice across many sectors or fields. In most cases, NBS are not primarily driven by environmental lobbyists. There are notable examples of where NBS innovations, and upscaling, have been led by sectoral interests. This bodes well for expanded uptake as it demonstrates their accepted utility. For example: in agriculture, applications are widespread and led by farmers and/or their support institutions and the integration of NBS into agricultural policy frameworks has demonstrably been led by agricultural agencies; NBS are already mainstreamed into some business sector approaches because of how they contribute to a sustainable business model; and green infrastructure has a long history of deployment led by enlightened civil engineers and traditional community-based initiatives. Environmental institutions, particularly at national level, are uniquely qualified to proactively come forward with NBS that also address the challenges faced by other sectors and to cooperatively identify win-win outcomes. This requires broadening their historical focus on the conservation of the 'natural' environment through rules and regulations, to also increase support for environmentally sustainable progress in managed or highly modified systems.

Secondly, there is ample evidence that attention to NBS is increasing. For example: investments in PES schemes, implemented through, for example, conservation and water funds, are increasing (see Chapters 3 and 5); rapidly escalating investments in urban green infrastructure demonstrate increasing uptake; and emerging 'green bond' markets show promising potential for mobilizing NBS financing and, notably, demonstrate that NBS can perform well when assessed against rigorous standardized investment performance criteria (Chapters 5 and 6). As might be expected, NBS have become mainstream in multilateral environmental agreements as they transition towards more explicitly linking environment to sustainable development and particularly so within the last ten years (Chapters 1 and 6). Importantly, NBS are now becoming mainstreamed into other relevant policy forums, including for food security and sustainable agriculture (Chapter 2), disaster risk reduction (Chapter 4), and financing (Chapter 6).

There is clear evidence across all chapters that the costs and benefits of NBS can compare favourably with alternative grey-infrastructure options, especially when considering the multiple co-benefits they deliver over the medium and longer term, although Chapter 6 points out that this is not always well established, and improved assessment, monitoring and evaluation of NBS are required if progress in the field is not to be undermined.

Although the optimum balance between green and grey investment is not well established and highly site-specific, the limited data available suggest that investment in green infrastructure remains only a fraction (possibly less than 1%) of total investment in water resources management. In addition, there remain many examples of policies, financing and management interventions where NBS are absent, even where they present an obvious option. Overcoming the significant challenges to upscaling NBS, which vary from the overwhelming dominance of 'conventional' grey-infrastructure solutions to an overall lack of awareness and understanding of what NBS can offer, essentially involves creating the right enabling environment for NBS to be assessed, and where appropriate financed and implemented, across a more level playing field (Chapter 6). NBS practitioners must play their role through improving the knowledge base, including demonstrating more robust assessments of NBS, in order to increase confidence in NBS and the capacity to evaluate and implement them.

7.2 How much further can we go?

This report concludes that increased deployment of NBS is central to meeting the key contemporary water resources management challenges of sustaining and improving water availability and its quality, while reducing water-related risks. It is well established in both the scientific literature and through policy consensus that, without a more rapid uptake of NBS, water security will continue to decline, and probably rapidly so. Assessing the relative potential for green versus grey approaches can not only be challenging but also distracting. As this report has argued, both are already, and should be, mutually supportive. Nevertheless, NBS are essential to achieving progress in a number of water resources challenge areas and are the only viable option to meet some major challenges over the long term. Previous World Water Development Reports, among others, have consistently argued that sustainable water security will not be achieved through business-as-usual approaches. NBS offer a key means to move beyond business-as-usual. However, the necessity for increased deployment of NBS is currently underappreciated. Justification for such claims arises from many factors, including:

- Ecosystem conservation and restoration is the primary response to reverse current trends in ecosystem degradation and their impacts on water, which have become a primary factor determining the current negative state of water resources (Prologue) – including mitigating water-related disaster risks, which are exacerbated by climate change and other global changes (Chapter 4).

