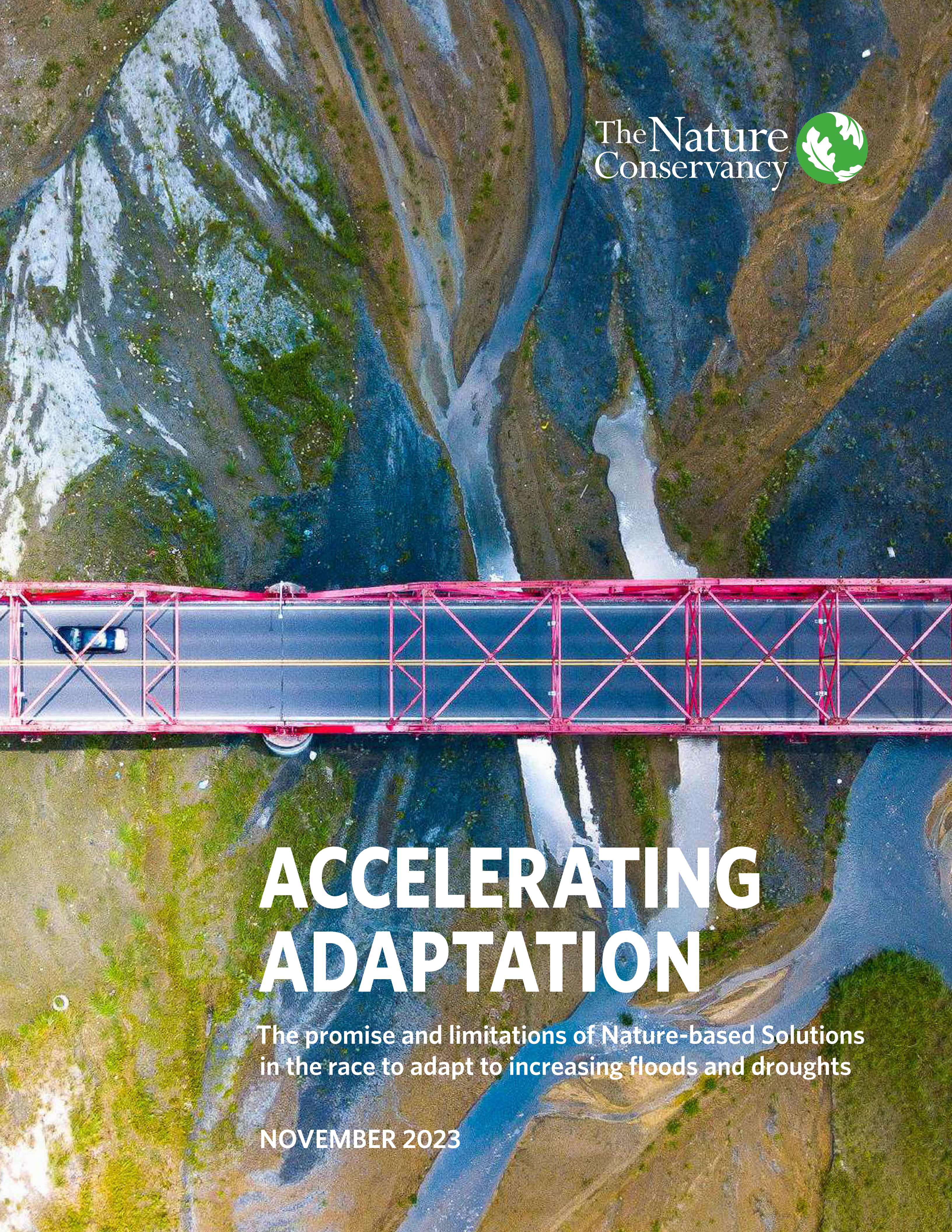

The Nature Conservancy

ACCELERATING ADAPTATION

The promise and limitations of Nature-based Solutions in the race to adapt to increasing floods and droughts

NOVEMBER 2023

ACKNOWLEDGMENTS

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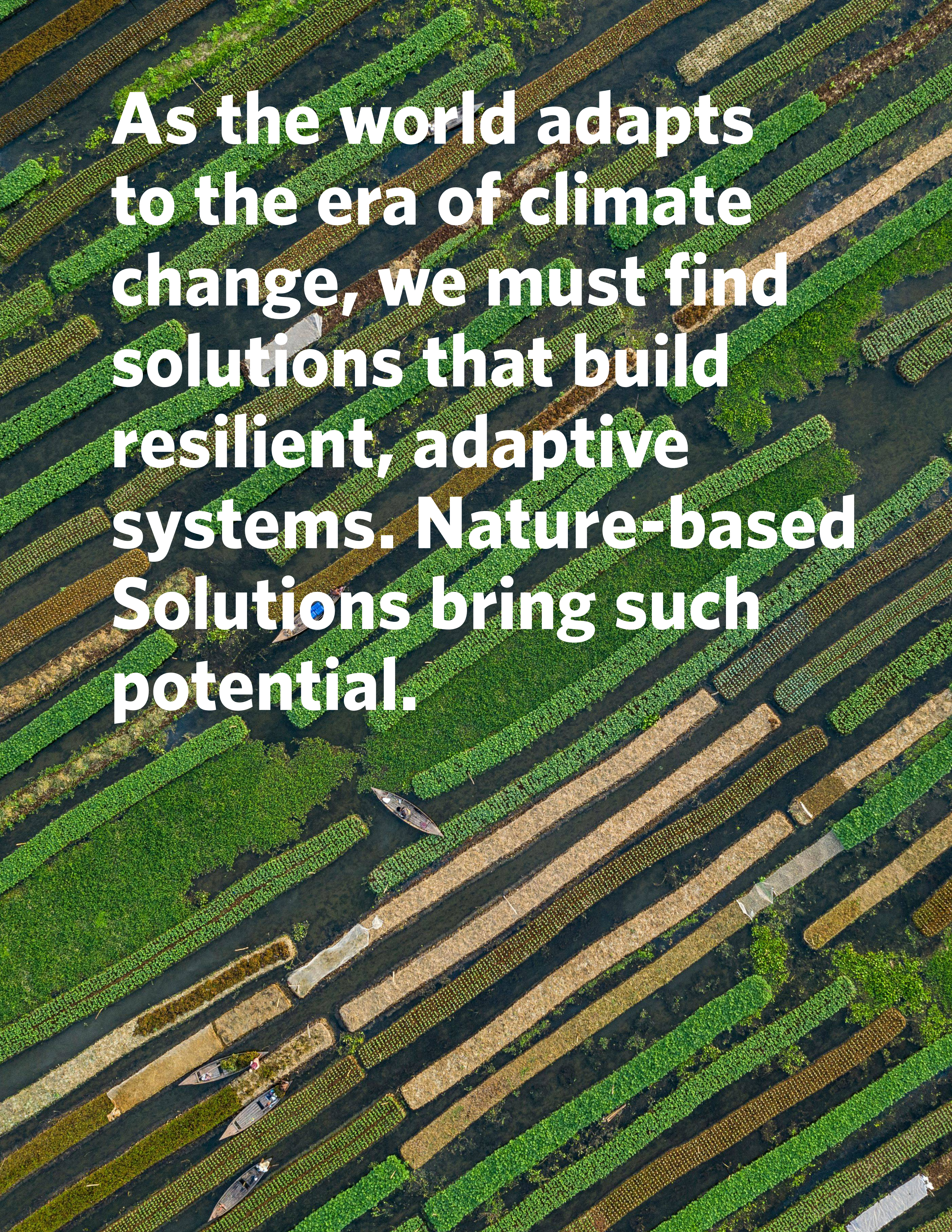
As the world adapts to the era of climate change, we must find solutions that build resilient, adaptive systems. Nature-based Solutions bring such potential.



CONTENTS

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Nature-based Solutions, deployed at scale and in the right places, have broad applicability to the mitigation of flood and drought and to helping communities adapt to climate change.

BOXES

FIGURES

TABLES

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EXECUTIVE SUMMARY

It is no longer news that climate changes are, quite literally, reflected through water. The combined challenges of flood and drought already impact a fifth of the world's population, disproportionately affecting vulnerable communities and ecosystems. These impacts are projected to rise drastically absent affordable adaptation solutions. Nature-based Solutions (NbS), deployed at scale and in the right places, have broad applicability to the mitigation of flood and drought and to helping communities adapt to climate change. Nevertheless, the global extent of their applicability remains misunderstood. This report offers guidance to disaster risk planners and adaptation funders on where and how to effectively harness nature to adapt to both a wetter and drier future

Water-related hazards like flood and drought are among the most damaging natural disasters on Earth. More than 1.8 billion people (roughly 20% of the global population) are estimated to have experienced large flood events over the last 20 years, with flood damages during that time reaching US$650 billion—equivalent to the GDP of Sweden. On the other hand, drought was responsible for 650,000 deaths, or nearly one-third of disaster-related deaths between 1970–2019, and drove an estimated US$124 billion in losses between 1998–2017.

Climate change is increasing the frequency, intensity and distribution of floods and droughts for many regions, with disproportionate impacts to some countries. An even wetter future is likely for many regions of the world, including Central Europe, the Eastern United States, central South America, and most of the Asia-Pacific. At the same time, the risk of drought is expected to increase for many areas of the world, including across the Americas, in Europe—particularly within Mediterranean areas, southern Africa, and Australia. And in some cases—like the Northwestern United States—communities can expect more floods *and* more droughts.

Nature-based Solutions can play a major role in mitigating the water-related impacts of climate change, but the synergies, trade-offs, and potential magnitude of the impacts of NbS on future flood and drought risk remain poorly understood. Building on a review of existing literature, this report seeks to clarify the mechanisms by which Nature-based Solutions can impact flood and drought risk, how Nature-based Solutions impact the components of natural disaster risk—hazard, vulnerability, and exposure—and how NbS can be combined with other flood and drought mitigation solutions such as gray infrastructure or early warning systems to create more effective adaptation plans.

This report identifies synergies and trade-offs of different Nature-based Solutions for flood and drought. For example, in areas that are expected to, or already, experience both extreme dry and wet periods, such as what has occurred in California over the past two years, aquifer recharge during high flow periods provides a way to both reduce the impact of floods and increase water availability longer into dry periods. Conversely, although tree planting or reforestation can lessen some flood impacts through the reduction of overland water flow and infiltration, increasing vegetative cover can also increase evapotranspiration, which may exacerbate drought impacts.

This report describes which Nature-based Solutions may be particularly good at reducing flood and drought risk in diverse contexts. For example, protection or reconnection of floodplains can have an outsized benefit for storing excess water, slowing down and retaining floodwater, and reducing both flood hazard and exposure. Natural water storage, such as in wetlands or aquifers, can help mitigate the impacts of droughts, along with agricultural best management practices that improve soil water-holding capacity and contribute to the reduction of communities' vulnerability to drought.

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This report finds that there is broad global applicability for Nature-based Solutions for flood and drought, notably in areas expected to face the greatest increased risks of climate-driven flood and drought. NbS can help reduce the risk of flood and drought in one-third of the places across the globe where flood and drought hazards are expected to increase due to climate change, suggesting NbS have strong relevance and high potential for adaptation within these areas. NbS have widespread potential in areas of increased future flood hazard risk within China, India, Brazil and the United States. Areas within southern Africa, Europe, Brazil, and the Western United States exhibit both high NbS potential and high future drought risk.

Disaster risk planners and adaptation funders interested in exploring NbS for drought and flood can learn from projects that have already been implemented. Through the lens of eight projects around the world, this report highlights strategies for effective and equitable NbS implementation as well as potential pitfalls to avoid. These cases also illustrate the importance of deep engagement with local communities and the diverse options for financing NbS. As shown in the case studies, NbS is applicable across multiple scales, from individual landowners to national programs, which makes them attractive to different types and levels of funding.

To address the impacts of climate change, adoption of Nature-based Solutions must be considered both as a complement to, and possible substitute for, existing management and infrastructure investments. Despite the critical need for increased investment in climate adaptation, less than 10% of total climate funding in recent years has gone toward adaptation. Current spending on adaptation needs to increase by a factor of three to seven by 2030 to meet the needs of communities in the face of expected climate change impacts. Similar funding shortfalls exist relative to other global goals, like the UN's Sustainable Development Goal 6, where NbS can play a crucial role. Given the multitude of co-benefits that can be achieved by NbS, from climate adaptation to water security to biodiversity conservation, these types of programs have the potential to draw in multiple funders with different yet complementary goals.

As the world adapts to the era of climate change, we must find solutions that build resilient, adaptive systems. NbS bring such potential to help protect, restore and sustainably manage landscapes and waterways in the face of climate change. **With the foundational knowledge offered in this report, disaster risk planners and adaptation funders can more confidently integrate NbS into flood and drought investments and understand where in the world these integrations are most likely to support climate adaptation.**

01 INTRODUCTION

CHANGING CLIMATE AND THE CHALLENGE OF TOO MUCH OR TOO LITTLE WATER

The world is facing the twin crises of climate change and biodiversity loss, with drastic impacts on communities and ecosystems expected to accelerate in the coming decades. These crises are inherently linked, driven by growing populations and expanding economies—which impact greenhouse gases in the atmosphere, and land and water degradation on the ground. Within our interconnected human-nature system, human impacts such as land-use change, accelerating use of natural resources, loss of biodiversity, and land and water pollution impact the resilience of ecosystems, communities and individuals and their ability to adapt to climate change (IPCC, 2022).

Freshwater systems are particularly at risk: some of the most significant climate change impacts will affect freshwater resources, and current trends in biodiversity loss indicate greater declines for freshwater species than either marine or terrestrial species (UN Water, 2020; WWF, 2022). This rapid loss of natural freshwater habitat is already impacting local and global water cycles alongside growing variability in rainfall patterns due to climate change (Global Commission on the Economics of Water, 2023).

Many will experience the effects of climate change through water. Indeed, we already know that the impacts of floods and droughts can be immensely disruptive. Over two million deaths and US$3.6 trillion in economic losses were experienced globally between 1970 and 2019 from all weather, climate and water hazards (Douris and Kim, 2021). Of the top ten disasters during this same period, drought had the biggest impact on human lives lost (650,000 lives lost over four distinct events), while floods are the most prevalent natural disaster. These events devastated communities and, in many cases, presented impossible choices with no clear winners (**Figure 1**).

FIGURE 1. Flooding in Pakistan in 2022 resulted in over 1,700 deaths and destroyed more than 1.7 million homes, affecting in total over 33 million people. © Imago/Alamy Stock Photo

Flood and droughts are also connected to other natural disasters. Landslides affect hundreds of thousands of people each year, and wildfires are increasing in intensity and frequency, forcing tens of thousands of people to have had to evacuate in 2023 alone (Center for Disaster Philanthropy, 2022; WHO, 2023). These weather-related disasters also have a huge impact on internal and international displacement of people, which is on a rapidly increasing trajectory. For example, in 2022, 31.9 million people were forced to migrate due to weather-related disasters—a 41% increase from the average over the previous decade (International Displacement Monitoring Center, 2023).

Even without increased risks due to climate change, the loss and degradation of ecosystems and their services increases the vulnerability of a population. This degradation has the most significant impact on those who are directly dependent on ecosystems to meet their basic needs, including Indigenous peoples. Water storage is a key component of the regulation of water to bridge gaps in water availability during dry periods and the mitigation of flooding. Between 1970 and 2020, 27 trillion m^3 of natural water storage was lost globally due to anthropogenic impacts such as destruction of wetlands and urbanization. This loss of natural storage is over 145 times the size of the biggest reservoir in the world, Lake Kariba (World Bank Group, 2023).

NATURE-BASED SOLUTIONS FOR FLOOD AND DROUGHT

Given our intimate relationship with water, humankind cannot continue on the same path if we hope to thrive—or even survive—in many areas of the world. Cost-effective, equitable, no-regrets solutions that increase our resilience to climate change are needed. Whether it is using forests to infiltrate groundwater while capturing carbon in the atmosphere, restoring streambanks to improve habitat for endangered freshwater species while maintaining water quality for human use, or protecting floodplains to allow floodwater to flow out onto natural landscapes instead of into people's homes, Nature-based Solutions (NbS) will be integral to our ability to adapt to a changing climate.

Nature-based Solutions are defined *as actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems that address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits* (UNEP, 2022a). Nature-based Solutions encompass a suite of approaches to address growing water-related disaster risks such as floods and drought (**Figure 2**). To ensure good practice in the selection and implementation of NbS, the International Union for Conservation of Nature (IUCN) provides an NbS standard framed by eight criteria, including net gain for biodiversity; economic viability; and inclusive, transparent and empowering governance processes (IUCN, 2020).

NbS have been shown to reduce the risk of many hazards, including floods and droughts (Opperman, 2014; Penailillo et al., 2022). NbS also provide multiple benefits, such as reducing exposure and vulnerability to climate-related impacts, mitigating the effects of climate change, improving human health and well-being, and increasing biodiversity (Woroniecki et al., 2023; Abell et al., 2017; Brill et al., 2023). Along with mitigating risks from flood and drought, NbS can also help communities adapt to other climate impacts and play an important role in meeting a diverse set of global goals concerning climate mitigation, the provision of safe drinking water, and biodiversity (Bonnardeaux, 2012; Griscom et al., 2017; Rees et al., 2023).

Given the complexity and uncertainty of the challenges presented by climate change, another particularly appealing aspect of NbS is their scalability. For communities or organizations acting at the local level, NbS can be implemented starting at a smaller scale. These solutions can provide local benefits that can grow with the scale of implementation—often at a lower cost and within a shorter timeline than larger gray infrastructure (engineering and structural solutions such as dykes, dams, levees, groundwater pumping and other subsurface water storage measures). In many contexts, NbS offer a no-regrets pathway to adaptation action for actors at various levels.

However, NbS alone will neither solve all water security issues nor neutralize the impact of floods and droughts under climate change. NbS need to be part of an integrated set of solutions that address specific hazards along with reducing the exposure and vulnerability of communities and individuals. The combination of green and gray infrastructure is powerful—gray infrastructure can offer the ability to make rapid changes in response to natural disasters, such as dam releases or levee closures—but green infrastructure can help mitigate hazards further upstream and provide a robustness and a variety of co-benefits that gray infrastructure alone cannot.

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NATURE-BASED SOLUTIONS FOR ADAPTATION ACROSS LANDSCAPES

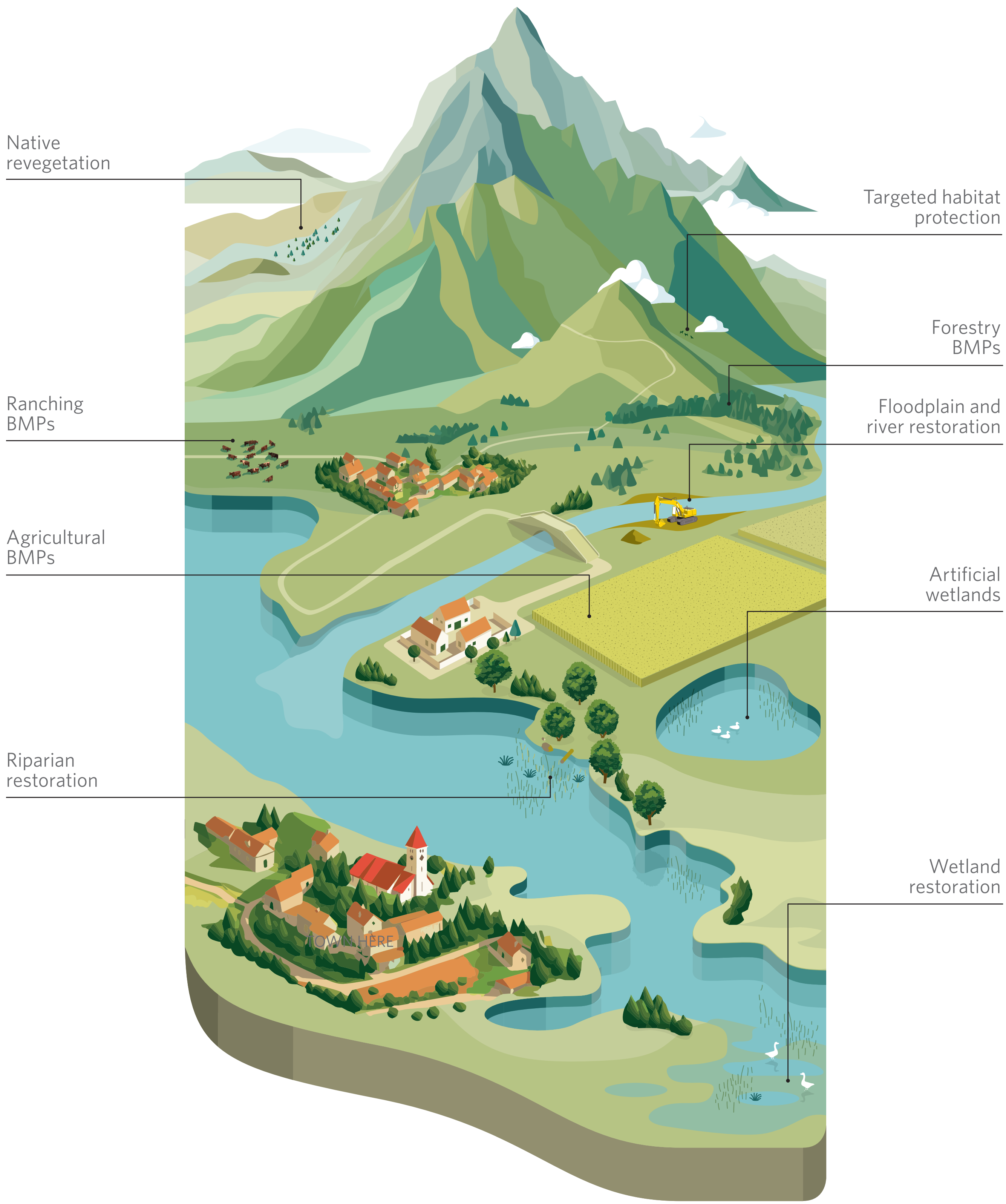

FIGURE 2. Conceptual diagram illustrating different types of Nature-based Solutions (NbS) with potential to address flooding and drought across different landscape types.

ABOUT THIS REPORT

The primary objective of this report is to highlight and clarify the role of NbS in helping people and ecosystems adapt to climate change—specifically, the impact of the increasing frequency and intensity of floods and droughts. This report does not evaluate the role of NbS in curbing severe heat, fire, landslides or coastal flooding.

Current literature largely describes the generalized potential of NbS for water-related disaster risk reduction. This report aims to present a more detailed look at the specific mechanisms that drive flood and drought risks to help readers understand *when* and *where* NBS might have the greatest potential for adaptation. Additionally, the report details what factors to consider when selecting and integrating NbS as part of adaptation planning. The intended audiences for the report are 1) adaptation funders, 2) adaptation planners, and 3) organizations designing and implementing NbS for water security and climate resilience.

02	**Chapter 2** describes current and future risks across the globe for droughts and floods, highlighting areas at highest risk now and in the future.
03	**Chapter 3** introduces NbS in more detail and describes the role of NbS in mitigating the risks of flood and drought through system diagrams and examples.
04	**Chapter 4** explores the global potential for NbS to support communities and ecosystems in adapting to changes in flood and drought risk.
05	**Chapter 5** summarizes findings for the application of NbS for flood and drought adaptation and provides recommendations for future efforts.
06	Finally, in **Chapter 6**, a set of robust case studies are presented to demonstrate what employing NbS for water-related adaptation looks like, with insights into enabling conditions and practical considerations.

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Nature-based Solutions alone will not neutralize the impact of floods and droughts. NbS need to be part of an integrated set of solutions.

02 INCREASING RISK OF FLOOD AND DROUGHT

THE LANGUAGE OF RISK: HAZARD, EXPOSURE, AND VULNERABILITY

The risk to any community or individual from a natural disaster depends on three components (IPCC, 2022, 2012): hazard, exposure, and vulnerability (**Box 1**). Climate change and human development impact these components in different ways:

- **Hazard** through changes to the atmospheric and hydrologic processes that alter how a climatic event, such as intensive rainfall or long, hot dry spells, impacts the timing, storage and availability of water;
- **Exposure** by changing whether or not people are within a hazard's way; and
- **Vulnerability**, by either bolstering or weakening people's ability to deal with a hazard without major long-term impacts to their livelihood and well-being.

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Disaster risks occur when vulnerable people and their assets are exposed to a hazard (**Figure 3** in **Box 1**). As introduced in Chapter 1, floods and droughts are among the most significant environmental hazards that we face globally, affecting more people than any other natural disaster (IPCC 2012; UNCCD, 2022). Critically, the negative impacts of flood and drought are not experienced equitably, with marginalized populations enduring the greatest hardships (Douris and Kim, 2021). For example, while rich countries dominate in terms of total economic losses due to disasters between 1998–2017, lower-income countries have the highest disaster damages relative to country GDP (UNDRR, 2018).

By taking a closer look at the biophysical causes of floods and droughts, we can better understand the relationship between such natural disasters and climate change. We can in turn improve our understanding of how NbS specifically reduce the impacts of floods and droughts.

BOX 1.

HAZARD, EXPOSURE AND VULNERABILITY

Risk can be conceptualized as comprising three primary components: hazard, exposure, and vulnerability. We reference these components throughout this report and focus on the *hazard* component—the physical basis of risk—within **Chapters 2**, **3**, and **4**. The definitions below clarify the distinction between these risk components.

HAZARD: Threatening event or condition (e.g., flood event, drought event). Commonly defined as the occurrence probability of an event that could potentially cause loss of life and economic damages. A *flood hazard* relates to the presence of excessive water due to heavy rainfall, rapid snowmelt, overflowing rivers, etc., which can inundate and damage surrounding areas. A *drought hazard* signifies a prolonged period of reduced precipitation, leading to water scarcity and decreased soil moisture levels.

EXPOSURE: Elements present in the area affected by flood or drought hazard (e.g., population, infrastructure, assets, economic activities). *Exposure* is characterized by an aggregation of the likelihood that people and assets are present at the time and location of the flood or drought events and measures the degree to which a community or a region is at risk of being affected by these hazards.

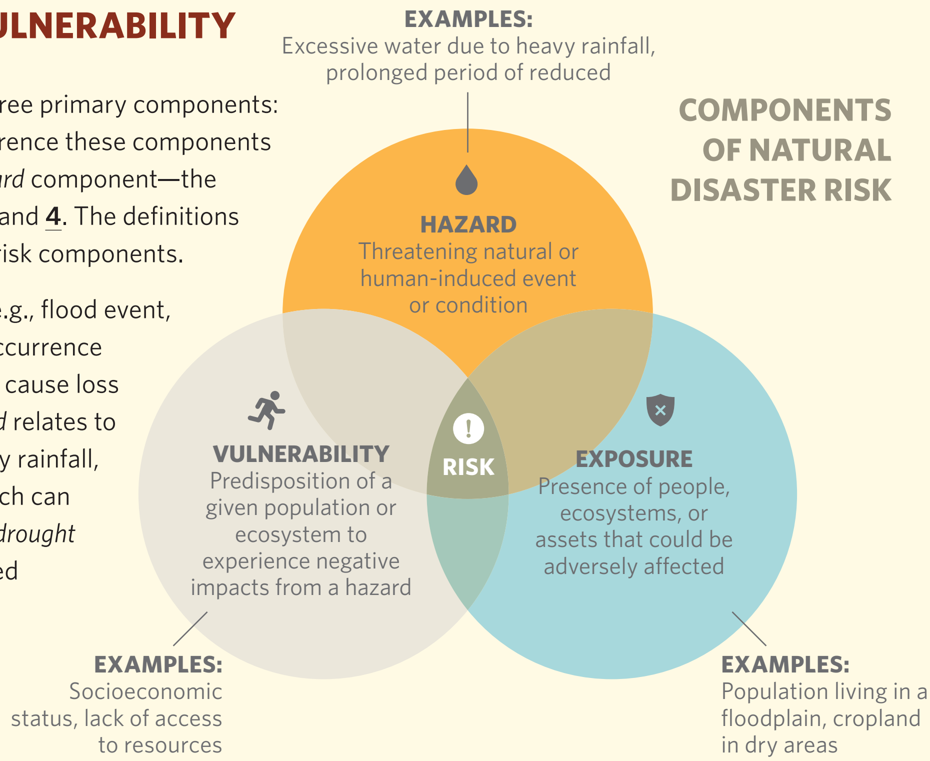

FIGURE 3. Depiction of natural disaster risk components with examples (adapted from IPCC 2022).

VULNERABILITY: The propensity or predisposition of a given system (a community or an ecosystem) to experience negative impacts when exposed to flood or drought hazards, because of changes to social functioning and processes (IPCC, 2022). *Vulnerability* includes *sensitivity* and *adaptive capacity*. *Sensitivity* refers to the degree to which system attributes are affected or altered as a result of pressures (Seddon et al., 2020); *adaptive capacity* refers to the ability of units (individuals, communities, etc.) that provide system functions and processes to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2022). *Vulnerability* encompasses various socioeconomic factors, including demographics and social status, poverty, lack of access to resources, and inadequate infrastructure.

DECIPHERING THE DRIVERS OF FLOOD HAZARD AND RISK

Floods are a natural part of the water cycle and can be critical for certain ecosystems and species (e.g., Okavango Delta, Amazon River). Nonetheless, they can also disrupt human economic activities and pose risks to human lives. Floods are defined as the inundation of normally dry land, triggered by meteorological processes including precipitation, temperature, evaporation, and snowmelt (**Figure 4**). These driving processes are further modulated through other biophysical processes and characteristics, including soil structure and moisture, vegetation characteristics, and catchment characteristics including geomorphology, along with human activities and interventions (Douville et al., 2021; Seneviratne et al., 2021). It is worth highlighting that there is not always a one-to-one relationship between heavy precipitation and flood events, due to additional factors affecting flood generation. While floods are fundamentally driven by meteorological processes, it is the combination of relevant factors that determines whether these processes result in flood generation.

Inland flooding can be grouped in multiple ways based on major drivers and processes, such as fluvial floods, pluvial floods, snowmelt floods, flash floods, long-rain floods, etc. (Douville et al., 2021; Nied et al., 2014). In this report, we focus primarily on fluvial (river) floods and pluvial floods.

- **Fluvial (river) floods** occur when the water level in a river, lake or stream rises and overflows onto adjacent lands. The major drivers of fluvial floods are prolonged or extreme precipitation and snowmelt events occurring within the basin. Other contributing factors include excess runoff due to a low infiltration rate or oversaturation of soil (e.g., high antecedent soil moisture), and watershed characteristics (e.g., a river network that leads to resonance of multiple flood peaks). These phenomena, on their own or in combination, cause the river flow discharge to increase and water level to rise.
- **Pluvial floods** are broadly defined as flooding that occurs when precipitation intensity exceeds infiltration and drainage capacity of natural or artificial drainage systems (soil, watercourse, sewer, etc.), independent of an overflowing water body (e.g., Rosenzweig et al., 2018). Pluvial flooding is oftentimes simply referred to as "urban flooding," as urban areas are particularly prone to pluvial flooding and therefore more frequently discussed in urban stormwater management contexts. In this report, we consider pluvial flooding occurring in undeveloped or agricultural landscapes when precipitation rates exceed natural infiltration rates.

Current flood hazard and risk

Floods and flood-related impacts comprise some of the most significant natural hazards for society (Rentschler et al., 2022). Globally, present-day flood risks are distributed broadly, with the most economically vulnerable in Southeast Asia and Sub-Saharan Africa (**Figure 5**) (Winsemius et al., 2016). More than 1.8 billion people globally are estimated to be currently exposed to large flood events of a 100-year return period (inclusive of both inland and coastal flooding). From 2000–2019, flood damages accounted for US$651 billion in economic losses, affecting more than 1.6 billion people globally—including more than 250 million people directly impacted by floodwater inundation (Browder et al., 2021; Tellman et al., 2021).

The loss of human life due to flooding has been decreasing over the past two decades due to significant advancements in management and early-warning systems. Nevertheless, the economic impacts of flooding continue to grow (Rentschler et al., 2022; Tellman et al., 2021; UNDRR, 2018). This increase is attributable in part to shifts in climate patterns, but also to changes in land-use practices, infrastructure development, and population demographics.

Both population and development have helped drive increased flood risk. For example, while the spatial extent of human settlements globally grew 85% from 1985–2015, human settlement exposure to high flood hazard increased by more than 120%—meaning that people have disproportionately moved into flood-prone areas (Rentschler et al., 2023, 2022). In East Asia, for example, settlements within high flood hazard areas expanded 60% faster than within flood-safe zones (**Figure 6**).

DRIVERS OF FLOODS

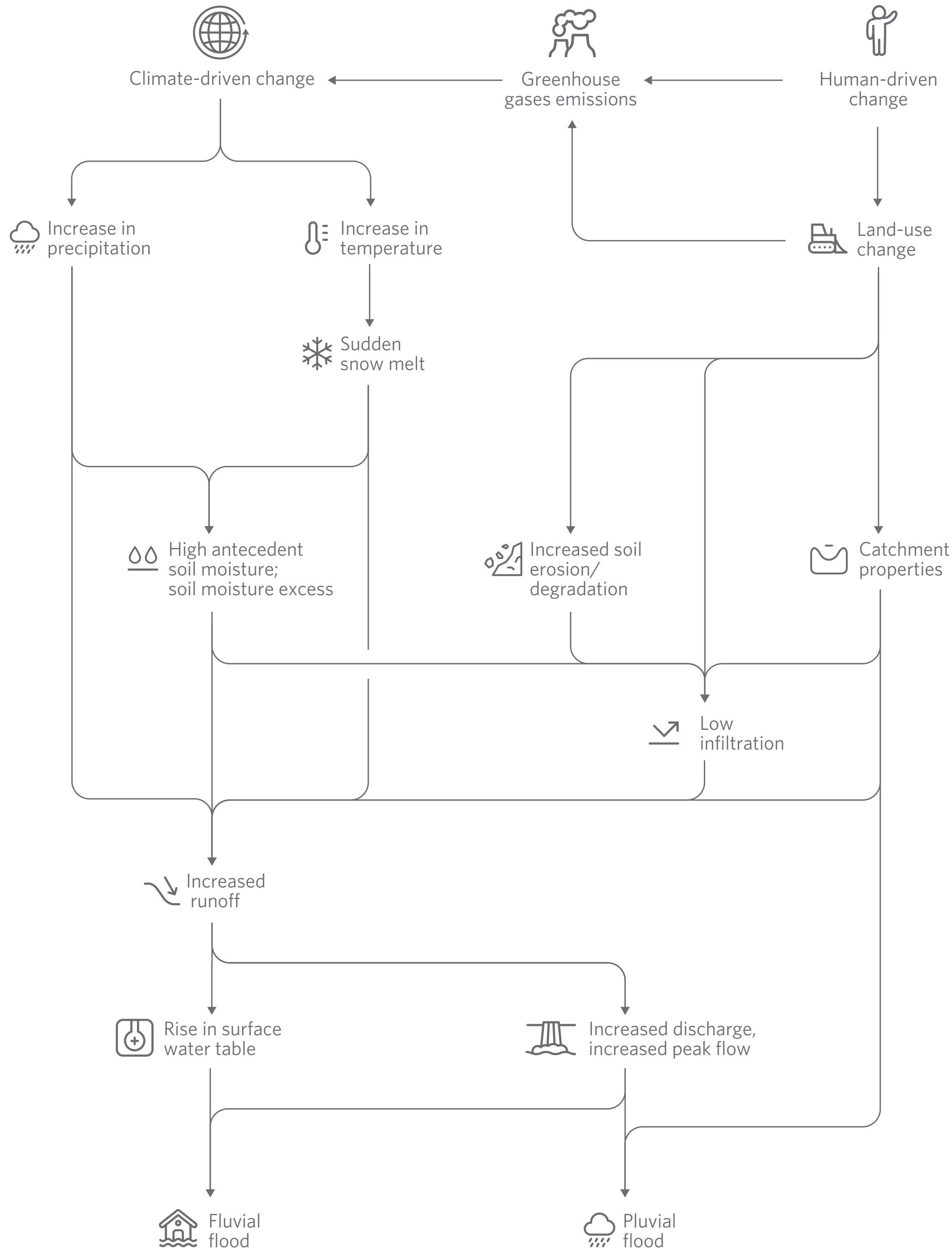

FIGURE 4. Diagram illustrating different categories of floods and their drivers, including climatic and anthropogenic factors. Summarized from Douville et al., 2021; Seneviratne et al., 2021; Debele et al., 2019.

CURRENT RIVER FLOOD HAZARD

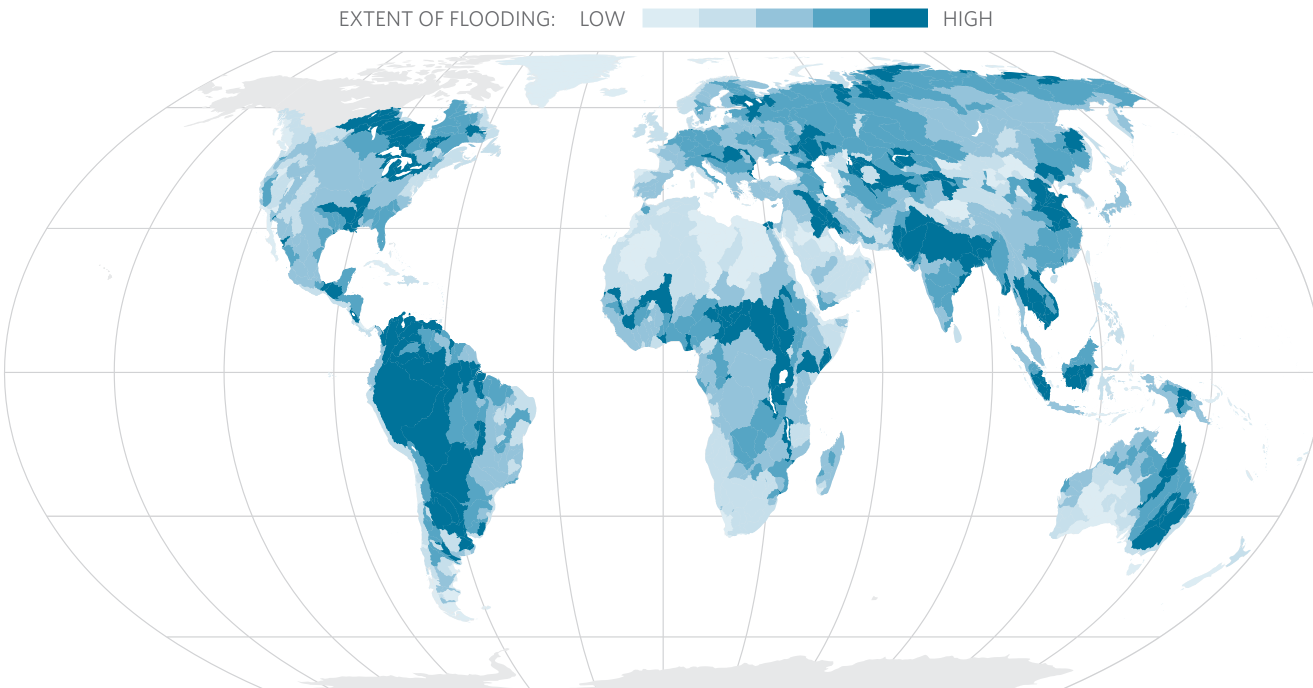

FIGURE 5. Extent of inundation for a 100-year flood event based on the historical period of 1980 to 2013. Shading indicates quantile (decile) of flood extent relative to total sub-basin area (HydroBASINS level 4). Data presented here pertain primarily to flood hazard (absent consideration of flood exposure or vulnerability). Data from Dottori et al., 2016.