- The assessment of the potential for NBS to address water scarcity in agriculture perhaps presents the most compelling example of their importance. Potential gains through better management of the soil–vegetation interface are massive. Restoring the ecological basis of crop and livestock production as a means to improve water security for farming and to moderate its water-mediated externalities is regarded as the priority approach to bring agriculture within sustainable limits and to achieve food security (FAO, 2011b; 2014a). Assessments cited in Chapter 2 suggest that the expanded application of NBS (primarily involving improved soil, vegetation and landscape management) to existing rainfed crop systems offers projected gains equivalent to about 50% of current crop production from irrigation. From a water footprint perspective, this translates to an improvement equivalent to 35% of current total water withdrawals worldwide. Therefore, and putting it somewhat simplistically, water savings from these NBS alone could account for more than the projected increased demand for water by 2050 (Prologue), simultaneously solving (at the global level) not only the water security for food security challenge, but also freeing up water supplies for other uses, and potentially reducing overall global water demand. Associated socio-economic benefits are also substantial, since most farming families in developing countries rely on rainfed crops. Similar NBS approaches offer opportunities to further improve crop water use efficiency in irrigated systems. In addition, such NBS approaches usually improve water quality, while strengthening system resilience and hence reducing risks. Rainfed crops rely on little (if any) grey infrastructure. Therefore, this example alone lays to rest any notion that NBS are somehow a minor supplement to grey-infrastructure solutions; the progress is achieved by simply managing ecosystem components (in this case, soils and land cover) better so that rainwater gets and stays where it is needed – in the plant root zone.
- NBS are the main, if not the only feasible, means to address land degradation and drought at scale (Chapters 2 and 4 – although in practice many NBS actually use similar approaches for this purpose as for improving rainfed agriculture as above). This makes NBS central to, for example, sustaining livelihoods in dryland areas and combating desertification through rehabilitating land productivity – a priority sustainable development and poverty reduction challenge.
- The key impacts of climate change on humans are mediated through water (UN-Water, 2010) and occur mainly through climate-induced water-related shifts in ecosystems (IPCC, 2014). This implies that the key means for adapting to climate change is through ecosystem-based adaptation that improves the resilience of ecosystems to these climate-induced water-related shifts – that is, deploying NBS. Hence the increasing attention to NBS in climate change adaptation measures. Chapters 2, 3 and 4 all provide examples of NBS for addressing water availability, quality and risks, respectively, most of which are also a climate change adaptation response. In addition, because many NBS for climate change adaptation involve restoring carbon in landscapes (e.g. soil carbon or forests) they also contribute to climate change mitigation – not an inconsequential benefit considering that land use change has been responsible for approximately 25% of global anthropogenic greenhouse gas emissions to date (FAO, 2014b).
- Deploying urban green infrastructure is now widely recognized as having great potential. There is significant scope to expand the retrofitting of green infrastructure or for incorporating it in an initial planning stage, together with improved urban and peri-urban landscape management, to achieve sustainable urban settlements with a proven track record of making significant contributions to urban water management and resilience, including risk reduction (Chapters 3, 4 and 6).

WaSH is another area where NBS offer significant potential although achieved primarily through improved water availability and access to it (Chapter 2), improved water quality (Chapter 3) and reduced water-related risks (Chapter 4). For example, ecosystem degradation is recognized as a major constraint to achieving universal access to safe drinking water and hence there is recognition of the scope for ecosystem restoration as a key way forward (World Bank, 2009). NBS that involve eco-sanitation approaches, such as dry toilets, also offer promise to practically eliminate water use requirements in many situations.

NBS contribute to improved and more sustainable jobs through creating overall direct benefits of improved water resources management, thus generating employment opportunities across a large array of sectors and unlocking the potential for indirect employment creation through its multiplier effect (WWAP, 2016). They can, however, also create jobs and livelihoods directly. For example, PES schemes enable financing for water resources management to be dispersed and shared among a larger range of beneficiaries – notably poor communities in rural areas (Chapter 5). NBS that contribute to improved profitability, resilience and sustainability of agriculture offer significant potential to improve in particular small-scale family farming – widely regarded as one of the most important means of lifting people out of poverty in most developing countries.

7.3 How do we get there?

If business-as-usual were a possible option, we would not need *World Water Development Report* series or indeed the 2030 Agenda for Sustainable Development. Previous *World Water Development Reports* have consistently argued for transformational change in how we manage water. Most related policy forums agree on this point. This edition of the report reiterates the same conclusion, but notes

that NBS offer a major means to achieve the required transformational change. It argues that the absence of adequate recognition of the role of ecosystems in water management is a key factor that reinforces the need for transformational change. This transformational change can no longer just be aspirational – the shift needs to rapidly accelerate and, more importantly, translate into fully operationalized policy and action. This report concludes that we have made a good, if somewhat belated, start in this process but there is a long way yet to go.