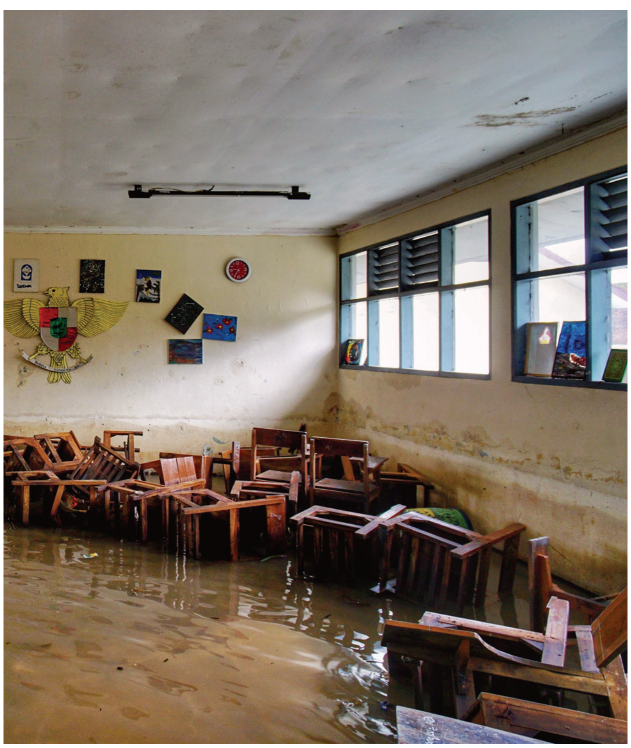

FIGURE 6. A state junior high school in Indonesia struggles with flooded classrooms after continual heavy rains. © Andaru Firmansyah/TNC Photo Contest 2022

Future flood hazard

Climate change is already altering the location, frequency, and severity of flooding, with projected increases in heavy rainfall in the future. While heavier rainfall does not always lead to greater flooding risk, the most severe flooding events are regardless expected to worsen (Douville et al., 2021; Seneviratne et al., 2021). As indicated in **Figure 5**, climate change is expected to drive several processes that will exacerbate current flood risk. Above-average rainfall typically increases soil moisture, and with wetter soils saturating more quickly during heavy rainfall events, surface runoff increases and can eventually contribute to the formation of floods. In cold regions, floods can be triggered by earlier-than-average snowmelt, potentially combined with a shift from snowfall to rain. Rapid melting of glaciers and snow is already increasing river flow in some regions, but as the volumes of ice diminish, flows will peak and then decline in the future. In subtropical regions, climate change may cause prolonged drying in soil, allowing the soil to infiltrate and hold more rainfall, thereby potentially reducing the likelihood of flooding from rainfall events. Furthermore, anthropogenic land-use changes, such as urbanization, deforestation, and agricultural extension, can reduce the amount of water infiltrating the soil and leading to frequent flooding; on the other hand, increased extraction of water from rivers can reduce water levels and the likelihood of flooding (Douville et al., 2021).

While projections of temperature increase are relatively certain given specific future scenarios of carbon dioxide equivalents, projections related to key elements of the water cycle (e.g., precipitation and evapotranspiration) have far greater uncertainty (Caretta et al., 2022). By extension, projections of water-related hazard and impacts—including flood and drought—entail even greater uncertainty.

This uncertainty further increases when considering projected changes at sub-global scales (e.g., regions, subregions, countries). At these scales, global models may omit key biophysical processes that drive flood- and drought-related impacts. As a result, individual models (or even ensembles of selected models) might suggest major disagreements in the magnitude and even directionality of future changes. Additionally, as described by the UN Intergovernmental Panel on Climate Change (IPCC) within their sixth and latest assessment, a large number of indicators can be employed to infer changes in future climate conditions (Gutiérrez et al., 2021). For example, for precipitation changes alone, the IPCC notes at least 13 indicators used to evince changes in various types of precipitation-related attributes.

A more robust approach to providing sub-regional projections was developed as part of the Assessment Report (AR6) by IPCC (Ranasinghe et al., 2021). Global and regional climate experts provided assessments of subregion risks using multiple data sources on historical trends, current conditions and future projections. This provides a consensus opinion on future flood changes (mid-21st-century) at sub-regional scales based on the best available science and expertise (**Figure 7**). In this report, we primarily rely on IPCC assessments due to their authoritative

INCREASING RIVER FLOOD HAZARD DUE TO CLIMATE CHANGE

FIGURE 7. Map depicting regional assessments of increased future (mid-century) river flood hazard of areas (44 land-based reference subregions) with medium- and high-confidence future change. Regional hazard assessments were developed by IPCC Working Group I based on a variety of models and data sources describing projections, current conditions and trends.

and consensus-based nature. We include other relevant data sources where applicable and appropriate, but note here the limitations of making inferences based upon singular studies.

While intensive rainfall is expected to increase across much of the globe with relatively high certainty, projections on river flooding are less encompassing and less certain (**Figure 7**) (Caretta et al., 2022). Projected increases in river flood hazard coincide with many regions already experiencing elevated levels of flood hazard. Central Europe, the eastern US, central South America, and most of the Asia-Pacific are regions with higher occurrences of large (100-year) flood events. All these regions are expected to face increased river flood hazard because of climate change. Flood hazard is expected to decrease for only a few regions of the world, including Northern Europe and areas of the Mediterranean. Substantial portions of the world, including Central America, northern South America, and large areas of Africa have conflicting evidence regarding the future direction or magnitude of river flood hazard changes due to climate.

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Compounding the expected increase of river flood hazard for large areas of the world is the likely increase in human and socioeconomic exposure. For example, flood exposure is likely to outpace population growth for 57 countries, particularly for parts of Asia and Africa—suggesting that future development is more likely to take place within higher flood risk areas (Tellman et al., 2021). However, this research also notes the challenge of predicting human migration patterns—including urbanization, which results in significant uncertainty about future exposure changes.

A "wetter" future is likely for many regions of the world, and advances are needed to adapt to potential increases in the frequency and severity of river flooding. Building from an understanding of the dominant processes that will drive this future river flooding risk, there are opportunities to consider a spectrum of approaches to support adaptation to future flood risk.

Deciphering the drivers of drought hazard and risk

Droughts refer to periods of time with substantially below-average moisture conditions, usually over large areas, where limited water availability leads to hydrological imbalance and negative impacts on natural systems and human societies (Seneviratne et al., 2021). Droughts usually begin as a deficit of precipitation and propagate to other parts of the water cycle. These are complex hydro-meteorological events and can be defined in different ways depending on specific indicators of processes and impacts (Van Loon, 2015).

The biophysical hazard dimension of drought includes atmospheric and terrestrial components of the water cycle (**Figure 8**). For example, the association between atmospheric (precipitation, temperature, evapotranspiration, snow accumulation) and hydrological (soil moisture, wetlands, streamflow and groundwater) variables is a crucial driver of water storage. As drought propagates into human society, it is also influenced by factors such as human land and water management (crop production, groundwater extraction, water allocation, etc.

DRIVERS OF DROUGHT

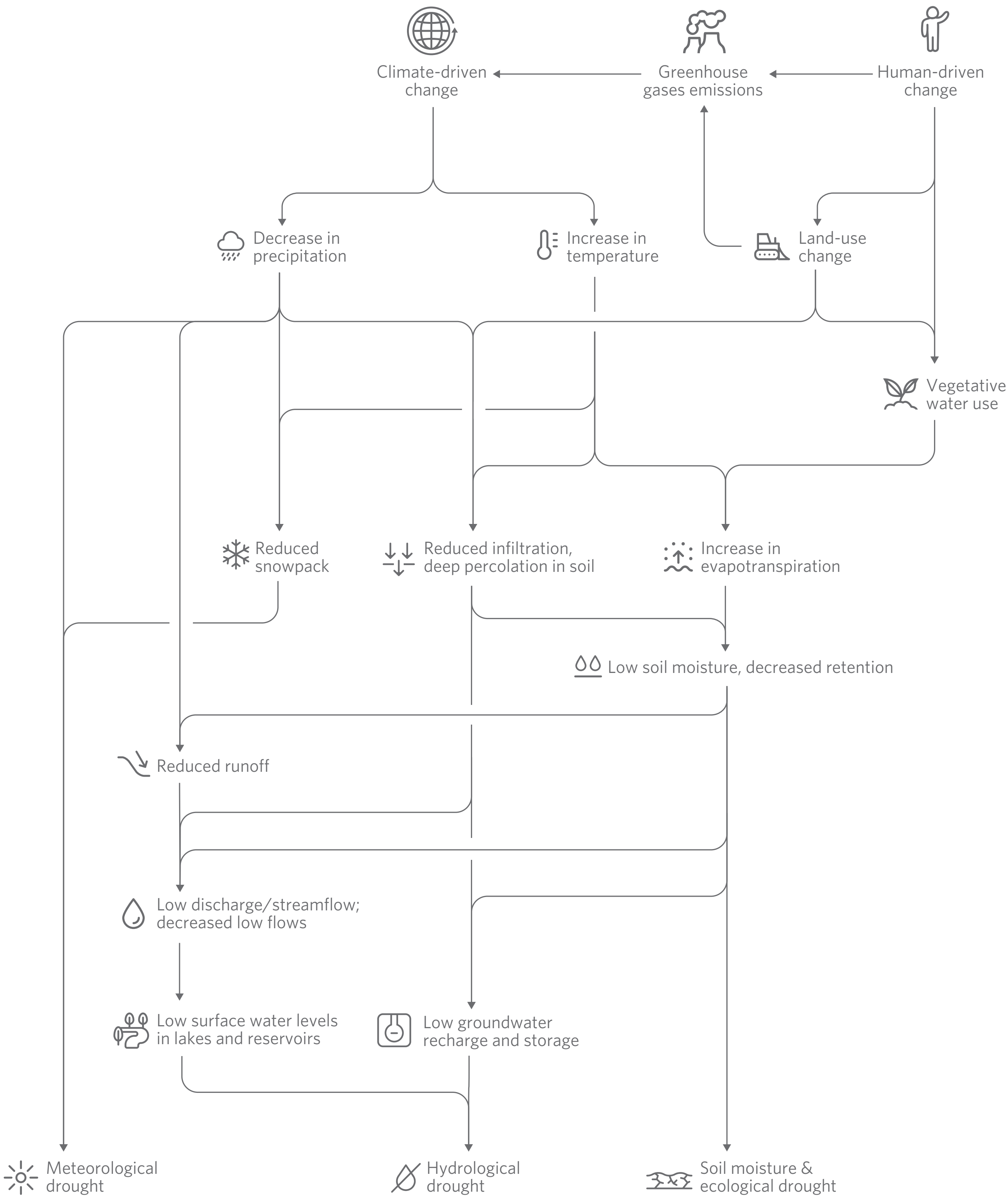

FIGURE 8. Diagram illustrating different categories of droughts and their drivers—both climatic and anthropogenic factors. Summarized from Douville et al., 2021; Seneviratne et al., 2021; Van Loon, 2015. Note: human water use, water resource management, and socioeconomic drought are not included in this figure.

Droughts are grouped into different categories based on where in the water cycle the moisture deficit occurs (Van Loon, 2015):

- **Meteorological drought** refers to a deficiency in precipitation, possibly combined with increased potential evapotranspiration, over a given region and spanning many months to years. Meteorological drought can further propagate and cause soil moisture drought.
- **Soil moisture drought** is a deficit of soil moisture (mostly in the root zone and upper soil layer), reducing the supply of moisture to vegetation. Soil moisture drought is strongly linked to crop failure (*agricultural drought*) and results in additional impacts on natural ecosystems (*ecological drought*). Soil moisture drought threatens food production through crop damage and decreases in yield, with consequent economic impacts. Soil moisture drought can further propagate into hydrological drought through a diminishing volume of water filtering into rivers, lakes, and aquifers.
- **Hydrological drought** is a broad term related to negative anomalies in surface and subsurface water triggered by a range of factors, such as below-normal groundwater levels or water levels in lakes, declining wetland area, and decreased river discharge. A decrease in groundwater levels and streamflow causes hydrological droughts to detrimentally affect the availability and quality of freshwater, which in turn impacts both human and natural systems.
- **Socioeconomic drought** (not shown in **Figure 8**) is associated with the impacts of the three above-mentioned types, usually measured by social and economic indicators. It can refer to a failure of water resources systems to meet agricultural irrigation water demands, biodiversity freshwater requirements, or health-related dependencies. Socioeconomic drought can also occur in the absence of hydro-meteorological anomalies, caused instead by unsustainable exploitation of water within a basin or through other water supply system deficiencies, leading to a failure to satisfy social and ecological water demands.

Current drought hazard and risk

Drought is one of the most significant natural hazards globally. Approximately one-third of disaster-related deaths between 1970–2019 can be attributed to drought events due to a combination of impacts, including food shortages and decreases in water availability (Tabari and Willems, 2023). The economic costs are also significant, accounting for an estimated US$124 billion in losses over the period 1998–2017 (UNCCD, 2022). While human and economic vulnerability has declined globally over the past decades due to effective risk management, the impacts of drought are still significant for many regions of the world (Kreibich et al., 2022) (**Figure 9**).

While the uncertainty in future projections can be significant, the dominant picture is one where existing drought hazard is compounded by climate change for many areas of the world. There is a clear need for management of existing drought hazards as well as adaptation strategies to potential future changes.

Different types of droughts manifest under different processes, and with different impacts. **Figure 10** presents global agricultural drought hazard and exposure for recent historical conditions. Areas of elevated drought hazard and exposure—including both irrigated and rainfed systems—span most

FIGURE 9. Record drought in Central Valley, California in 2021 reduced water in the San Luis Reservoir to just 15% of capacity. © Stuart Palley

CURRENT AGRICULTURAL DROUGHT HAZARD AND EXPOSURE

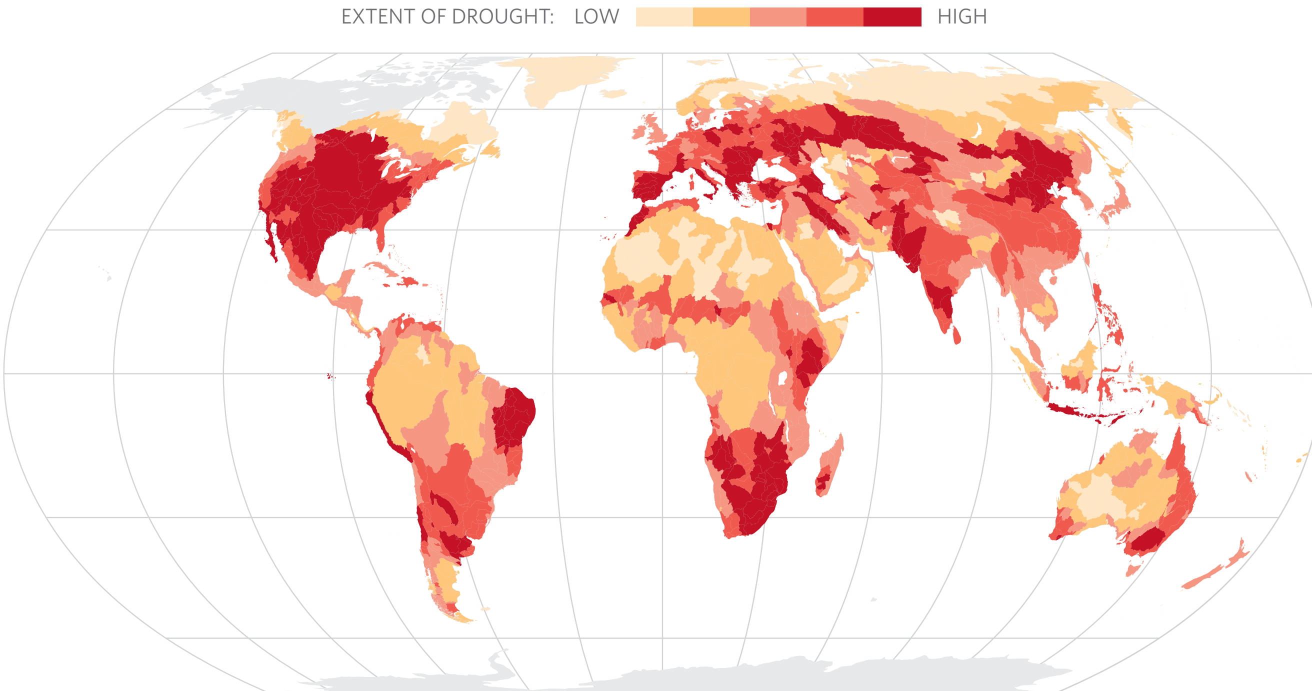

FIGURE 10. Hazard and exposure of agricultural drought for irrigated and rainfed systems based on the period 1980–2016. Shading indicates quantile (deciles) of combined (rain-fed and irrigated) harvest area weighted hazard-exposure index aggregated to sub-basins (HydroBASINS level 4). Data from Meza et al., 2020.

regions of the world. Agricultural areas with particularly high exposure to drought hazard include southern Africa, the Mediterranean, Australia, and the central United States. The potential economic and social costs of such agricultural drought can be staggering. For example, the 2020–2022 drought in California (US) is estimated to have cost more than US$1.1 billion (Medellín-Azuara et al., 2022), and the 2022–2023 drought in the Horn of Africa resulted in acute food insecurity for over 23 million people, including five million malnourished children (World Food Programme, 2023).

Concurrent with impacts on agriculture, drought can also cause significant impacts for ecological systems. Besides the immediate and direct consequences for fish and other aquatic wildlife within drought-affected streams with declining streamflow (**Box 2**), drought conditions can drive far-reaching ecosystem changes with significance for both human and natural systems. Agricultural and ecological drought can increase tree vulnerability and mortality, leading to widespread changes in vegetation such as the transition from forest to shrubland (Crausbay et al., 2017). Such a transition can have profound consequences on both biodiversity and communities dependent on historical vegetation conditions. For example, in the western US, interactions of intense drought, heat waves, insect outbreaks, and severe wildfires are likely to drive large-scale transformations, particularly for semi-arid forests.

Future drought hazard

In a warmer world, we can expect a decrease in precipitation in certain regions as well as an increase in evaporation and transpiration. In general, as temperatures rise, there will likely be higher water vapor loss (evapotranspiration), resulting in drier soil conditions and increasing susceptibility to drought (Douville et al., 2021). Reduction in soil moisture hinders the amount of water filtering into rivers. Intensifying aridity also creates conditions for more wildfire. Increasing temperatures may also decrease snowpack, resulting in less runoff and streamflow to

BOX 2.
FLOOD AND DROUGHT EFFECTS ON BIODIVERSITY

While species and ecosystems have evolved with and adapted to local water cycle and hydrologic conditions that include flood and/or drought events (Junk and Wantzen, 2007), changes to the frequency, intensity, and duration of these events under climate change can have significant impacts, direct and indirect, on biodiversity. Examples of detrimental impacts include:

HABITAT DESTRUCTION: Floods can lead to the destruction of habitats by submerging land areas, resulting in loss of vegetation, nesting sites, and food sources for species (Zhang et al., 2021). Droughts can cause large-scale die-off of vegetation due to water scarcity (Brodribb et al., 2020), as well as decreasing the available surface and groundwater, leading to the decline of aquatic ecosystems and species. Drought can also cause habitat fragmentation as water sources shrink or disappear, isolating populations and reducing genetic diversity (Huggins et al., 2022), water scarcity and decreased soil moisture levels.

SHORTAGES OF FOOD AND OTHER RESOURCES: Floods and droughts can introduce a series of physiological-ecological responses in plant ecosystems and species (Brodribb et al., 2020; Kozlowski, 2002), and may lead to food shortages as plants and animals struggle to survive. This affects herbivores, carnivores, and omnivores alike, disrupting food webs and potentially causing population declines (Wright et al., 2015). Such shortages may force species to relocate, disrupting established ecological relationships and leading to competition for resources in new areas. This competition can result in changes in population dynamics and community structure (Archaux et al., 2010).

DISTURBANCE TO WATER AND SOIL QUALITY: Floods can introduce pollutants and contaminants into water bodies, decreasing water quality and affecting ecosystems and species across biomes. Flooding can also alter the composition of soil by depositing sediments and nutrients, thereby impacting the growth and survival of plants and the organisms that depend on them. Drought is expected to reduce the abundance and diversity of soil biota in response to reduced water availability (Blankinship et al., 2011; Lindberg and Bengtsson, 2005).

A woman removes invasive pine species outside of Cape Town, South Africa, where invasive plants threaten the limited water supply. For more details, see Chapter 6. © Roshni Lodhia

SPREAD OF INVASIVE SPECIES: Floods can facilitate the spread of invasive species by transporting them to new areas. These invasive species may outcompete native species, leading to a decline in biodiversity (Čuda et al., 2017).

WILDFIRE RISK: Drought conditions often increase the risk of wildfires. Fires can destroy habitats and displace or eliminate many species, leading to significant losses in biodiversity (Green and Sanecki, 2006; Pastro et al., 2011; Pelegrin and Bucher, 2010).