This transformational change needs to be built upon a much more holistic, systems-based approach to the ways we manage water. Business-as-usual perspectives hold that water is a linear problem (upstream–downstream) that has largely to do with managing surface water and groundwater supply and demand, usually separately and principally for direct human use. Trade-offs with ecosystems are recognized but are considered to be secondary to water for people. Water is managed for a subset of its values, not its delivery of maximum system-wide benefits. The conventional response to improving water supply and quality, addressing climate change and reducing disaster risk has been to build more grey infrastructure and, where recognized, NBS are considered a fringe benefit, not core business. An ecosystems approach, however, recognizes that water moves through and between landscapes in a series of interconnected cycles from small to regional/global scales and many of these challenge an upstream–downstream perspective. For example, it highlights the current gap in attention to managing the impacts of land use change on moisture recycling from outside the basin, thus challenging the notion of a watershed being the single most appropriate unit of management (Chapters 1, 2 and 6) – although the watershed boundaries certainly remain far more appropriate than administrative units, which are still commonly used in water resources management. The NBS focus is on managing systems, including integrated green–grey infrastructure approaches, and maximizing system-wide benefits. For example:

- using ecosystems to get water back where it is needed, where it is safest; reducing water quality issues at source; and delivering improved overall system-wide socio-economic benefits, including sustainability and resilience;
- ambient water availability for human needs in landscapes is not seen as predetermined by climatic factors beyond our influence, but can be managed, for example through land cover management to influence moisture recycling or through improvements in soil management;
- the issue is not simply allocation among competing uses; water availability, quality and risks for some users can be improved whilst simultaneously improving benefits to others;
- the role of and need for grey infrastructure is recognized but so are its limitations, including how it can significantly increase risks; one role of NBS is to address those limitations and increase the hydrological and economic performance of grey options while offering opportunities for enhancing social benefits;
- water storage is not seen purely as maximizing the performance of artificial structures but from the perspective of how water storage is best managed across both rural and urban landscapes, focusing on interconnected systems (e.g. reservoirs, wetlands and aquifers) that integrate both natural and artificial storage features – the priority is storing water where it is safest and can be utilized for various uses with an emphasis on resilience of systems, and not over-focussing on artificial storage capacity;
- building resilience is paramount; approaches to managing risks, including disaster and climate change-mediated risks, should focus on addressing systemic root causes of such risks: ecosystem change;
- not just water-related outcomes should be considered, but overall system-wide benefits, including co-benefits of all options collectively;
- systems are best managed through multi-stakeholder involvement and use NBS to achieve consensus on win-win outcomes while managing trade-offs; and
- addressing drivers is a way of dealing with underlying causes as opposed to symptoms – an understanding of the direct and indirect drivers of ecosystem degradation and loss is crucial to identify opportunities where a focus on ecosystem services can help improve the management of water resources.

Business-as-usual perpetuates fragmented ineffective policies – a death knell for sustainable water outcomes identified in most previous editions of the *World Water Development Report*. Many policy forums have recognized the need to integrate policies across multiple policy areas and scales, not just among water-related agendas but with regards to how these relate to, support or conflict with other social, economic and environmental needs. This trend has culminated in the 2030 Agenda for Sustainable Development that has a much improved integrated approach as compared to its precursor, the Millennium Development Goals, by recognizing that interlinked goals and targets need to be achieved collectively. NBS offer Member States a mechanism, among others, to achieve such integrated approaches through linking the environmental, economic and social pillars of sustainable development. The technical approach to assessing and articulating such interdependency is through using an ecosystem services framework. It is critical that governments respond by not only harmonizing policy and regulations across policy areas, but also review policy at scale to ensure that policy guidance, or regulations, are clear and support, rather than constrain, implementation of improved decision making down to local levels.

Implementation of NBS can involve the participation of many different stakeholder groups, from governments to NGOs and citizen groups (e.g. local farmer associations, landowner

groups, private sector interests, etc.). Institutional constraints to promoting intersectoral dialogue are well known (Chapter 6) and have been well recognized in many previous editions of the *World Water Development Report*. Achieving the required institutional change remains challenging, and no less so for NBS. However, importantly, NBS offer a means to encourage such change through consensus-building on overall system objectives and the identification of win-win outcomes among multiple interests. NBS offer a bridge between the sectors and their interests.