For an additional overview of direct responses of species to climate change, see Oliver and Morecroft (2014). As discussed further in **Chapter 3**, the ways in which floods and droughts, as well as other climate change-induced disasters, negatively affect the feasibility and viability of ecosystems and species has major significance in the selection and implementation of NbS.

INCREASING DROUGHT HAZARD DUE TO CLIMATE CHANGE

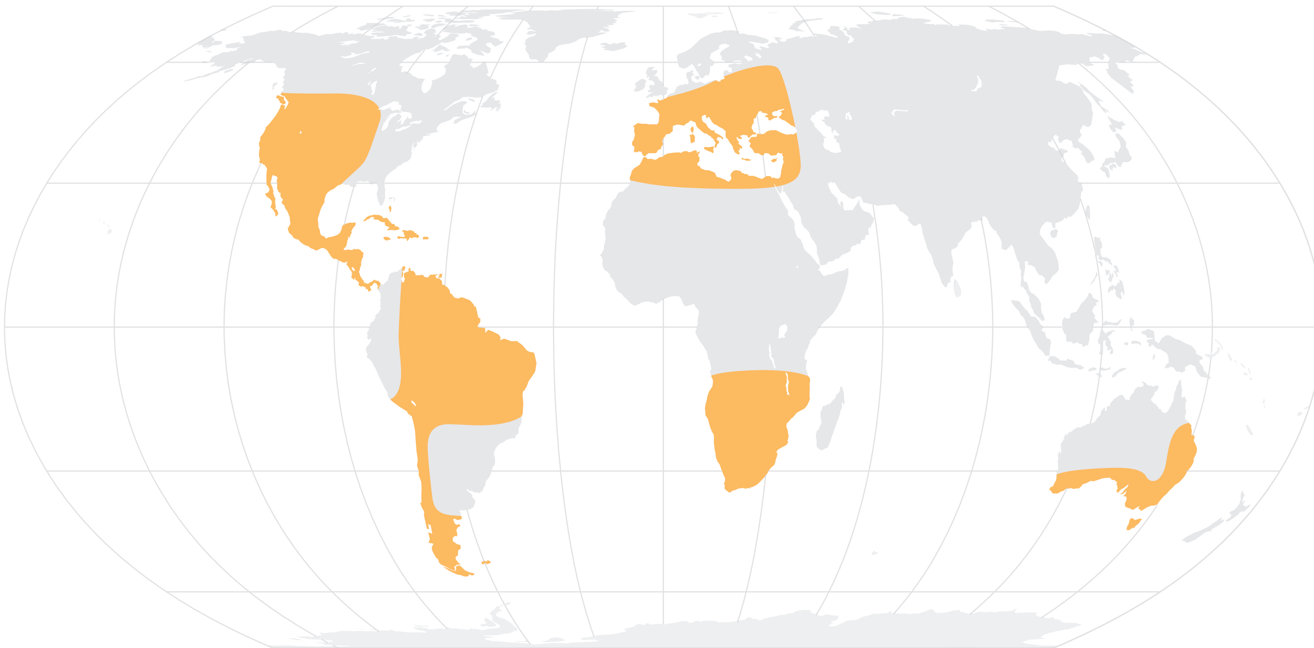

FIGURE 11. Map depicting regional assessments of increased future (mid-century) agricultural and ecological drought hazard for areas (44 land-based reference subregions) with medium and high confidence of future change. Regional hazard assessments were developed by IPCC Working Group I based on a variety of models and other data sources describing projections, current conditions, and trends.

downstream areas, and thereby amplifying drought in regions where snowmelt is an important water resource (e.g., the high Andes, the Himalayas, the western US).

As with flood hazard, forecasting future changes in drought hazard entails considerable uncertainty, with agreement varying widely between models and other information sources. **Figure 11** presents consensus appraisal from IPCC on future agricultural and ecological drought hazard based on multiple data sources (Ranasinghe et al., 2021). Increased drought hazard is expected throughout the Americas, potentially spanning large portions of North, South and Central America. Evidence is also relatively strong for increased drought hazard for many parts of Europe, particularly within Mediterranean areas, as well as in southern Africa and Australia. Many of these same areas currently experience increased agricultural and ecological drought risk. Therefore, for many places in the world, including southern Africa, Europe, and North America, climate change will exacerbate current drought risk and challenge efforts to mitigate existing levels of drought hazard.

Besides changes in overall drought hazard occurrence and distribution, at least one study indicates that the severity of these droughts is also expected to increase. While the occurrence of mild-severity drought may decrease in the future, conversely, the frequency of more severe moderate and extreme droughts could increase (Liu and Chen, 2021). In South Africa, for example, projections of future drought in the Western Cape suggest drought severity will be closely coupled to increased global warming levels, with both drought severity and frequency likely to increase (Naik and Abiodun, 2020).

While the uncertainty in future projections can be significant, the dominant picture for many areas of the world is one in which existing drought hazard is compounded by climate change. There is a clear need for management of existing drought hazards as well as strategies for adaptation to potential future changes.

03

LEVERAGING NBS FOR FLOOD AND DROUGHT ADAPTATION

Given globally increasing trends in the frequency and impacts of flood and drought, the need for effective adaptation approaches is urgent. Historically, physical disaster risk reduction measures have relied more on gray infrastructure (Ward et al., 2020). While important for reducing the impacts of flood and drought, these solutions are showing limitations in the face of climate change, including low adaptive capacity, severe consequences after failure (e.g., floodwall collapse, dam failure), increasing costs of construction and maintenance, negative impacts on ecosystems, and limited co-benefits (Hoffman and Henly-Shepard, 2023; IFRC and WWF, 2022).

© JOCELYN AUGUSTINO/FEMA

Nature-based Solutions (NbS), as described in **Chapter 1**, are gaining momentum in mainstream discourse as an effective approach to complement traditional engineering solutions and to build resilience (Caretta et al., 2022; Chausson et al., 2020; Debele et al., 2019; Sudmeier-Rieux et al., 2021). Several related concepts, including natural climate solutions (NCS), ecosystem-based disaster risk reduction (Eco-DRR), ecosystem-based adaptation (EbA), and green infrastructure, were developed over the years and with increasing policy support by several organizations and government agencies (e.g., the 2030 Agenda for Sustainable Development, the New Urban Agenda, the Sendai Framework for Disaster Risk Reduction 2015–2030).

Evidence is increasing for the positive role of NbS in climate change adaptation and disaster risk reduction at different scales (Chausson et al., 2020; IFRC and WWF, 2022; Seddon et al., 2020; UNEP, 2022b; van Zanten et al., 2023). In addition, NbS also provide a suite of co-benefits with potential to address other environmental and societal challenges, such as nonpoint source pollution, biodiversity loss, wildfire risks and food production (Abell et al., 2017; IFRC and WWF, 2022).

In general, NbS can reduce natural disaster risks by addressing one or a combination of the three components of risk (**Chapter 2**) by:

- Preventing or mitigating the incidence and severity of *hazards*;
- Reducing people's and/or assets' direct *exposure* to hazards; and
- Reducing people's and communities' *vulnerability*, and bolstering adaptive capacities.

In this chapter, we elaborate on the mechanisms and conditions by which NbS contribute to flood and drought risk reduction and management. We further describe the specific pathways by which NbS can support hazard mitigation. Finally, we present a review of major NbS types and potential impacts—including addressing exposure and vulnerability to climate hazards—and trade-offs with respect to climate adaptation.

LEFT: © DAVID Y. LEE; RIGHT: © JASON HOUSTON

BOX 3.

EQUITY WITHIN NBS

It has become clear to the conservation community that commonly applied conservation approaches have, in the past and in some cases currently, marginalized local communities and Indigenous peoples, which has negatively impacted these communities' livelihoods, cultures and social structures. Many conservation organizations have committed to repairing these impacts, finding ways for conservation to uplift and support these communities, and concurrently transforming how conservation is carried out to avoid further damage.

As with gray infrastructure, the selection, design, implementation and management of NbS also have the potential to create inequities and negatively impact communities if pursued without considering the five dimensions of equity and justice: 1) **distributional** (the distribution of the costs, benefits, burdens, and rights of NbS projects), 2) **procedural** (inclusiveness in decision-making around NbS projects), 3) **recognitional** (respect for knowledge systems, values, and rights of stakeholders), 4) **contextual** (the broad social, economic, political, and cultural contexts, both past and present, that influence the ability of an actor to participate in decision-making, ensure fair distribution, and gain recognition), and 5) **transformative** (the need to address systemic inequalities based on the understanding that vulnerability to climate change arises from the underlying structural injustices within society). (Bremer et al., 2021; Newell et al., 2021; Pascual et al., 2014; McDermott et al., 2013)

To more deeply integrate equity and justice into NbS, The Nature Conservancy recently developed a set of five principles based on literature review, case studies and discussions with experts (Atieh et al., 2023):

1. Community members and local stakeholders are experts, partners, knowledge-holders, managers, and resource users and protectors before, during and after the NbS project implementation.
2. Capacities and ideas are exchanged, incorporated, and built among all actors starting from the design phase, respecting as equal the different disciplines, experiences, knowledge systems (traditional and Indigenous), perspectives and priorities regarding people, nature and the purpose of NbS.
3. Bringing together long-term visions, robust socioeconomic analysis, diverse values for nature, and a systems-based approach facilitates the creation of NbS that are sustainable and responsive to social, political, and environmental shifts over time.
4. What would be—and how to attain—transformational outcomes, especially for the most vulnerable and marginalized, that redress historical imbalances in access to resources and current systemic inequalities are collectively defined.
5. Prioritizing accountability, collaboration, and continuous improvement by designing Monitoring, Evaluation and Learning systems that measure equity, justice, adaptation and environment impacts and co-benefits that are meaningful to all stakeholders.

NBS AS INSTRUMENTS OF FLOOD AND DROUGHT ADAPTATION

As described in **Chapter 2**, to effectively employ NbS for flood and drought adaptation, it is critical to understand the specific mechanisms by which these solutions can alter flood- or drought-related processes. While several existing reports have broadly described the potential for NbS to support adaptation, few of these have focused specifically on water-related hazards, and most provide only generalizations about how NbS can mitigate these hazards (Fedele et al., 2019; Kapos et al., 2019; Matthews et al., 2019; Tye et al., 2022; WWF, 2019). The review here supports critical discussion beyond generalizations to better consider the conditions and limits under which NbS can support flood- and drought-related adaptation.

NbS can neither generate more water nor influence precipitation in most cases, instead influencing natural processes to redistribute water over time and space within a watershed—changing how water moves across the landscape, into the subsurface, and back into the atmosphere. Exceptions include large-scale forest protection that can influence precipitation patterns (Creed et al., 2019; Ellison et al., 2019), such as tropical montane cloud forest systems regulating water supplies through cloud and fog capture (Bruijnzeel et al., 2010). In general, NbS affect a discrete set of landscape features, including surface and subsurface vegetation characteristics (e.g., leaf area, species assemblages, and root depth), land surface characteristics (e.g., slope, surface roughness, and surface permeability), and soil characteristics (e.g., infiltration rate, water retention capacity, hydraulic conductivity, and soil depth). By changing these features, NbS can affect hydrologic pathways and processes in ways that matter to people and ecosystems, including changes in surface runoff, infiltration, groundwater recharge, peak flow, and low flow (Dennedy-Frank et al., 2020; Karres et al., 2018; Vogl et al., unpublished data). Spatially, the location and scale of NbS interventions influences the directionality and magnitude of impacts. Interventions are likely to have diminishing hydrologic effects as distance increases relative to the waterbody of interest. Similarly, hydrologic responses tend to diminish as watershed area increases relative to the extent of intervention. Still, local-scale effects may be large even if watershed-scale effects are not. This is an important consideration when NbS are primarily intended to improve local conditions.

The effects of NbS on various hydrologic processes may change over time, particularly for interventions that alter vegetation characteristics, as species assemblage and/or age structure naturally change. For example, forest thinning increases water yield (Saksa et al., 2017); after the initial increase, however, water yield declines as the remaining trees grow and understory vegetation cover increases (Farley et al., 2005).

Importantly, NbS often affect several different hydrologic processes simultaneously—sometimes with opposing effects—raising challenges in predicting the net impacts of any given NbS on water flow at the landscape scale (see example in **Box 4**). As a result, it is imperative to consider the specific pathways by which NbS might affect critical processes that drive flood or drought hazard.

Although the impacts of individual NbS may be limited to specific areas, their cumulative effects can still contribute to broader disaster risk regulation efforts. When implemented across multiple locations, and at sufficient scale, these localized solutions can have a cumulative impact on water redistribution and ecosystem health at the basin level or at even larger scales. Combining NbS with other disaster risk management strategies can also help bridge the scale gap. Integrated water resource management approaches that incorporate NbS alongside improved water infrastructure, resource governance, and policy frameworks can create a more comprehensive and effective response to water-related climate disasters (see **Box 5**). By considering multiple strategies and their interactions, the effectiveness of NbS can be enhanced and better aligned in coping with large-scale flood or drought impacts.

BOX 4.

NBS AND PROCESS COMPLEXITY: FOREST RESTORATION AS AN EXAMPLE

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The example of forest restoration well illustrates the complex processes and interactions that can result from NbS implementation for adaptation. When restoring forests on previously deforested or degraded lands, new trees generally increase local infiltration through changes in above- and below-ground vegetation. Above ground, as trees grow, tree canopies protect soils from the direct impact of raindrops, while tree roots, litterfall, and understory vegetation slow above-ground water flow. Below ground, large and deep tree roots create more and larger macropores for water to flow. Reforestation can also affect soil characteristics over longer time periods, with litterfall and associated microfauna helping to build soil, enhancing the capacity to capture and hold rainwater. As a result, reforestation will result in less soil compaction and more developed volume and structure of the soil, which will reduce surface runoff and increase local infiltration of water into the ground. Together, these changes contribute to reduction in peak flow, diminishing the volume and velocity of water entering water bodies and thereby reducing overall flood hazard. However, water that infiltrates into the subsurface does not necessarily increase groundwater recharge or enhance low flows; this balance is determined by additional processes and factors as well.

Reforestation also mediates hazard changes through effects on evapotranspiration: new vegetation tends to increase the overall evaporative demand because trees generally have greater water requirements than grasses. Above ground, plants with greater leaf area and height tend to also have greater evaporative demand. In addition, because trees have greater access to subsurface water than grasses due to their deeper root structure, total evapotranspiration could be expected to increase. This increasing flux of water from deeper soil layers back to the atmosphere through evapotranspiration reduces the amount of infiltration available for recharging seasonal baseflow or groundwater aquifers. In some field experiments of reforestation, infiltration increases are frequently offset by greater evapotranspiration, resulting in a net reduction in baseflow (Van Meerveld et al., 2021). These changes could generate negative impacts on drought hazard reduction and create trade-offs that require careful planning and management. Put simply, it is critical to examine the balance between soil infiltration and forest water use (evapotranspiration) to assess the overall impact of restoration on hydrology. One study in the seasonally dry tropics proposed an optimum tree cover theory, suggesting that intermediate tree densities on degraded lands may maximize groundwater recharge via improved soil hydraulic properties, indicating that achieving a balance between enhancing infiltration and increasing evapotranspiration is possible (Ilstedt et al., 2016). Because NbS affect multiple hydrologic processes and simultaneously influence the surface flow, evapotranspiration, infiltration and percolation of water into the subsurface, the net impact depends on the magnitude of effects specific to a particular location.

NBS AND FLOOD HAZARD PROCESSES

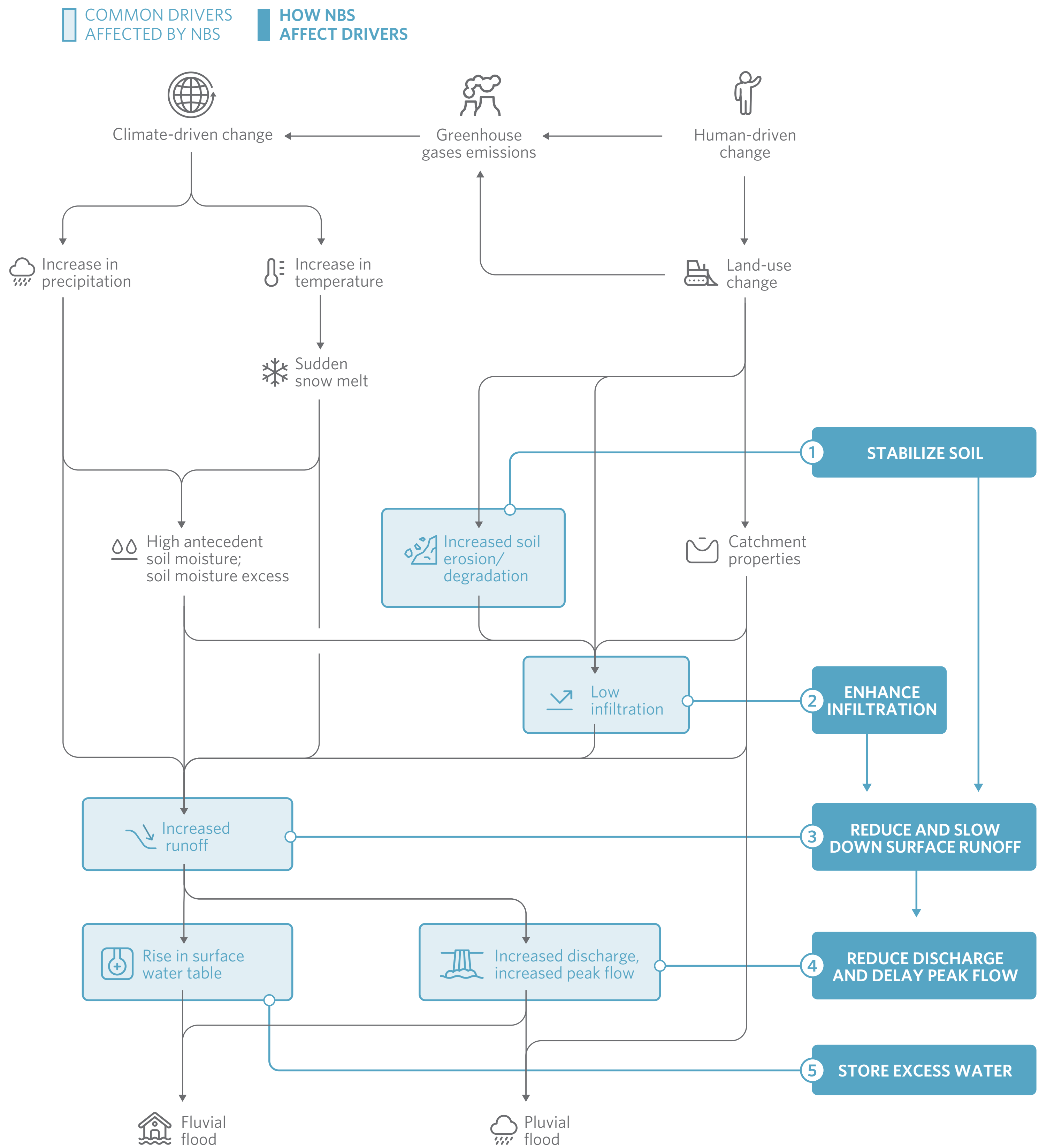


FIGURE 12. Hydrologic processes commonly affected by NbS for flood hazard regulation. Light blue boxes highlight processes and factors along the flood generation pathway that can be affected by NbS. Dark blue boxes illustrate how NbS are affecting these processes.

UNDERSTANDING NBS ADAPTATION MECHANISMS ON FLOOD AND DROUGHT

Figure 12 and **Figure 13** capture the major hydrologic processes for flood and drought that are commonly affected by NbS (summarized based on reviews including Acreman et al., 2021; Dennedy-Frank et al., 2020; Karres et al., 2018; van Zanten et al., 2023; Vogl et al., unpublished data). These figures illuminate the complexity of pathway connections between flood and drought as well as the significance of processes beyond the influence of NbS.

A variety of NbS can be employed to support reduced flood risk (**Figure 12**). River and floodplain restoration activities (including floodplain reconnection, floodplain regeneration, river rewilding, dike or dam removal to restore natural river flow regime, adding woody debris into rivers, etc.) allow rivers to naturally overflow and create natural water storage areas that can slow down, retain and attenuate floodwater flow (④, ⑤ in **Figure 12**). They can also create bypasses to move floodwater from human settlements, and are particularly effective in regulating fluvial flood hazard and exposure. The restoration of meadows and wetlands has the potential to store excess water during periods of heavy rainfall, to slow down water flow, and to reduce the magnitude and delay the timing of peak flow (③, ④, ⑤). For floodplain and wetland restoration interventions, it is important to recognize their position in the watershed. NbS in the headwaters slow down the flow mostly by means of retention. In the middle and lower reaches, where discharge is generally higher, NbS act as a buffer to reduce peak floodwater levels, store excess water, and keep floodwater from reaching human settlements. For example, the Stroud Valleys Natural Flood Management Project in the United Kingdom (**Chapter 6**) demonstrates how a combination of NbS implemented at the watershed scale—river channel restoration, floodplain restoration, etc.—can delay the arrival of peak flooding.

© KEN GEIGER/TNC

Restoration of native vegetation can reduce pluvial flood hazards. Vegetation on hillsides, in riparian zones, and in other flood-prone areas can intercept rainfall, stabilize soil, increase soil infiltration and soil water retention capacity, enable evapotranspiration, and create more diverse physical land surface structures that increase roughness and slow down surface runoff (①, ②, ③). Ellison et al. (2017) suggest that different tree species for restoration ought to be chosen based on the specific geography: in water-rich areas, fast-growing, high-water-consuming tree species might reduce, but not eliminate, flood risks. In water-limited areas, however, slow-growing, low-water-consuming tree species might increase infiltration and help moderate flooding.

Vegetative buffers can also act as natural flood barriers, attenuating peak flows and reducing the probability of damaging human settlements (addressing exposure). In agricultural lands, terracing, hedgerows, buffer strips, cover crops, treatment wetlands, and drainage ponds can decrease overland flows. Restored soils then absorb more water, which enhances infiltration and sediment deposition as well as slowing down and capturing surface runoff (②, ③), thereby contributing to the regulation of pluvial floods. For example, Deasy et al. (2014) compared the impacts of different best management practices, or BMPs (minimum tillage, contour cultivation, etc.) on the size, duration, and timing of flood peaks in the UK, and suggested that these practices can affect local-scale runoff generation. However, the authors also noted that treatment effects were not significant, and the benefits to mitigating downstream flood risk remain largely theoretical.

While NbS can influence several processes in the triggering pathway to flood, they are unlikely to eliminate the possibility of flooding in extreme weather events, particularly when rainfall intensity or energy of peak flow exceeds the natural water retention capacity of the NbS. For instance, NbS can reduce peak flow for low- to moderate-intensity storms, but performance will decline once soils become oversaturated.

There are many hydrologic processes and pathways to consider when implementing NbS for drought hazard regulation (**Figure 13**). As described in **Chapter 2**, drought is triggered not only by atmospheric processes, which NbS would have limited capacity to impact, but also by the hydrological processes (water storage, runoff) that feed moisture to the atmosphere. NbS have the potential to modify these feedbacks through changing surface and subsurface vegetation characteristics, land surface characteristics and soil characteristics.

NbS for drought adaptation have a more limited capacity to address exposure, because droughts develop more slowly, cover extensive areas and can last for months to years. Most NbS aiming to manage drought risks target hazard regulation (focusing on soil moisture and hydrological droughts) and vulnerability reduction instead. For example, agricultural BMPs such as terracing, maintaining vegetative buffer strips (hedgerows, grass buffers, etc.), mulching, and contour plowing can slow down surface runoff and enhance water infiltration, reduce soil compaction, and reduce evaporation, contributing to the retention of soil moisture (②, ③, ④ in **Figure 13**). Wetland restoration, retention ponds, swales, and constructed wetlands can also store rainwater to allow more water infiltration and recharge (③, ④, ⑤). The Uganda case study (**Chapter 6**) illustrates how wetland restoration can retain water for infiltration into shallow aquifers and enhance resilience during drought. The Peru case study (**Chapter 6**) offers another example of restoring drained wetlands and protecting peatlands (*bofedales* in the Andes) to slow runoff and increase water storage. Agroforestry, reforestation, and other native revegetation interventions can change above- and below-ground vegetation characteristics, create shade to reduce evaporation from the soil surface to preserve soil moisture, break up compacted soil, and restore soil water retention and infiltration capacity (②, ③, ④). In agroforestry systems, for example, studies on tropical coffee and cocoa agroforests in Latin America showed improvement in soil properties and reduction in surface runoff (Benegas et al., 2014), as well as potential impacts on streamflow regulation and aquifer recharge (Gomez-Delgado et al., 2011). In dryland landscapes in Africa, agroforestry can improve infiltration and preferential flow (Bargués Tobella et al., 2014).

Removal of invasive tree species in certain dryland or shrubland ecosystems restores the water-use characteristics of native vegetation and reduces transpiration and evapotranspiration rates, thus reducing soil moisture deficit and contributing to sustained baseflow (①, ②). For example, in the fynbos biome in South Africa, clearing invasive alien trees could ameliorate streamflow reductions through reduction in evapotranspiration (Holden et al., 2022; Stafford et al., 2019) in the Cape Town case study (**Chapter 6**). The removal of juniper to control woody encroachment into grasslands, where evidence shows an increase in streamflow following the removal, is another example (Huang et al., 2006).

In addition to reducing soil moisture drought hazards, many agricultural BMPs (some of which are considered NbS) can also contribute to the reduction of people's vulnerability to drought events through crop diversification, switching to drought-resistant crop varieties, creating local seed banks, and other strategies that aim to reduce food insecurity during drought (maintaining agricultural productivity and crop yield), while also providing additional income and increasing adaptive capacity in general.

NBS AND DROUGHT HAZARD PROCESSES

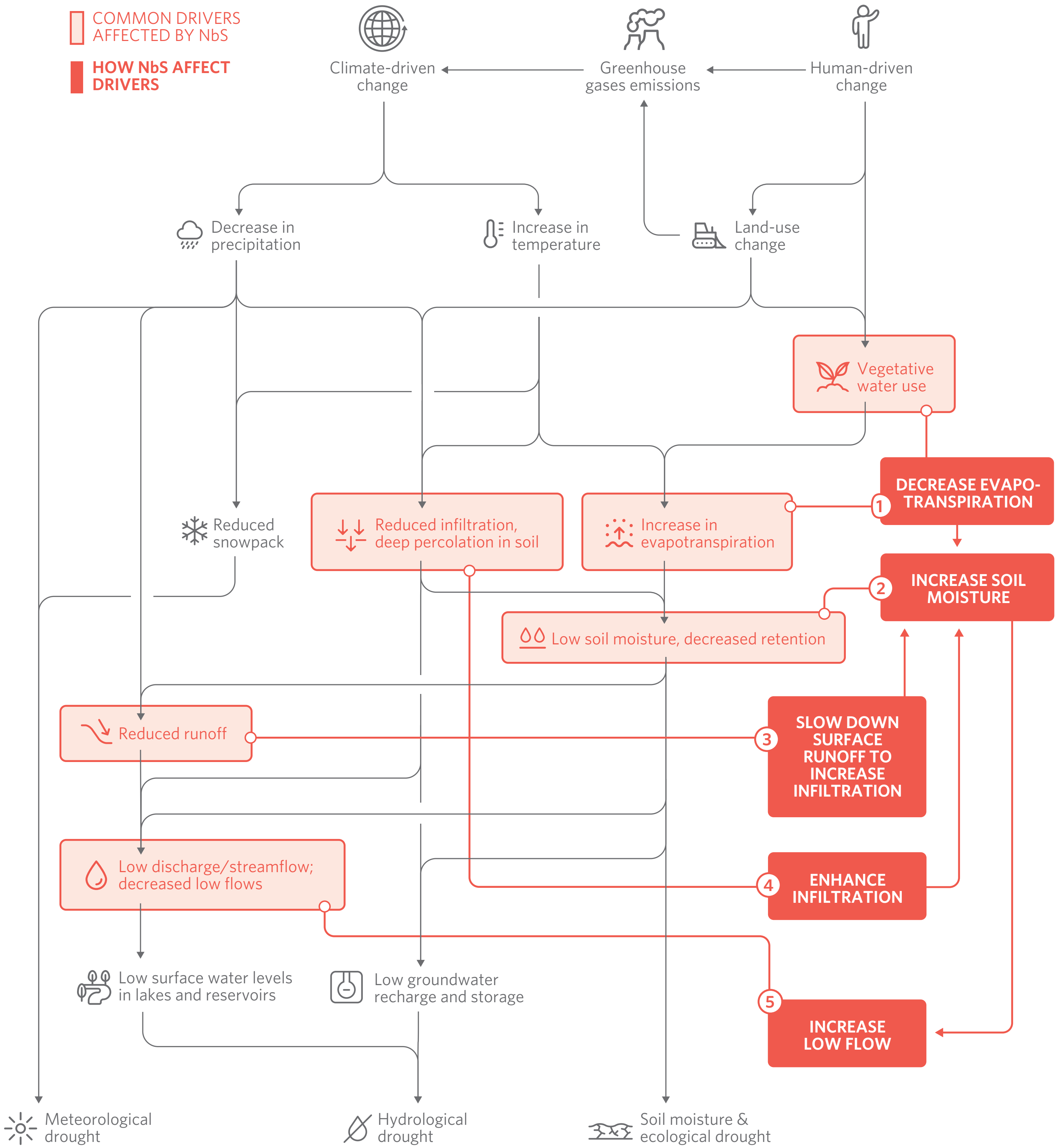


FIGURE 13. Hydrologic processes commonly affected by NbS for drought hazard regulation. Light red boxes highlight processes and factors along the drought generation pathway that can be affected by NbS. Dark red boxes illustrate how NbS are affecting these processes. Note: human water use, water resource management, and socioeconomic drought are not included in this figure.

TYPOLOGIES OF NBS FOR FLOOD AND DROUGHT ADAPTATION

Besides supporting flood and drought hazard reduction, NbS can also reduce exposure and vulnerability to climate change. As described earlier in this chapter, various NbS have the potential to reduce exposure by making room for floodwaters and keeping floods from reaching communities. Other NbS can address various aspects of vulnerability, such as by creating additional income, securing land tenure, improving governance capacity, and securing access to food and water—thereby reducing sensitivity and increasing adaptive capacity.

While NbS can bring many benefits, there are limitations and potential trade-offs. For example, NbS implemented for flood or drought are likely to affect both processes (Ward et al., 2020). Floods and droughts are two extremes of the same hydrological cycle, triggered by overlapping but different factors (**Figure 4**, **Figure 8**), and regulated by NbS through the same hydrologic processes (**Figure 12**, **Figure 13**). Globally, there are increasingly more examples of places experiencing both flood and drought events in which major droughts change rapidly into destructive floods, or vice versa. For example, Krysanova et al. (2008) described increased risks in both flood and drought in seven river basins. Recent events in California (US) (Jarvis, 2023) and Australia (Australian Associated Press, 2023) provide examples of societies facing challenges in coping with the two extremes. Actions taken to decrease risk from one hydrological extreme (e.g., flooding) may unintentionally lead to an increase in risk from another hydrological extreme (e.g., drought), given the shared key hydrologic processes (infiltration, soil moisture, runoff generation, streamflow, etc.). These considerations are not unique to NbS and apply equally to traditional infrastructure and disaster risk reduction measures such as dams, levees, and stormwater control measures. For the design and implementation of NbS, given its nascency, carefully assessing the synergies and trade-offs related to the interactions between floods and droughts, and implementing more holistic risk management approaches using lessons learned from gray infrastructure, is critical.

As described in **Box 2**, extreme events can also compromise the viability and efficacy of NbS. The likelihood of consecutive, compound, and concurrent flood and drought events is increasing with climate change, and these events introduce large uncertainties in the suitability and performance of NbS (Ward et al., 2020). For example, flooding can directly destroy protected habitat, or increase the mortality rate of restored ecosystems due to prolonged inundation. Despite increasing yield during periods of drought, switching to low-water-requirement crops may entail risks of lower yield during above-normal precipitation. Droughts can limit water availability for vegetation regrowth in restored ecosystems and agricultural landscapes, and can also lead to increased fire risks that threaten protection or restoration. In this way, flood and drought can reduce the success of NbS implementation.

LIST OF NBS TYPOLOGIES	
Protection	
1	Targeted Habitat Protection
Management	
2	Agricultural Best Management Practices
3	Ranching Best Management Practices
4	Forestry Best Management Practices
5	Artificial Wetlands
Restoration	
6	Native Revegetation
7	Wetland Restoration
8	Floodplain and River Restoration
9	Riparian Restoration

TABLE 1. List of NbS typologies

While Nature-based Solutions can bring many benefits, there are limitations and potential trade-offs. Carefully assessing these is critical.

Below we summarize the climate risk mitigation potential for common NbS types (**Table 1**). We primarily summarize NbS for three major categories: *protection* of intact landscapes, *management* of working lands, and *restoration* of high value habitats (Cook-Patton et al., 2021). Within these categories, we describe nine key NbS types for flood and drought risk reduction, with each summary describing key attributes of the solution, flood and/or drought risk mitigation potential, potential co-benefits, and the possible synergies and trade-offs of implementing the NbS. As benefits to biodiversity conservation and human well-being are essential to all NbS by definition (**Chapter 1**), the described co-benefits are additional to these core benefits. For more details on each NbS type, including enabling conditions, constraints, risks, and cost estimates, please reference *Factsheets of Nature-based Solutions for Water Security* (Vigerstol, 2022).

Synergies and Trade-offs Key

- ⊕ Postive impact on flood adaptation
- ⊖ Negative impact on flood adaptation
- ⊕ Positive impact on drought adaptation
- ⊖ Negative impact on drought adaptation

1 Targeted Habitat Protection

Description

Protection and avoided conversion of existing and at-risk natural ecosystems such as forests, wetlands, and grasslands. They can be implemented as preventative measures to reduce risk of future adverse environmental impacts that may result from land use and water use changes.

The Iguaçu River in Parana, Brazil. One bank is dominated by agriculture and the other marks the protected forest of Iguaçu National Park. Protecting intact ecosystems like this one is the most effective form of NbS.

Risk Mitigation Potential

Hazard
- Flood: reduces and slows down runoff, reduces and delays peak flows
- Drought: retains infiltration and soil moisture, maintains low flow and groundwater recharge

Exposure
- Flood: reduces the probability of population and assets being present in flood-prone areas

Vulnerability
- Can generate income through diversified livelihood options and increase general adaptive capacity

Co-benefits

- Improved water quality
- Recreation + tourism
- Increased carbon storage

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.

Retained infiltration and soil moisture
- More water captured/delayed upstream results in reduced flood hazard ⊕
- High antedecent soil moisture can increase flood hazard ⊖
- Maintains low flow and enhances groundwater recharge ⊕

PHOTO: © SCOTT WARREN

P36: © NICK HALL

2 Agricultural Best Management Practices

Description

Agricultural practices that work with ecological and hydrological processes to provide multiple benefits beyond yield and income. They include soil management (e.g., reduced tillage, mulching, terracing), crop and vegetation management (e.g., cover crops, buffer strips, intercropping, agroforestry), and runoff management (e.g., ditches, ponds, constructed wetlands).

Risk Mitigation Potential

Hazard →
- Flood: Enhances infiltration, reduces and slows down runoff, stores excess water, stabilizes soil
- Drought: enhances infiltration, increases soil moisture, slows down runoff, reduces evaporation

Exposure →
- Flood: reduces the probability of floodwater reaching human settlements

Vulnerability →
- Ensures food security, stabilizes agricultural production, and generates income for farmers "as soil is higher quality and more productive

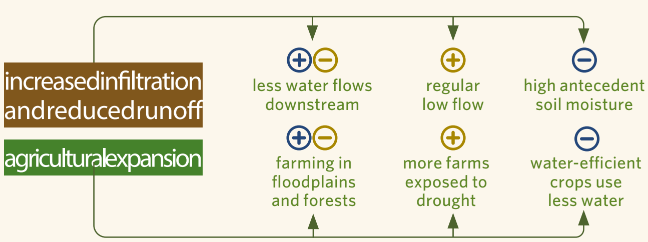
Co-benefits

Improved water quality

Improved air quality

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.



A shade-grown coffee agroforestry system in its fifth year in the Yaque del Norte watershed, Dominican Republic. TNC works with Fondo Agua Yaque del Norte, Plan Sierra and other partners to promote agroforestry in the country.

PHOTO: © SHITENG KANG/TNC

3 Ranching Best Management Practices

Description

Rangeland and grassland management activities that reduce impacts of ranching or grazing. Common practices include grazing management (e.g., rotational grazing, exclosures), silvopasture (e.g., integration of forages, trees, and livestock), and land treatment (e.g., brush management, range seeding, buffer zones).

A young boy on horseback minding his family's herd of goats in the grassland steppe of eastern Mongolia's Tosonhulstai Nature Reserve. In recent decades, the transition to a market economy has led to overgrazing. Communities are working together to reduce grassland degradation through sustainable ranch management.

Risk Mitigation Potential

Hazard →
- Flood: reduces soil compaction, enhances infiltration, stabilizes soil, slows down runoff
- Drought: reduces soil compaction, enhances infiltration, reduces evaporation

Exposure →
- Prevents floodwater from reaching human settlements.

Vulnerability →
- Ensures food security, maintains livestock production, and generates income

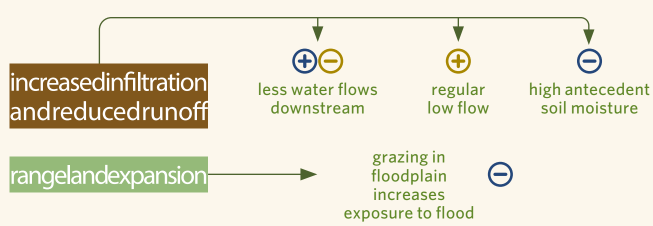
Co-benefits

Improved water quality

Improved carbon storage

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.



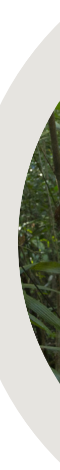


PHOTO: © NICK HALL

4 Forestry Best Management Practices

Description

Forest management to achieve goals related to water quality, water quantity, silviculture, wildlife and biodiversity, aesthetics, and/or recreation. Ensures sustainable forestry that integrates environmental, social, and economic benefits. Can include canopy alterations along with harvesting, planting and thinning trees when appropriate.

Risk Mitigation Potential

Hazard → Drought: increases runoff and streamflow

Exposure → n/a

Vulnerability → Generates income

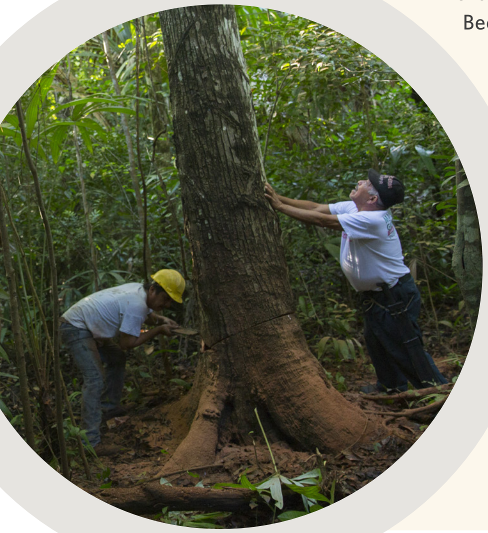
Co-benefits

- Improved air quality
- Recreation + tourism
- Increased carbon storage

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.

increased runoff → high river discharge ⊖



The logging community of Noh Bec, Mexico has adopted reduced-impact logging techniques to selectively harvest specific trees, generating revenue while maintaining a healthy forest. This work is supported by TNC's Mexico REDD+ Program.

PHOTO: © ERICH SCHLEGEL

5 Artificial Wetlands

Description

Constructed areas created with the aim of mimicking hydrological processes of natural wetlands. They usually take the form of shallow depressions created through excavation and function as biological treatment systems. They are often used to mitigate the effects of excess surface runoff and damper extreme flood and drought events by releasing stored water slowly.

Scientists testing the water quality in an artificial wetland in Jarabacoa, Dominican Republic. TNC and Plan Yaque are using this NbS to help filter water runoff and keep waterways clear and clean.