Moving investments towards green approaches will be necessary in order to achieve improved investment efficiency and to sustain the performance and investment returns of grey infrastructure. An opportunity, therefore, is to transform investments so that NBS can fully contribute to efficiency gains, including maximizing co-benefits and potential system-wide improvements. Chapter 6 highlights some promising developments in this regard, including the emergence of rigorous assessments of the comparative financial performance of green and grey investments. It is promising that these have often identified green approaches as a viable investment, further strengthening the case for the efficacy of NBS approaches.

Whilst transformational change is required at various policy and financing levels, sooner or later decisions about water management interventions will be mostly made at site level. The objective needs to be to minimize costs and risks, maximize system returns and robustness, while providing optimal 'fit-for-use' performance. A role of policy should be to enable the right site-level decisions to be taken in these regards. A continuing bias towards grey-infrastructure approaches points at the need for recognition of the synergies between green and grey infrastructure, and the need for a common framework under which to assess available options (Chapters 1 and 6). Only under a common framework can it be determined what option, or most usually what blend of options, is most appropriate. This requires the use of common criteria, indicators and methodologies for assessments, comparisons and decision-making. Developing such a common framework, and the tools and capacity to support it, is a priority need to translate transformational policy change into delivery of optimal solutions at local level.

Agriculture stands out as a key sector where opportunities for transformational change stand out, due to its dominance in water use, links between water and food security, potential for poverty reduction, and opportunities for further deployment of NBS. The water security for food security dialogue needs to fully expand beyond its business-as-usual over-focus on irrigation. The opportunities to improve irrigation water use efficiency through grey-infrastructure approaches (e.g. drip irrigation) and demand-side measures (such as growing more locality-appropriate crops, unlocking opportunities to address virtual water in food trade, improvements in crop water productivity through genetic improvement, etc.) are well recognized, as is the scope for irrigation expansion in some areas. But, as above, the greater opportunities lie in improving water availability/supply through the more widespread uptake of NBS, particularly in rainfed systems, with complementary gains achieved in improved water quality and risk reduction outcomes. Whilst some policy forums recognize these opportunities (FAO, 2011b; 2014a), others continue to underemphasize the importance of ecosystems. The 'water–energy–food nexus' dialogue (FAO, 2014c) is a conspicuous example where ecosystems need to be more explicitly integrated (as a 'water–ecosystem–energy–food nexus'), because ecosystems determine many of the key interlinkages between water, energy and food, and NBS offer a key means to reconcile the potentially competing interests involved (Prologue and Chapter 2).

Scenario analyses have consistently shown that, in many areas, the path towards not only improved sustainability but also longer-term economic prosperity is through fully integrating environmental sustainability. A very positive outcome of the preliminary water resources scenario analysis undertaken by Burek et al. (2016) is that the *sustainability*[20] pathway delivers not only improved environmental, water and food security outcomes, but also, contrary to some beliefs, the highest and fastest mid-term benefits in terms of economic development. For example, under the alternative *regional rivalry*[21] scenario, global GDP peaks at US$220 trillion by the year 2100 but is US$570 trillion under the *middle-of-the-road*[22] scenario and US$650 trillion under the *sustainability* scenario, with a similar pattern for GDP per capita. This is consistent with contemporary conclusions that environmental sustainability is not a constraint to social and economic development, but a requirement to achieve it. NBS offer an understandable and practical means to operationalize water resources policy and management to achieve this end.

7.4 Achieving the 2030 Agenda for Sustainable Development through NBS for water resources management

This report concludes that NBS have high potential to meet contemporary and future water resources management challenges, as reflected in the 2030 Agenda for Sustainable Development, the SDGs and their targets.

[20] The *sustainability* scenario depicts a world making relatively good progress towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency.

[21] In the *regional rivalry* scenario, the world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Countries focus on achieving energy and food security goals within their own region, and international trade, including energy resource and agricultural markets, is severely restricted.

[22] The *middle-of-the-road* scenario assumes world development is progressing along past trends and paradigms, such that social, economic and technological trends do not shift markedly from historical patterns (i.e. business-as-usual).