Risk Mitigation Potential

Hazard → Flood: stores excess water, increases infiltration, reduces and slows down runoff
Drought: enhances water storage, increases soil moisture, increases low flow

Exposure → Flood: reduces the probability of floodwater reaching human settlements

Vulnerability → Secures access to water

Co-benefits

- Improved water quality
- Lower water temperature

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.

increasedinfiltration and reduced runoff → ⊕ recharges groundwater; ⊖ high antecedent soil moisture

increasedwaterstorage → ⊕ water captured upstream; ⊕ water source during drought; ⊕ increased evaporative cooling

PHOTO: © TIM CALVER

6 Native Revegetation

Description

Restoration of native habitats in forests, grasslands, and shrublands via active planting, removal of invasive species, or creating suitable enabling environments for passive regeneration.

Risk Mitigation Potential

Hazard → Flood: reduces and slows down runoff, enhances infiltration
Drought: enhances infiltration, slows down runoff, increases soil moisture, reduces evapotranspiration

Exposure → Flood: reduces the probability of floodwater reaching human settlements

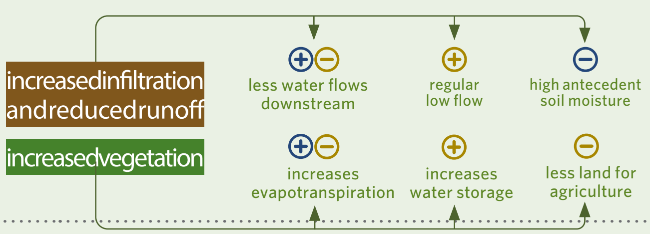
Vulnerability → Reduces insurance costs for flood damage and increases secure access to freshwater

Co-benefits

- Improved water quality
- Increased carbon storage
- Lower water temperature

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.



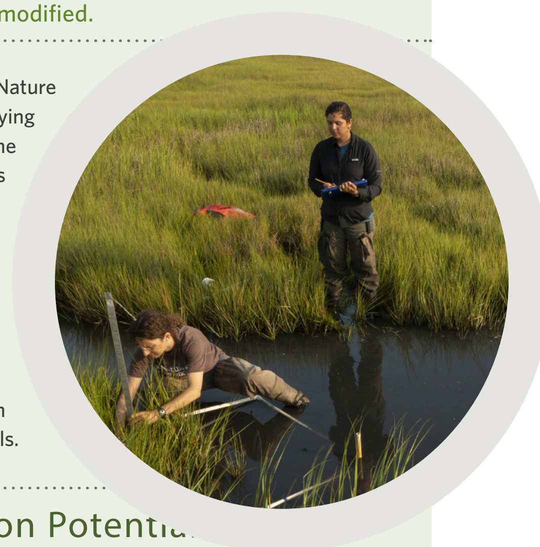
A local tree-planter helps reforest the Mantiqueria Range of Brazil's much-depleted Atlantic Forest. The restoration will contribute to 10 percent of Brazil's national forest restoration commitment under the Paris Agreement, and is part of TNC's Tackle Climate Change Program.

PHOTO: © FELIPE FITTIPALDI

7 Wetland Restoration

Description

Restoring the hydrology, plants, and soils of former or degraded wetlands that have been drained, farmed or otherwise modified.



Contractors for The Nature Conservancy surveying plants and wildlife in the Cape May Wetlands (Oldman Creek) near Avalon, New Jersey. They are studying how the ecosystem is recolonizing low areas of the marsh after dredged sediments were pumped from navigation channels.

Risk Mitigation Potential

Hazard → Flood: stores excess water, increases infiltration, reduces and slows do
Drought: enhances water storage, increases soil moisture, increases low flow, recharges groundwater

Exposure → Flood: reduces the probability of floodwater reaching human settlements

Vulnerability → Generates income, reduces insurance costs for flood damage, and increases secure access to freshwater

Co-benefits

- Increased water quality
- Recreation + tourism
- Increased carbon storage
- Lower water temperature

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.

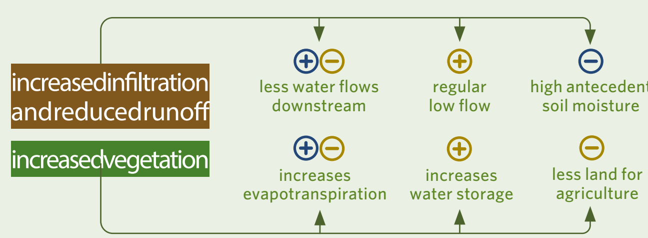


PHOTO: © GEORGE STEINMETZ

8 Floodplain and River Restoration

Description

Restore the floodplain retention capacity and ecosystem functionality by reconnecting the area to the river. This can include modifying the channel, removing legacy sediment, and creating oxbow lakes or ponds.

Risk Mitigation Potential

Hazard → Flood: enhances infiltration, reduces and slows down runoff, reduces and delays peak flow, attenuates floodwater energy, stores excess water
Drought: enhances infiltration, enhances water storage, recharges groundwater

Exposure → Flood: reaching human settlements and/or population and assets being present in flood-prone areas

Vulnerability → Generates income, reduces insurance costs for flood damage, and increases secure access to freshwater

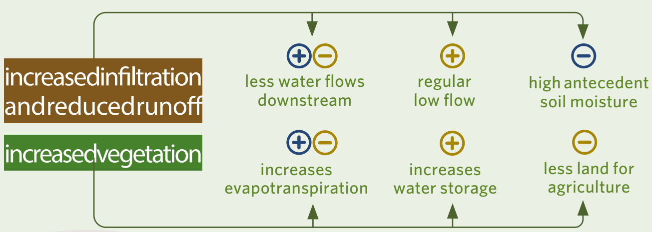
Co-benefits

Increased carbon storage

Lower water temperature

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.



The Nature Conservancy's Emiquon Preserve along the Illinois River. Emiquon is one of the largest floodplain restoration projects in the Midwest. This project allows the river and floodplain to connect again, restoring important habitat and protecting local farms from flooding.

PHOTO: © TODD WINTERS

9 Riparian Restoration

Description

Re-establish riparian functions and related physical, chemical, and biological linkages between terrestrial and aquatic ecosystems. This includes revegetation of the riparian area by planting or decreasing human hydrological disturbance of the area.

The Laguna Grande Restoration Area, located on the Colorado River in Mexico, is the largest and most dense stand of native riparian habitat along the river in Mexico. The Sonoran Institute and Pronatura Noroeste have restored more than 150 acres of native vegetation.

Sonoran Institute 2017

Risk Mitigation Potential

Hazard → Flood: reduces and slows down runoff, reduces and delays peak flow, attenuates flood water energy, stabilizes soil
Drought: slows down runoff to allow more infiltration, reduces evaporation

Exposure → Flood: reduces the probability of floodwater reaching human settlements

Vulnerability → Generates income, reduces insurance costs for flood damage, and increases secure access to freshwater

Co-benefits

Increased carbon storage

Lower water temperature

Synergies and Trade-offs

Each NbS can have a negative or positive effect on the opposite hazard.

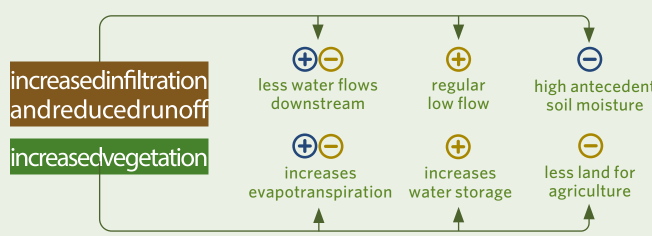


PHOTO: © NICK HALL

04 DEMONSTRATING THE POTENTIAL FOR NBS ADOPTION

In **Chapter 3**, we described how NbS can affect critical processes that drive flood and drought, and how adopting such measures can support adaptation to changes in these hazards. Here, we elaborate on this potential, leveraging different approaches to consider how such conceptual potential might translate into actual implementation potential. We consider this potential from three perspectives: (a) the spatial extent of NbS relative to current and future flood and drought hazard; (b) potential funding opportunities to support broader adoption of NbS for adaptation; and (c) examples of existing projects where NbS have been implemented for flood or drought adaptation.

ALIGNMENT OF POTENTIAL NBS AND CLIMATE HAZARDS

To illustrate the potential relevance of NbS for supporting adaptation to flood and drought hazards, the spatial alignment between potential areas of NbS and areas of climate hazards are assessed. We utilize indicators of three broad NbS typologies as described in **Chapter 3** (protection, management, and restoration) (Cook-Patton et al., 2021). While such global-scale assessments present limited practical value regarding local intervention selection, design, and implementation, this information is presented to elucidate broad patterns of NbS potential relative to flood and drought climate hazards. We explicitly and transparently present largely unmodified indicators of NbS spatial extent, acknowledging that meaningful scenario development and prioritization can only occur with respect to specific contexts and stakeholder interests (Wyborn and Evans, 2021).

For each NbS type, the spatial extent within flood and drought hazard categories have been summarized. Using the same data on current and future flood and drought hazard as presented in **Chapter 2**, we summarize flood and drought hazard by IPCC working group I (WG I) reference region. Current hazard levels are categorized using relative values (percentile ranks). Future hazard change categories are taken directly from IPCC WG I assessments. *High hazard areas* are defined as regions within the highest one-third of current hazard levels (upper tercile), and where future change is indicated as "increasing" or "uncertain."

Figure 14 illustrates the extent of NbS categories (maps) and summarizes the area of each NbS category within areas of high flood or drought hazard (circles). The overall distribution suggests that NbS have broad global relevance for flood and drought adaptation. More than one-third of total NbS extent is observed within areas of high flood or drought hazard—suggesting NbS have strong relevance and high potential for adaptation within these areas. However, this distribution is not uniform, and the relative proportion of NbS differs between areas of high flood and drought hazard. For example, a considerable proportion of low-human-influence areas suitable for protection are located in high latitude boreal zones—areas with generally fewer people and, consequently, less exposure.

We also observe differences in the spatial alignment—and the potential relevance—of NbS categories with respect to areas of high flood or drought hazard. As indicated in the circle plots within **Figure 14**, NbS categories within areas of high flood hazard are broadly proportional to the total NbS area globally, respectively. Opportunities for protection, management, and restoration are abundant within high flood hazard areas, suggesting all three NbS types have potential to support adaptation to flood-related risks. For example, NbS are prominent in areas of increased future flood hazard risk within China, India, Brazil and the US.

GLOBAL NBS OPPORTUNITY FOR FLOOD AND DROUGHT ADAPTATION

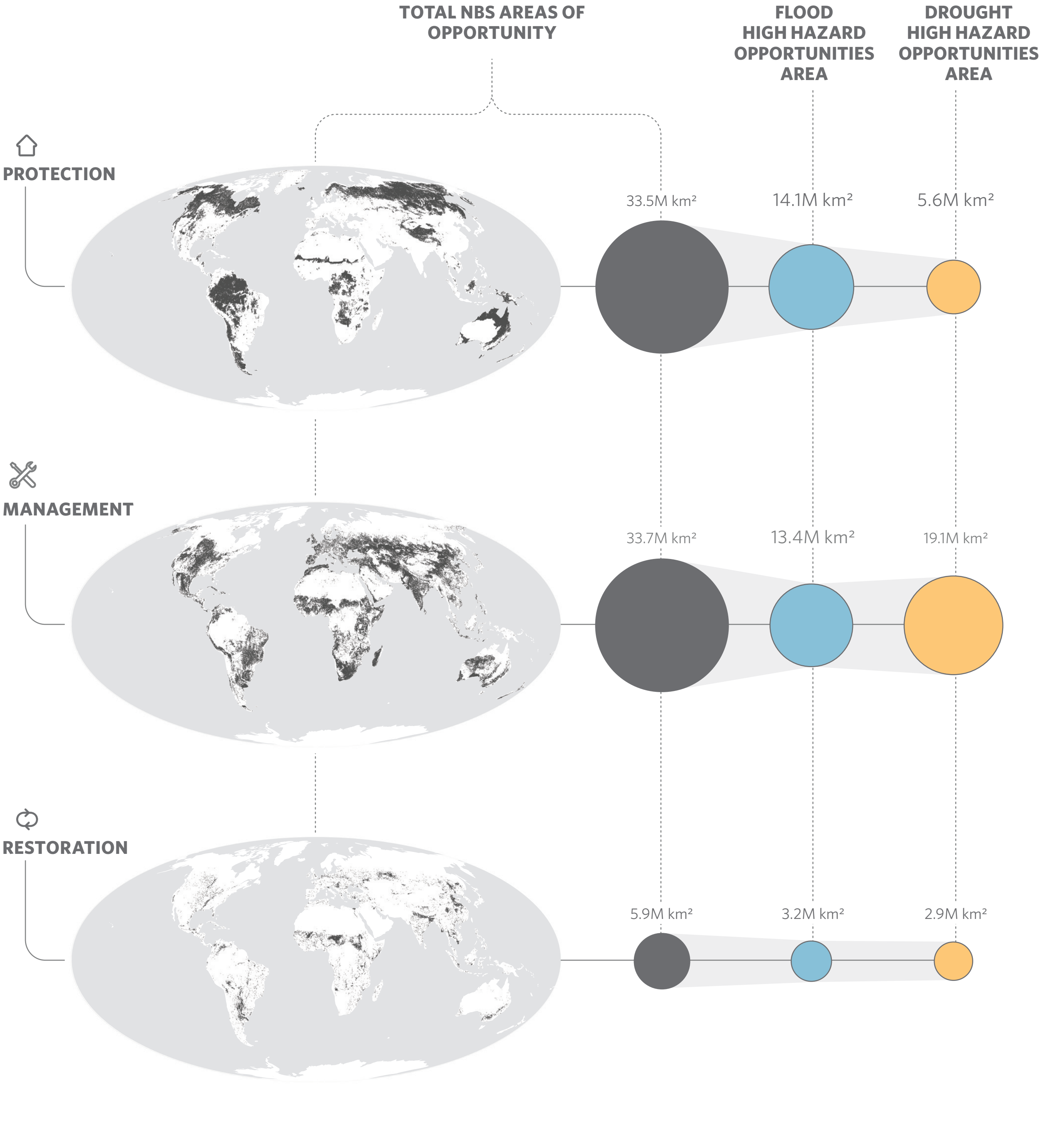


FIGURE 14. Spatial extent of NbS categories (left) and sum of NbS area (right). High hazard areas are identified according to current hazard level (upper tercile) and future hazard change ("increasing" or "uncertain"). See text and Table 1 for information on indicators, data sources and methodology.

In contrast, some NbS types exhibit greater relative potential within areas of high drought hazard. Potentially suitable areas for working landscape management are relatively more abundant within such high drought areas. For example, areas within southern Africa, Europe, Brazil, and the western US exhibit both high NbS potential and high future drought risk. The implications are twofold: crop and pasture lands comprise a large proportion of areas threatened with high drought hazard, so NbS that strengthen management of these areas can support climate adaptation for these landscapes as well as the broader benefits for the river basins that encompass these lands.

While these indicators offer a limited perspective on the practical potential for NbS implementation, they do suggest that NbS have broad global relevance for flood and drought adaptation. Areas of potential NbS implementation exist within much of the world's areas expected to face high flood or drought hazard. This spatial alignment of NbS with areas of high flood and drought hazard implies that NbS should be considered an integral component of adaptation planning.

Indicators, data sources, and methodologies for assessing each of the three NbS categories are described in **Table 2**. To indicate areas for potential habitat *protection*, we utilize data on human landscape influence to identify areas of low influence or modification (Riggio et al., 2020). To indicate areas of potential improved *management* of working landscapes, we utilize data on cropland and pastureland extent (Winkler et al., 2021). To indicate areas for potential habitat *restoration*, we utilize data on floodplain extent in addition to the cropland and pastureland data (Nardi et al., 2019). Floodplain areas have been selected based on data availability and in consideration of the high ecological and ecosystem service value of floodplains relative to other watershed areas (Jakubínský et al., 2021). For all NbS categories, issues of implementation feasibility, such as policy enabling conditions or territorial rights, have not been considered.

NbS category	Indicator
Protection	Riggio et al. (2020) assessed agreement among four global data sources on human influence. Areas of "low influence" are selected with agreement among a majority of these sources, and exclude terrestrial tundra and desert ecoregional biomes (Olson et al., 2001).
Management	Landscape management opportunities are identified using indicators of cropland and pastureland extent using the HILDA+ land cover and land use dataset (Winkler et al., 2021). Floodplain areas as identified by Nardi et al. (2019) are excluded.
Restoration	Landscape restoration opportunities are identified using the same data sources as *management* above. Cropland and pastureland areas within floodplains are identified as potential areas with high restoration value.

TABLE 2. Indicators and data sources for inferred spatial extent of each NbS opportunity.

BOX 5.

NBS AS INTEGRATED INFRASTRUCTURE SOLUTIONS

A robust and cost-effective adaptation or disaster risk reduction plan most often comprises a suite of solutions that address the hazard, exposure and vulnerability of potential disasters, including green and gray infrastructure investments alongside governance and programmatic investments such as early warning systems and disaster assistance programs. In terms of infrastructure investment, there is a spectrum of natural and built infrastructure that ranges from protection of fully intact ecosystems, to hybrid solutions that include natural and built elements, to fully engineered gray infrastructure (Vigerstol, 2022) (**Figure 15**).

SPECTRUM OF GREEN TO GRAY INFRASTRUCTURE SOLUTIONS TO FLOOD AND DROUGHT

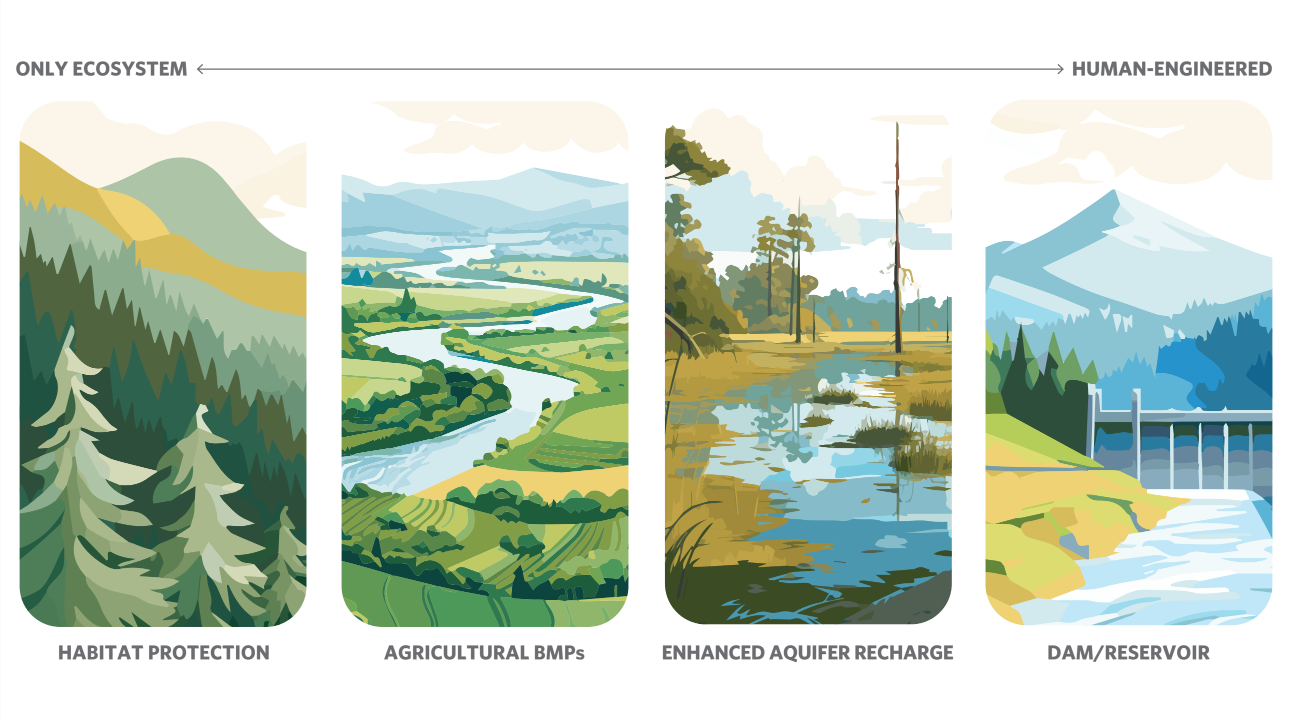


FIGURE 15. Spectrum of green to gray infrastructure solutions to flood and drought.

Beyond defining individual solutions and selecting between interventions, integrated planning requires consideration of how different interventions support each other to deliver more robustly on key objectives. Here are some simplified examples of pairings of interventions to demonstrate how NbS can help support other types of solutions:

- Ecosystem protection or restoration of upland areas can help slow overland flow and timing (and height) of flood peaks. When paired with an early warning system, communities have more time to evacuate, and the likelihood of injury or death is reduced.
- Agricultural BMPs that help maintain soil moisture and maximize yield, combined with crop insurance programs, can help farms survive through extended drought periods.
- Protection or restoration of floodplains combined with levees in areas of high population and infrastructure, such as through a city, can provide space for flood waters to go and reduce the likelihood of overflowing levees and impacting infrastructure and livelihoods.

© CHARLIE OTT

- Ecosystem protection and restoration of forests, wetlands and grasslands, along with practicing agricultural best management practices upstream of a reservoir, can help avoid erosion and filter out sediment that might otherwise reduce the storage capacity and the lifespan of the reservoir.

Despite the huge benefits, there are several barriers to integrated adaptation planning. These include inexperience with planning, design and implementation of NbS by many entities tasked with the delivery of disaster risk management or adaptation planning. Many government and private-sector planning, design, and funding processes are structured in a way that prioritize and incentivize solely gray solutions. There are challenges in the quantification of predicted benefits from NbS, in part due to the lack of cost-benefit cases to draw from and inexperience in many institutions tasked with addressing water security challenges. There are inadequate or inappropriate policies on supporting integration or implementation of NbS to address water security challenges, including flood and drought, and limited standardization due to differences required by application in local contexts. Finally, funding and financing NbS may be difficult due to many of the points mentioned above (Brill et al., 2023; Cassin et al., 2021; UNEP-DHI Partnership, 2014; Vigerstol, 2022).

The good news is that several efforts have been undertaken or are currently underway to address some of these barriers, or to provide knowledge and capacity to others to help overcome these barriers. A few of these include:

- The EU Horizon 2020, which brings together many projects that are focused on addressing barriers to NbS and are managed through Nature-based Solutions Task Forces.
- The U.S. Army Corps of Engineers Engineering with Nature program, which works to better integrate NbS into engineering planning, design and implementation.
- The CEO Water Mandate, which has partnered with The Nature Conservancy, Danone and LimnoTech on an initiative to provide guidance and tools to help practitioners identify and quantify the multiple benefits of NbS for water.
- Oxford's Nature-based Solutions Initiative, which aims to increase understanding of the potential for NbS to address critical global problems and to support the implementation of NbS around the world.
- The Global Green-Gray Community of Practice, led by Conservation International, which aims to scale up green-gray solutions to help address biodiversity loss and climate impacts.
- The World Bank has supported changes to design, procurement and financing to encourage integration of NbS into development projects, alongside partners such as World Resources Institute (WRI). They have also published several guidance documents to help with integrated planning, including one on implementing Nature-Based Flood Protection.

FUNDING POTENTIAL OF NBS FOR ADAPTATION AND OTHER GLOBAL GOALS

The previous section suggests that NbS have the potential to support climate adaptation for flood and drought at globally relevant scales. To realize this potential, funding is needed at commensurate scales to support implementation of nature-based adaptation to the effects of climate change.

Accurately tracking spending on NbS for adaptation is difficult since these activities are frequently not specifically tracked within existing sector and use categories (United Nations Environment Programme et al., 2020). However, data is unambiguous regarding the overall insufficiency of current global adaptation funding levels directed to climate: of the total US$653 billion of climate spending in 2020, it is estimated that just $49–67 billion (7–10%) was spent on adaptation (B. Naran et al., 2022). By comparison, the United Nations Environment Programme (UNEP) estimates that US$160–340 billion is needed annually for adaptation efforts by 2030—suggesting potential expansion of adaptation funding by three to seven times current spending levels (UNEP, 2022c). While these figures derive from different sources, making direct comparison difficult, the primary conclusion is clear: current levels of funding for adaptation are woefully inadequate.

Similar funding shortfalls exist relative to other global goals for which NbS can play a crucial role (**Figure 16**). For example, UNEP estimates that finance flows for NbS must increase to US$484 billion yearly by 2030 in order to meet climate, biodiversity, and land protection goals (United Nations Environment Programme and The Economics of Land Degradation (ELD) Initiative, 2022). Combined with adaptation funding needs, these funding gaps suggest a critical need to identify complementarity and synergies among solutions for these global goals. Given the multitude of co-benefits that can be achieved from a given solution type, NbS are well positioned to address multiple goals concurrently, and should therefore be considered a critical tool for supporting multi-benefit investments. While efficiencies and economies of scale cannot substitute for the provision of adequate global funding for adaptation—including where adaptation needs go beyond nature-based approaches—leveraging the inherent multi-benefit nature of NbS can help extend the value of scarce adaptation funding.

Some evidence indicates that NbS can exhibit cost efficiencies relative to other adaptation approaches. For flood mitigation, one group modeled that the initial cost of implementation and maintenance of NbS to reduce flood risk is lower than the costs for the equivalent gray infrastructure; however, unless the co-benefits were included, the cost of implementation did not outweigh the cost of avoided damages

CHALLENGE OF THE ADAPTATION FUNDING GAP

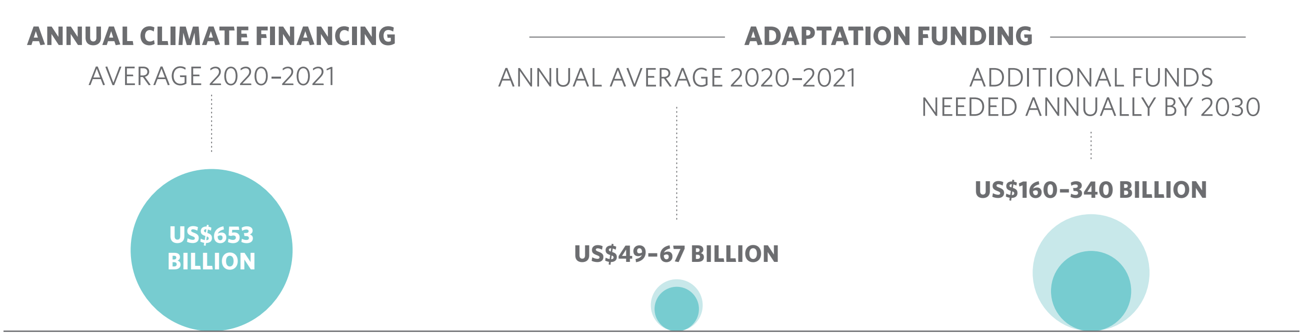


FIGURE 16. While annual funding for climate is substantial (left), funding flows for adaptation (center) are comparatively limited and well below the estimated need for adaptation funding (right).

P51: © IAN SHIVE

NbS can help reduce hazard risk in one-third of places expected to experience increased flood or drought due to climate change.

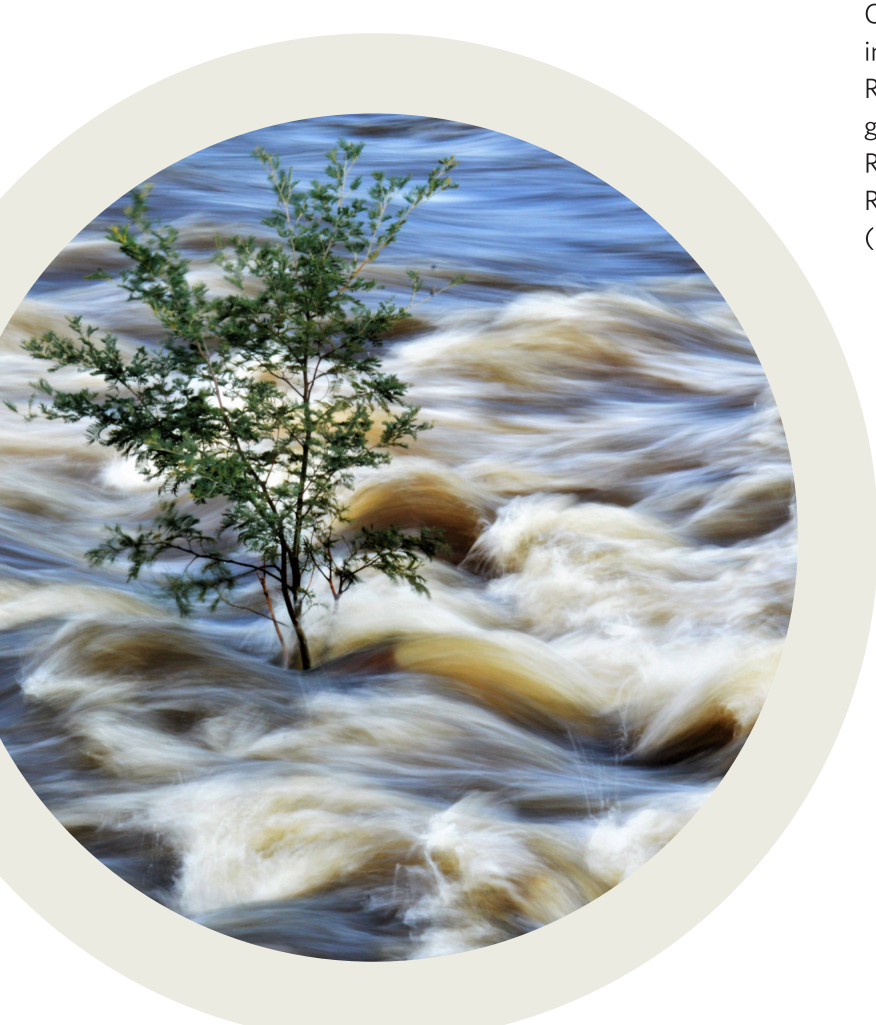
(Le Coent et al., 2021). Another group modeled that NbS to prevent flood damages are cost-effective if a newly planted ecosystem can mature within nine years (Vogelsang et al., 2023). For drought mitigation, return on investment analysis showed that native vegetation restoration through invasive species removal was more cost-effective than other water augmentation solutions, supplying water at one-tenth the unit cost of gray alternatives (Stafford et al., 2019).

EXISTING IMPLEMENTATION OF NBS FOR ADAPTATION

While earlier in this chapter we highlighted the global potential for future action, NbS are already being implemented across the globe to support adaptation to flood and drought. To demonstrate how NbS can be leveraged in practice to support this adaptation, we document eight case studies from a diverse set of projects where NbS are being used to help communities adapt to challenges related to flood and drought (**Figure 17**). Described in detail in **Chapter 6**, these studies showcase a diverse set of climate adaptation responses to increasing threats from flood and drought.

Other groups have also documented cases where NbS are supporting adaptation to water-related hazards, including flood and drought. A growing body of literature and case study compilations are generating evidence to showcase the positive contributions of NbS for flood and drought adaptation. For example, Oxford's Nature-based Solutions Initiative identifies at least 56 cases that target drought and/or freshwater flooding (University of Oxford, 2023). Several other collections exist, including the United Nations Office for Disaster Risk Reduction (UNDRR) NbS for Disaster Risk Reduction guide (United Nations Office for Disaster Risk Reduction, 2021), Global Center on Adaptation's Role of the Natural Environment in Adaptation (Kapos et al., 2019), UNEP's Nature-based Solutions Compendium (UNEP, 2019) and EBA Project Pages (UNEP, 2021), and the Partnership for Environment and Disaster Risk Reduction (PEDRR) web page (Partnership for Environment and Disaster Risk Reduction, 2020).

As awareness of Nature-based Solutions continues to grow (Seddon et al., 2020), these examples can provide templates for scaling NbS to other projects and locations. While collecting and assessing evidence of effectiveness will be a critical priority, the growing proliferation of these projects already demonstrates that implementation is possible and growing rapidly.



LOCATIONS OF NBS ADAPTATION CASE STUDIES

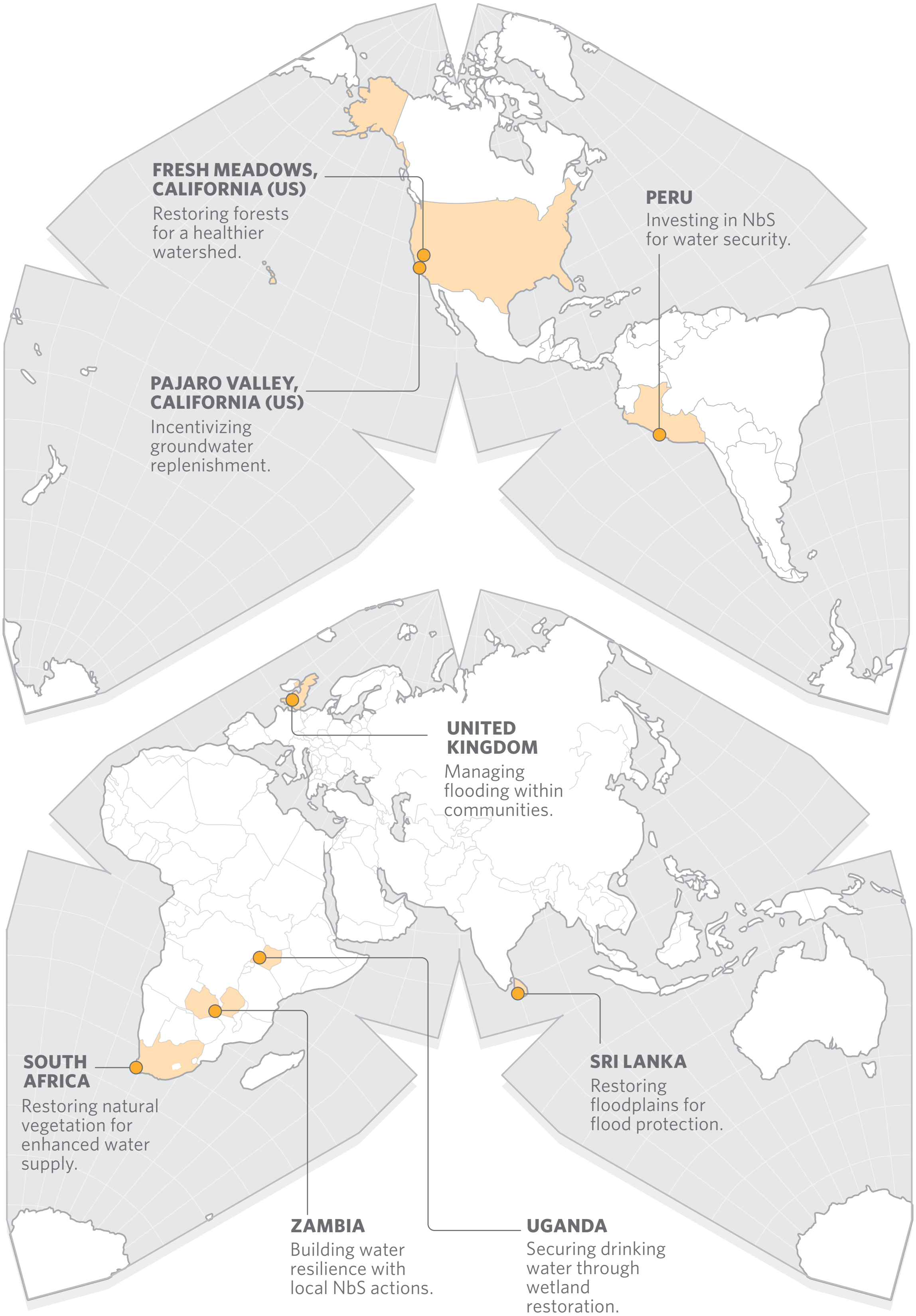


FIGURE 17. Locations of climate adaptation case studies described in Chapter 6.

05

CHARTING THE PATH FORWARD

Floods and droughts bring about some of the most detrimental disasters across the globe, causing loss of lives and enormous suffering, economic losses on the scale of billions of dollars, and forcing the displacement of millions of people each year. With a changing climate, the frequency, intensity and distribution of these hazards will increase for many regions and countries. Nature-based Solutions (NbS), including protection of existing natural ecosystems, improved management of productive areas, and restoration of degraded landscapes, have the potential to mitigate the impacts of flood and drought. In particular, the co-creation of NbS with local communities can help the most vulnerable groups adapt to climate impacts. In addition to providing localized benefits to people and nature, NbS can play a significant role in helping achieve global goals of water and food security, climate change mitigation and biodiversity.

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Globally, a broad portfolio of NbS can be deployed in areas expected to face the greatest increased risks of flood and drought due to climate change. More than one-third of areas with NbS potential—protection, management and restoration—are situated within areas of high future flood or drought hazard. NbS interventions that help lower and mitigate climate impacts are already being implemented in locations across the world, and are exemplified by the specific case studies presented in **Chapter 6** of this report. When NbS and adaptation solutions are co-created with communities and developed using locally relevant scientific and traditional knowledge, these solutions offer a robust toolset for building community and ecosystem resilience that is adaptable and scalable across different contexts. To meet the challenge of climate change and build more resilient watersheds, we need to scale up the adoption of NbS, complementing existing management and infrastructure investments to advance shared objectives between water security and climate adaptation.

KEY CONSIDERATIONS

The success of NbS in helping communities adapt to increasing risk of floods and droughts in a way that reflects the core NbS criteria from the IUCN depends in part on how, and with whom, NbS are selected, designed, implemented and managed, alongside gray infrastructure and other adaptation solutions. Based on the approaches presented in this report, here are some key guidelines:

- The application of any NbS for addressing risks in a specific place is context-dependent. Although lessons can be learned from deployment of the same NbS elsewhere in the world, each application requires an understanding of the current and potential future local hydrologic processes human dimensions, and community needs. This also suggests that NbS design and implementation necessitates input from a diverse set of knowledges (*transdisciplinarity*) to be relevant and appropriate.
- A full cost-benefit assessment should be conducted of NbS potential alongside, and in combination with, other solutions. This assessment should consider the full range of benefits and costs/possible negative impacts, how they might accrue or diminish over time, and who the potential beneficiaries and negatively impacted groups would be.
- As with all adaptation responses, the effective design and implementation of NbS requires considering, understanding and responding to local social context and community needs. Given this, stakeholder engagement from the earliest steps in the planning process is critical (Brill et al., 2022)—ensuring participation is fair and aligned with local community context, and distribution of benefits is carefully considered (**Box 3**).
- Consider trade-offs of proposed NbS—for example, the positive benefits that NbS can provide for flood risk reduction vis-à-vis their negative impact outcomes for water scarcity. Often, NbS that increase biomass will decrease water availability, at least at an annual average level, possibly impacting communities' water security.
- Core to long-term success of NbS are 1) consideration of maintenance and adaptive management (such as continued removal of invasive plant species or making changes in an implementation plan to account for changing socioeconomic or governance factors), and 2) local leadership and capacity. Related to this is awareness of the potential impact of climate change on the effectiveness of NbS, including by reducing the ability of the NbS to deliver benefits over time (Gómez Martín et al., 2021).
- NbS include actions that impact how land is used and managed, and requires agreement and close collaboration with local communities and landowners or managers. For example, the Free, Prior and Informed Consent (FPIC) process, recognized in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), ensures the right of self-determination of Indigenous peoples to give or withhold consent for any action that impacts them or their lands.

CALL TO ACTION

This report offers clarity on how NbS can build watershed and community resilience to floods and droughts. Through exploration of the specific hydrologic mechanisms that NbS can affect, alongside their role in reducing exposure and vulnerability, the report highlights which NbS can be most effective and presents where there is the greatest potential for flood and drought disaster risk reduction along with limitations and trade-offs within the application of NbS. Finally, in the case studies that follow, readers can get a sense of the range of the challenges and opportunities in applying NbS in specific places to build resilience to extended periods of drought and flood events—including the governance, funding and management aspects of NbS integration into adaptation, water security and disaster risk planning.

With the foundation of knowledge offered in this report, readers can more confidently integrate NbS into adaptation and disaster risk planning for flood and drought. However, continued efforts on several fronts are needed to maximize the potential for NbS to help build resilience to the increasing frequency, severity and extent of flood and drought, including:

- **Drastically increasing investment in adaptation globally** as part of the overall climate funding and finance, and ensuring that investments in NbS comprise a significant portion of this investment.
- **Continuing efforts to develop guidance, tools and protocols** that pave the way for integrated adaptation planning (building on those offered by the World Bank, WRI, UNDRR and others).
- **By building from a growing set of examples around the world, enacting national and subnational policies** that include investment in NbS as part of adaptation planning, specifically for flood and drought, including a focus on NbS as part of "building back better" after significant natural disaster events.
- **Investing in the monitoring and evaluation of watersheds where NbS are deployed**, to help support the business case for NbS and promote further understanding about how to best design, implement and manage NbS for flood and drought.
- **Ensuring knowledge and experience in NbS is included in the training** of those who will be tasked with managing our land and water systems, providing water to people, and managing for flood and drought risks, as well as those engaged in agricultural production.