Lake Naivasha (Kenya)

A summary of the findings from Chapters 1 to 5 with respect to the potential for NBS to contribute to the SDGs and their targets is provided in Tables 7.1 and 7.2. Table 7.1 summarizes the potential contribution of NBS to each of the water targets under the SDG 6 for Water and Sanitation vis-à-vis non-NBS options to achieve the same target. Since water underpins most social and economic aspects of the SDGs, it is widely recognized as cross-cutting most of the SDGs and their targets. Therefore, the contributions of NBS to SDG 6 translate into further water-related benefits for other SDGs and their targets, alongside contributions from non-NBS interventions. These linkages are too complex to include in Table 7.1 but are reviewed further by UN-Water (2016a) and in the forthcoming *UN-Water Synthesis Report* on SDG 6 (to be published in mid-2018). The non-water-related co-benefits that NBS also provide, and the ways in which these help to achieve other SDGs and their targets, are summarized in Table 7.2.

NBS offer high potential to contribute to the achievement of most of the targets of SDG 6 (Table 7.1). Areas in which this contribution translates into particularly striking positive impacts on other SDGs are with regards to water security for underpinning sustainable agriculture (SDG 2, notably Target 2.4), healthy lives (SDG 3), building resilient (water-related) infrastructure (SDG 9), sustainable urban settlements (SDGs 11), and disaster risk reduction (SDG 11 and, as related to climate change, 13).

A significant advantage of NBS is the co-benefits they offer, beyond immediate water management outcomes. These include improving overall system resilience and the social and economic benefits associated with improved economic, cultural, recreational and aesthetic values of improved landscapes, as well as nature conservation. These benefits can be substantial and need to be factored into assessments, cost–benefit analyses and, consequently, policy and decision making. Some areas where these co-benefits deliver particularly high rewards in terms of achieving the SDGs (Table 7.2) are with regards to: other aspects of promoting sustainable agriculture (SDG 2); sustainable energy (SDG 7); promoting sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (SDG 8); other aspects of making cities and human settlements inclusive, safe, resilient and sustainable (Goal 11); ensuring sustainable consumption and production patterns (SDG 12); taking urgent action to combat climate change and its impacts (SDG 13); and in particular through promoting improved overall environmental outcomes and halting and reversing land degradation and biodiversity loss (SDGs 14 and 15). NBS also offer significant opportunities to strengthen the means of implementation and revitalizing the global partnership for sustainable development (SDG 17).

7.5 Coda

The nature of the relationship between ecosystems, hydrology and human well-being needs not be as precarious as evidenced in certain cases of ancient and recent history. As humankind charts its course through the Anthropocene, adopting NBS is not only necessary for improving water management outcomes and achieving water security, it is also critical for ensuring the delivery of co-benefits that are essential to all aspects of sustainable development. Although NBS are not a panacea, they will play an essential role in building a better, brighter, safer and more equitable future for all.

Table 7.1 The potential contribution of NBS to meeting targets of SDG 6 on water and sanitation and their potential for contributing to other targets*

SDG 6: Ensure availability and sustainable management of water and sanitation for all **Targets**	**Potential NBS contribution to the target**	**Examples of NBS**	**Potential NBS contribution to other SDG 6 targets**
6.1 Achieve universal and equitable access to safe and affordable drinking water for all	High	Watershed management, including conservation agricultural practices; water harvesting; urban green infrastructure	High 6.3, 6.4, 6.6
6.2 Achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Medium	Dry toilets, constructed wetlands	Medium 6.1, 6.3, 6.6
6.3 Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	High	Constructed wetlands, urban green infrastructure, watershed management (including agricultural land management), riparian buffers, vegetated waterways and wetlands	Medium 6.1, 6.4 (where wastewater is reused), 6.6
6.4 Substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	Very high	NBSs that improve soil water availability for rainfed crops (e.g. conservation agriculture etc.)	Very high 6.1, 6.3, 6.6
	High	Water harvesting, conjunctive uses of groundwater and surface water, enhanced groundwater recharge through improved land management, urban green infrastructure (e.g. permeable pavements, sustainable urban drainage systems)	High 6.1, 6.3, 6.6
6.5 Implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	High	Implementation of larger-scale NBSs that promote collaboration between stakeholders, e.g. river basin restoration	High 6.1, 6.3, 6.6
6.6 Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	-	All. Target 6.6 is mainly the application of NBS SDG Targets refer to their respective Goals. Therefore, in this context, the primary purpose of protecting and restoring water-related ecosystems is to support the availability and sustainable management of water and sanitation for all. That is, Target 6.6 refers to deploying NBS as defined in this report. Protecting and restoring ecosystems for other objectives, beyond water resources outcomes, is covered under co-benefits of NBS in Table 7.2.	-
6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	High	NBS as a key focus of capacity-building support and expanding international cooperation	-
6.b Support and strengthen the participation of local communities in improving water and sanitation management	High		-

*Potential is assessed with respect to how NBS can contribute vis-à-vis other means of achieving the same target.

Table 7.2 The potential contribution of NBS (for water) to some other SDGs and their targets through delivering non-water related co-benefits

SDG and Target	Potential co-benefit achieved through NBS	Examples
SDG 1. End poverty in all its forms everywhere 1.5 ... build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	High	NBS deliver non-water-related ecosystem services that help build resilience of the poor and overall system resilience; for example, reforestation reduces landslides, ecosystems provide food sources during times of crisis
SDG 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture 2.4 ... ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	Very high	The non-water-related co-benefits of NBS for water supply in agriculture (e.g. through conservation agriculture and landscape restoration) are significant and include pest and disease regulation, nutrient cycling, soil regulation, pollination etc. All improve overall system resilience, sustainability and productivity
SDG 3. Ensure healthy lives and promote well-being for all at all ages 3.3 ... end the epidemics of ... malaria and ... combat water-borne diseases ...	Modest	Healthy ecosystems, promoted through NBS, help regulate human water-borne diseases and parasites
SDG 7. Ensure access to affordable, reliable, sustainable and modern energy for all 7.3 ... double the global rate of improvement in energy efficiency	Modest	NBS for improving water quality reduce energy requirements for subsequent water treatment
SDG 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all 8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation ...	High	NBS applied at scale reinstate positive feedbacks between economic growth and environment
SDG 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation 9.4 ... upgrade infrastructure and retrofit industries to make them sustainable, with increased resource use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	High	NBS promote green infrastructure, which increases resource use efficiency and clean and environmentally sound technologies. An approach particularly suited to countries with low capacity and limited financial resources
SDG 11. Make cities and human settlements inclusive, safe, resilient and sustainable 11.7 ... provide universal access to safe, inclusive and accessible green and public spaces ... 11.a ... support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning 11.b ... substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels 11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials	High	Green infrastructure within urban areas. Deploying NBS in urban catchments to link urban and peri-urban (and catchment-scale) planning for safe, resilient and sustainable settlements – particularly appropriate for developing countries

SDG 12. Ensure sustainable consumption and production patterns 12.1 Implement the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns ... 12.2 ... achieve the sustainable management and efficient use of natural resources 12.5 ... substantially reduce waste generation through prevention, reduction, recycling and reuse ... 12.7 ... public procurement practices that are sustainable, in accordance with national policies and priorities	High	NBS are a key means to implement the 10-Year Framework. They are particularly effective in promoting sustainable consumption of resources (e.g. of chemicals, fertilizers and land) in farming.
SDG 13. Take urgent action to combat climate change and its impacts 13.1 ... strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries 13.2 ... integrate climate change measures into national policies, strategies and planning	High	In addition to significant contributions to strengthening resilience to water-related hazards (covered under Goal 6 in Table 7.1), NBS help improve overall system resilience and adaptive capacity. NBS also help mitigate climate change through improved sequestration of carbon through, for example, reforestation and the rehabilitation of soil organic carbon. They also help integrate climate change policies, strategies and planning across sectors.
SDG 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development 14.1 ... prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution ... 14.2 ... sustainably manage and protect marine and coastal ecosystems ... strengthening their resilience, and take action for their restoration ...	Medium to high	NBS for reducing impacts of pollution from land-based activities are high and as these are mediated through water, they are covered under Goal 6 above – a notable example being reducing nutrient inputs from agriculture. NBS applied in coastal areas, for example coastal forest and/or wetlands restoration, has significant potential for improving the resilience of coastal ecosystems.
SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss All targets	Very high	One of the most important co-benefits of NBS is the way in which they support Goal 15 by supporting the conservation, restoration and sustainable use of ecosystems (target 15.1), including forests (target 15.2) and mountains (target 15.4), while they are the principle means to combat desertification (target 15.3), safeguard natural habitats (target 15.5), support integration of biodiversity values (target 15.9) and are the major means to mobilize finance for biodiversity conservation (targets 15a and 15b).
Multi-stakeholder partnerships 17.16 ... enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships ... 17.17 ... encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships	Medium	NBS promote integration across stakeholder interests, thereby promoting partnerships and helping identify mutually reinforcing links between the social, economic and environmental pillars of sustainable development.

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ABBREVIATIONS AND ACRONYMS

ACWFS-VU	Amsterdam Centre for World Food Studies, Vrije Universiteit
AGWA	Alliance for Global Water Adaptation
CBD	Convention on Biological Diversity
CRED	Centre for Research on the Epidemiology of Disasters
CRP	Conservation Reserve Program (USA)
CSO	combined sewer overflows
CWA	Clean Water Act (USA)
DEP	Department of Environmental Protection (New York City)
DRR	disaster risk reduction
EC	European Commission
EPMAPS	Empresa Pública Metropolitana de Agua Potable y Saneamiento – Public Metropolitan Enterprise for Drinking Water and Sanitation (Quito)
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FONAG	Fondo para la Protección del Agua – Water Conservation Fund (Ecuador)
GDP	gross domestic product
GPA	Global Programme of Action
GWD	groundwater depletion for irrigation
HIV	Human Immunodeficiency Virus
IAHS	International Association of Hydrological Sciences
ICPR	International Commission for the Protection of the Rhine
IHE	Delft Institute for Water Education
IHP	International Hydrological Programme
IIASA	International Institute for Applied Systems Analysis
ILO	International Labour Organization
IUCN	International Union for Conservation of Nature
ISRBC	International Sava River Basin Commission
IWMI	International Water Management Institute
IWRM	integrated water resources management
LAC	Latin America and the Caribbean
LULUC	land use and land use change
MAR	managed aquifer recharge
MoU	memorandum of understanding
NBS	nature-based solutions
NGO	non-governmental organization

NUA	New Urban Agenda
NYC	New York City
NWRM	Natural Water Retention Measures
OECD	Organisation for Economic Co-operation and Development
PES	payment for environmental services
SASS	stream assessment scoring system
S2S	source to sea
SDGs	Sustainable Development Goals
SIWI	Stockholm International Water Institute
SPR	source to pathway to receptor
SRI	system of rice intensification
SUDS	sustainable urban drainage systems
TNC	The Nature Conservancy
UK	United Kingdom
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNECE	United Nations Economic Commission for Europe
UNECLAC	United Nations Economic Commission for Latin America and the Caribbean
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCWA	United Nations Economic and Social Commission for Western Asia
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UNU	United Nations University
USA	United States of America
USAID	United States Agency for International Development
US EPA	United States Environmental Protection Agency
UTFI	underground taming of floods for irrigation
WaSH	water, sanitation and hygiene
WBCSD	World Business Council for Sustainable Development
WFD	Water Framework Directive of the EU
WMO	World Meteorological Organization
WWAP	World Water Assessment Programme
WWDR	World Water Development Report
WWF	World Wide Fund for Nature

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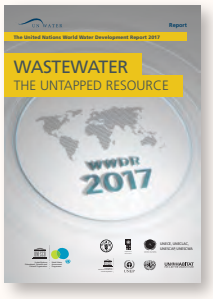
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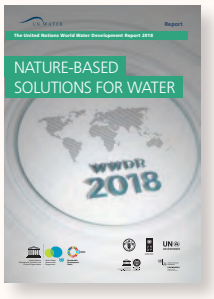
THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT





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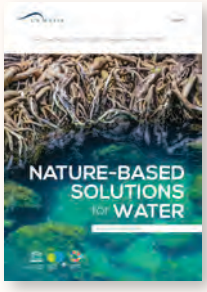
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United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

WWDR 2018

UN-WATER REPORTS

UN-Water is the United Nations (UN) inter-agency coordination mechanism for freshwater related issues, including sanitation. It was formally established in 2003 building on a long history of collaboration in the UN family. UN-Water is comprised of UN entities with a focus on, or interest in, water-related issues as Members and other non-UN international organizations as Partners.

The main purpose of UN-Water is to complement and add value to existing programmes and projects by facilitating synergies and joint efforts, so as to maximize system-wide coordinated action and coherence. By doing so, UN-Water seeks to increase the effectiveness of the support provided to Member States in their efforts towards achieving international agreements on water.

PERIODIC REPORTS

World Water Development Report (WWDR)

is the reference publication of the UN system on the status of the freshwater resource. The Report is the result of the strong collaboration among UN-Water Members and Partners and it represents the coherent and integrated response of the UN system to freshwater-related issues and emerging challenges. The report production coordinated by the United Nations World Water Assessment Programme of UNESCO and the theme is harmonized with the theme of World Water Day (22 March). From 2003 to 2012, the WWDR was released every three years and from 2014 the Report is released annually to provide the most up-to-date and factual information of how water-related challenges are addressed around the world.

- ✓ Strategic outlook
- ✓ State, uses and management of water resources
- ✓ Global
- ✓ Regional assessments
- ✓ Triennial (2003-2012)
- ✓ Annual (since 2014)
- ✓ Links to the theme of World Water Day (22 March)

UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS)

is produced by the World Health Organization (WHO) on behalf of UN-Water. It provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking water. It is a substantive input into the activities of Sanitation and Water for All (SWA).

- ✓ Strategic outlook
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional assessments
- ✓ Biennial (since 2008)

The progress report of the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP)

is affiliated with UN-Water and presents the results of the global monitoring of progress towards access to safe drinking water, and sanitation and hygiene. Monitoring draws on the findings of household surveys and censuses usually supported by national statistics bureaus in accordance with international criteria and increasingly draws on national administrative and regulatory datasets.

- ✓ Status and trends
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional and national assessments
- ✓ Biennial (1990-2012)
- ✓ Annual updates (since 2013)

UN-WATER PLANNED PUBLICATIONS 2018

- SDG 6 Synthesis Report 2018 on Water and Sanitation
  The SDG 6 Synthesis Report 2018, prepared by a Task Force of 13 UN-Water Members and Partners, will be published in June 2018 ahead of the High-level Political Forum on Sustainable Development where Member States will review the Sustainable Development Goal 6 – Ensure availability and sustainable management of water and sanitation for all – in-depth. The report will show the global status for all SDG 6 targets and indicators based on SDG 6 monitoring mechanisms; provide an analysis of intralinkages and interlinkages and suggest policy relevant messages aiming to accelerate the implementation of the 2030 Agenda for Sustainable Development.
- Update of UN-Water Policy Brief on Water and Climate Change
- UN-Water Policy Brief on the Water Conventions
- UN-Water Analytical Brief on Water Efficiency

More information on UN-Water Reports at: www.unwater.org/publications

The United Nations World Water Assessment Programme (WWAP) is hosted and led by UNESCO. WWAP brings together the work of numerous UN-Water Members and Partners to produce the United Nations World Water Development Report series.

The annual World Water Development Reports focus on strategic water issues. UN-Water Members and Partners as well as other experts contribute the latest knowledge on a specific theme.

The 2018 edition of the World Water Development Report seeks to inform policy and decision-makers, inside and outside the water community, about the potential of nature-based solutions (NBS) to address contemporary water management challenges across all sectors, and particularly regarding water for agriculture, sustainable cities, disaster risk reduction and water quality.

Water management remains heavily dominated by traditional, human-built (i.e. 'grey') infrastructure and the enormous potential for NBS remains under-utilized. NBS include green infrastructure that can substitute, augment or work in parallel with grey infrastructure in a cost-effective manner. The goal is to find the most appropriate blend of green and grey investments to maximize benefits and system efficiency while minimizing costs and trade-offs.

NBS for water are central to achieving the 2030 Agenda for Sustainable Development because they also generate social, economic and environmental co-benefits, including human health and livelihoods, food and energy security, sustainable economic growth, decent jobs, ecosystem rehabilitation and maintenance, and biodiversity. Although NBS are not a panacea, they will play an essential role towards the circular economy and in building a more equitable future for all.

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