As the world enters the era of climate change with impacts already being felt around the world, including through more intense and frequent natural disasters, we need to find solutions that build resilient, adaptive systems—solutions that address specific hazards as well as communities' exposure and vulnerability to events. At the same time, the world is striving to meet ambitious goals of climate mitigation, biodiversity and socioeconomic development, all of which NbS can help support. Nature, and the myriad services it provides, has been the sustaining force for humans since the beginning. Protecting, restoring and sustainably managing the landscapes and waterways on which we depend will help see us through this challenging time in a way that supports and enhances our built systems and diversity of communities across the globe.

When NbS are co-created with communities, they offer a robust toolset for building community and ecosystem resilience.

06

CASE STUDIES: NBS FOR ADAPTATION TO FLOODS AND DROUGHTS

SUMMARY

Eight case studies were developed, exploring the implementation of Nature-based Solutions (NbS) across a spectrum of ecosystems, climate change conditions, financing mechanisms, benefits, and lessons learned (**Table 3**). While all the case studies showcased a specific NbS response to flooding or drought conditions that have become more intense under shifting climate conditions, there were some common themes that arose across the geographically diverse case studies.

Leadership is key

Leadership comes in different forms and is key to igniting action and sustained engagement in projects. In each of the case studies, there were champions, from local communities committed to implementation to the highest levels of government, weighing in on policy. For example, the California French Meadows project has been a success because of the collective level of commitment and engagement across the spectrum of local and regional partners. In Uganda, leadership among national government officials underscored the importance of wetland protection efforts.

Small and big NbS projects are important

The case studies in this report are evidence that NbS can be effective in both small increments and as large watershed-level actions. In the United Kingdom case study, the community installed multiple—and often redundant—NbS features across the landscape to slow flood waters and bolster waterways, which provided room to learn what actions worked and what actions were not as effective. In this case, many small projects added up to regional results. In South Africa, early planning efforts identified ambitious, though feasible, water savings goals. NbS actions were strategically planned with those goals, aiming for significant and measurable regional results.

Financing is a catalyst

While NbS techniques can be less expensive and more cost-effective than large engineered gray infrastructure solutions, financing is a critical catalyst for putting projects into motion. Peru is investing both capital and political support in large-scale NbS projects to bolster watershed health and increase water security in Lima and surrounding urban areas. Significant investment at the top level of the country has been important in generating support, engagement, and actions at local levels. This scale of financial investment is on the opposite side of the spectrum from Zambia, where the ingenuity and contributions of individual landowners are creating momentum and energy. Whether financing and support is generated nationally or locally, investing those resources in local actions is essential.

REGION	SCALE	HAZARD	FUNDING SOURCE	NBS TECHNIQUES	SUMMARY
AFRICA					
Lower Kafue Sub-Catchment, Zambia	Watershed	Drought	National and International Governments	Agricultural BMP	Integrating green and gray infrastructure to improve watershed health and increase water security for small-scale farmers.
Kamwenge District, Uganda	District	Drought	National Government, Local Watershed Authority	Wetland Restoration	Investing in wetland restoration to increase water and food supply and promote Water, Sanitation, and Hygiene (WASH) practices.
Cape Town, South Africa	District	Drought	Public Agencies, Private Entities, Local Government, NGOs	Native Revegetation	Increasing the groundwater supply by removing alien invasive plants and allowing native plants to re-establish.
ASIA					
Colombo, Sri Lanka	Watershed	Flood	National and International Governments	Targeted Habitat Protection, Wetland Restoration	Restoring and protecting wetlands to improve flood resiliency.
EUROPE					
Stroud Valleys, United Kingdom	Watershed	Flood	Regional Government	Floodplain and River Restoration	Slowing flood flows with natural riparian structures through collaboration with individual landowners.
NORTH AMERICA					
French Meadows, California	Watershed	Flood	Local and Federal Governments, NGOs, Water Utilities, Private Entities	Forestry BMP	Implementing prescibed burns to reduce sediment load during flooding and decrease evapotranspira-tion during drought.
Central Coast, California	District	Drought	State and Federal Grants, Philanthropic Donors	Enhanced Aquifer Recharge	Replenishing groundwater by offering rebates on pumping fees to users if they construct water infiltration sites on their properties.
SOUTH AMERICA					
Peru	National	Drought	Regional Government, Public Ministries, Water Utilities	Wetland Restoration, Ranching BMP	Investing in wetland restoration, peatland restoration, and traditional water management techniques country-wide to maintain flows during the dry season.

TABLE 3. Final summary of case studies.

CALIFORNIA, US
FRENCH MEADOWS AND PAJARO VALLEY

Boats dock in remaining water within Lake Oroville, CA in 2021, California, a land of extremes, faced its driest and hottest summer on record.
© Stuart Palley

INTRODUCTION

The landscape of California shifts from a vast Pacific Ocean coastline, through globally important agricultural regions in the Central and Imperial Valleys, into the high Sierra mountains. With geographic diversity and a globally important economy, California is a case study in both impacts from, and responses to, climate change. And the climate of California is rapidly changing—in addition to an observed upward trend in average annual temperature, the state's already highly varied climate is becoming more unpredictable and punctuated by increasingly frequent extreme weather events.

Two key climate change signals anchoring two sides of a wide weather spectrum are driving impacts to the state: fewer precipitation events on one end, and more intense precipitation events on the other end (Scripps Institution of Oceanography, 2023; McCoy, et al., 2022). California is expected to experience deeper droughts and greater flood event intensity, which pose threats to humans, infrastructure, and economies across the state. In the last five years, drought conditions sparked the biggest fires in California history in the years 2018 and 2020, followed by the record-setting snowfall in the winter of 2022–2023 and heaving flooding across much of the state in spring 2023. The combination of more extreme individual events and a broader spectrum of possible (and plausible) events places California in the center of the climate change stage.

California is the most populous US state and has the largest economy; if California were a country, it would have the fourth- or fifth-largest economy in the world. It is also the biggest agriculture-producing state in the country, and 90% of crops harvested in California are grown on irrigated land (EPA, 2016). Therefore, water-related climate impacts have potential ramifications not only for the health and well-being of California's residents, but also food supply chains and consumers across the US and abroad.

Numerous stakeholders, from government agencies to private donors, recognize the need for action and are implementing a variety of innovative Nature-based Solutions (NbS) focused on climate adaption and resilience across the state, in concert with a variety of other types of adaptation measures. As the impact of climate change manifests in a variety of ways, NbS must respond with approaches and activities tailored to the geography and needs of local communities.

Two projects featuring NbS are presented here, highlighting examples of different efforts to safeguard headwater forests in the Upper American River Watershed and to recover groundwater tables in the Pajaro Valley on the Central Coast of California. These case studies reflect the broad spectrum of climate change impacts in California—from the drying effects of drought and increased fire risks at the top of watersheds to the ways groundwater pumping has made coastal areas more vulnerable to sea level rise and extreme weather events. In these two examples, NbS are helping to not only restore healthy forests and recover groundwater tables, but also create a buffer to absorb rapidly shifting climate conditions.

A crop being watered in the Central Valley, California. © Stuart Palley

FRENCH MEADOWS: RESTORING FORESTS FOR A HEALTHIER WATERSHED

The Upper American River Watershed begins in the mountains near Lake Tahoe (California) and has three forks—the North, Middle and South. The watershed is popular for a variety of recreational activities, particularly whitewater rafting. Like many rivers in the United States, numerous dams have been installed on the American River that produce hydroelectric power and create reservoirs to supply water for downstream municipal, industrial and agricultural use. The watershed also provides critical habitat for endangered and threatened species.

The forests in the French Meadows Restoration Project (FMRP) area are severely degraded (Edelson and Hertslet, 2019). A variety of factors—climate change, selective logging, excessive livestock grazing, and fire exclusion, among others—have altered forest fire regime and resulted in heavy fuel loadings. Historically, fire-adapted species such as pine dominated these forests, but they now contain a disproportionate amount of fir as well as an excessive amount of brush and smaller trees. Exacerbated by increasing temperatures and declining rainfall, the watershed's forests are at risk of atypical catastrophic wildfires, which pose a significant threat to both the natural environment and the human communities that value and benefit from the ecosystem services provided.

In 2014, the King Fire burned more than 97,000 acres in the American River watershed. In addition to severe impacts on forest health and wildlife habitat, increased erosion and runoff as a result of the fire sent more than 300,000 tons of soil downstream,

Smoke rises from a prescribed burn on a hill side in the French Meadows project area. © Jerry Dodrill along with logs, silt and debris, clogging infrastructure and impairing the quality of water used for domestic and hydroelectric purposes. The impacts (and associated costs) of this fire served as one catalyst for implementing the FMRP—the goal of which is to improve forest resiliency in the face of climate change using NbS, thereby both reducing wildfire risk and protecting water supply.

NBS APPROACHES

The main approach for this project is forest ecosystem restoration, which aims to manage a forest to mimic historical (pre-settlement) conditions. In the case of the project area, this involves ecological thinning, biomass removal, prescribed fire, reforestation and aspen/meadow restoration. While the primary goal of the project is to reduce wildfire risk (increasing resiliency), ecosystem restoration will also protect and enhance the social, economic and ecological benefits the forest provides.

In terms of supporting drought resiliency in the face of climate change, the benefits are threefold: 1) reduced risk of high-severity wildfire that leads to loss of headwater forests and negatively impacts water quality downstream; 2) reduced drought-induced mortality of forest vegetation by reducing competition for water; and 3) improving stability of the municipal water system and hydroelectric generation capacity by decreasing the likelihood of high erosion and debris flows impacting the water infrastructure post-fire.

PROJECT OVERVIEW

The French Meadows Restoration Project covers almost 28,000 acres in the Sierra Nevada, 80% of which are national forest lands. From its conception, the project has been a partnership based on a two-part shared interest: 1) minimizing the risk to both humans and the environment of catastrophic wildfire, and 2) finding ways to increase the pace and scale of projects focused on reducing this risk. Project partners include: the US Forest Service; The Nature Conservancy; American River Conservancy; Sierra Nevada Conservancy; Placer County Water Agency; Placer County; and the Sierra Nevada Research Institute at the University of California, Merced. Planning for the project officially began in 2016 with the creation of a steering committee and the signing of a memorandum of understanding (MOU) by the project partners.

Given that most of the project area is federally managed, federal guidelines for implementing a project had to be followed. Spurred by a desire to move the project forward as expeditiously as possible, the project partners secured funding from a variety of sources, including private donors, non-governmental organizations, government agencies (local, state and federal) and the local water utility.

Collaborative management of the project planning process proved to be a successful strategy, taking only 18 months to complete. As a point of comparison, for Forest Service projects of a similar scope and scale, the planning process may take four years or more to complete. From project initiation to approval, planning costs totaled US$1.3 million (or approximately $46/acre).

Project implementation began in 2019, and is estimated to take an additional two to three years for thinning and biomass removal (and 10 years for prescribed burns). Total budget for the forest thinning portion of the project was originally estimated at US$12–14 million. Costs—particularly those related to hauling and transportation—have increased, however, in part due to extensive damage to access roads caused by the Mosquito Fire (2022) and several atmospheric rivers (A. Hertslet, personal communication 2023). Since the 2022 fire season, more than 6,000 acres have been treated.

IMPACTS AND OUTCOMES

In addition to addressing drought-related risks of increased wildfire and impacted water supply, the co-benefits of this project are significant and varied—some are direct benefits of the project itself, while others are avoided impacts. Given the number of benefits provided by the FMRP, they are loosely grouped into three categories: environmental, social and economic.

Environmental: In addition to generally improving forest health (i.e., reduced stand density, greater species and structural diversity) and reducing the risk of catastrophic wildfire, other direct environmental benefits include:

- Increased forest resilience to future wildfire, insects, disease, drought and changing climate conditions;
- Revegetation of impaired areas;
- Improved wildlife habitat (terrestrial, riparian and aquatic); and
- Enhanced watershed function, including slowing runoff and increasing soil moisture.

Social: Key social benefits include protecting and minimizing risk of high-severity wildfire to both a culturally significant landscape for Indigenous communities and popular destination for recreation and the municipal water supply and hydroelectric generation infrastructure.

Economic: Benefits included both direct contributions of the project to the local economy (e.g., job creation) and avoided costs (e.g., firefighting, unclogging and repairing water delivery infrastructure, lost hydroelectric power generation, and post-wildfire restoration costs).

ENABLING FACTORS

Among the most important key enabling factors for the FMRP were shared interests among a diverse group of stakeholders and a willingness to partner to address those interests. Other enabling factors are summarized by category in the table below.

ENABLING FACTORS	
Institutional	US Forest Service leadership support for an innovative and partner-based approach allows the project to utilize staff time, funding and expertise from outside the agency. Inclusion of both public and private lands allows for an "all-lands" approach that focused on landscape-scale restoration and allowed funds to be accessed from sources that prioritized restoration on private lands.
Social	A diverse set of stakeholders established a formalized partnership. Regular meetings of the partnership, along with shared responsibility and costs attuned the focus of the partnership to entities that were committed to project success.
Technical	Expertise in forestry, wildlife, botany, archaeology, fire behavior modeling, fundraising, as well as the National Environmental Policy Act (NEPA) and other laws and policies, was all needed for the project planning process. As both project planning and project implementation is accomplished through shared fundraising and contracting, expertise in fundraising and contract management are the essential areas of expertise. The Sierra Nevada Research Institute (SNRI) is conducting research and monitoring to both better understand and monitor project benefits (both to the forest and water supply). This component was a key factor in fundraising success, and the research/models developed during the project will likely benefit similar projects in the future. On-the-ground work requires expertise in hand and mechanical tree removal, mastication, biomass removal, prescribed burns, road repair, forest and meadow restoration, and transport of lumber. In addition, timber sales and resource specialists provide oversight.
Economic	Funding came from a variety of sources, including government (local, state and federal), water utilities, NGOs and private donors. Viable timber removed as part of project efforts was sold to local mills to help offset project expenses.

LESSONS LEARNED

As summarized in Edelson and Hertslet (2019), while the project is still ongoing, the FMRP already can provide a number of lessons learned that may be valuable for similar efforts in the future.

1. **Collaboration.** The pace and scale of forest restoration projects can be increased through the use of partnerships—particularly ones that include local and diverse stakeholders.

2. **Formalized Partnership.** Signing an MOU, setting regularly scheduled meetings, and requiring partners provide both staff time and funding to the project limited the partnership to entities committed to project success.

3. **Project Development.** The use of contractors and delegation of key tasks across project partners substantially reduced the time required for the planning component of the project. Additional opportunities for making the project planning phase more efficient (and less costly) were also identified. Many of these opportunities are dependent on the willingness of the Forest Service to adopt recommendations (specifically those related to surveys and NEPA compliance). Of more general relevance is the use of fire behavior modeling in the planning process to inform both what type of treatment(s) to use on the landscape and where.

4. **Consultants/Contractors.** Consultants and contractors have benefitted both the planning and implementation phases of the project by providing expertise and helping to accelerate the project timeline. A substantial amount of time is required, however, for contracting and managing consultants, including coordinating different tasks and timelines, ensuring guidelines and requirements are followed, and facilitating communication between consultants and with agencies.

Wildland Firefighters use a drip torch during a prescribed burn within the French Meadows project area. © Jerry Dodrill

5. **Scalability and Replicability.** The partnership "all-land" approach to this project was highly successful and can serve as a model for future forest restoration projects in the Sierra Nevada and elsewhere. For example, the North Yuba Forest Partnership is drawing from the enabling conditions of the French Meadows project to inform their steps in building a 275,000-acre forest restoration project in the Yuba watershed.

Strawberries growing in the region of the ReNeM pilot projects. The area is known for its berry production, but production is 100% reliant on groundwater. © Kiliii Yuyan

PAJARO VALLEY: INCENTIVIZING GROUND-WATER REPLENISHMENT

The Pajaro Valley is located on the Central Coast of California, bridging the southern part of Santa Cruz County and northern portion of Monterey County. Because of its Mediterranean-like climate, it is a highly productive agricultural region known for its fruit and vegetable production—in particular, its berry crops. In addition to agricultural production, the region also has several food processing facilities that support the local economy. While the Pajaro Valley's climate and long growing season are beneficial to agricultural production, precipitation varies seasonally, and access to surface water sources is limited. Groundwater, therefore, accounts for over 90% of current water use.

High demand coupled with limited regulation has resulted in decades-long overexploitation of ground-water resources in the Pajaro Valley. Documentation of groundwater overdraft and seawater intrusion has been recorded since the 1950s. In addition to the overdraft of groundwater resulting from human use patterns, climate change is expected to amplify more erratic precipitation patterns (i.e., higher intensity/shorter duration storms), affecting groundwater recharge potential and accentuating flood risk as well as stoking higher temperatures and greater risk of drought. Proximity to the Pacific Ocean also increases the risk of climate change-related sea-level rise and seawater intrusion. It is also worth noting that the Pajaro Valley's groundwater geology is not connected to those of neighboring areas, making local solutions to groundwater overdraft particularly important.

The Pajaro Valley Water Management Agency (PVWMA) was created by the California Legislature in 1984 to manage groundwater resources. Since then, the PVWMA has implemented a variety of programs and initiatives aimed at reducing groundwater overdraft, some of which employ NbS to improve aquifer recharge. One of these programs is Recharge Net Metering (ReNeM), which provides financial incentives to private landowners (primarily agricultural producers) for recharging groundwater on their own property.

NBS APPROACHES

The intentional recharge of water to aquifers (above what would occur naturally) is called managed aquifer recharge (MAR), which can be an effective approach for improving groundwater levels. Projects focused on MAR can take a variety of forms, like a household replacing a cement driveway with permeable pavement, or coordinated efforts to time reservoir releases to optimize recharge capacity. In the case of the agricultural areas ReNeM is focused on, MAR interventions generally consist of landowners taking small areas out of production, in which they dig retention basins. Water retained in these basins—e.g., following storm events—gradually infiltrates through the soil into the groundwater below.

PROJECT OVERVIEW

In 2016, PVWMA launched Recharge Net Metering (ReNeM)—a five-year pilot groundwater recharge program. The program draws inspiration from the energy sector, where net energy metering credits customers for any excess electricity they generate and export to the grid (e.g., from solar panels). The intent of the ReNeM pilot was twofold: 1) to assess the viability of the ReNeM methods and approach; and 2) to contribute to groundwater recharge in the amount of 1,000 acre-feet per year, or approximately 8% of the then-estimated groundwater overdraft).

The PVWMA charges water users pumping fees for the extraction of groundwater. The ReNeM program essentially works by offering participants rebates on these pumping fees in line with the quantity of groundwater they recharge through MAR. These rebates are intended to financially compensate landowners for the costs of installing and maintaining the MAR sites. As the program is incentive-based and entirely voluntary, its success is heavily dependenton landowners or tenants willing to install infiltration projects on their properties. However, the distributed nature of MAR sites that ReNeM's financial incentive allows for means that many high-quality sites for groundwater recharge from a biophysical perspective (e.g., due to soil characteristics and drainage area) that are privately owned can be brought into the program.

Other project partners include the University of California at Santa Cruz (UCSC) and the Resource Conservation District of Santa Cruz County (RCD), both of which assisted in securing funding for projects and selecting, siting and installing projects that were designed to infiltrate 100AF (acre-feet) or more annually under median precipitation conditions. In addition, they serve a key role as the "third-party certifiers" that coordinate with landowners/tenants, and monitor and validate project performance. The results of this monitoring, which determine the amount of the rebate to be paid to the recharger, are then fed back to the PVWMA.

Most of the funding for the pilot project activities and capital costs currently comes from state and federal grants. The different partners in ReNeM—UCSC, RCD and the PVWMA—each also make significant in-kind contributions to ReNeM: for example, through the involvement of their staff. This is because they see ReNeM as directly contributing to their own organizational objectives.

Although the legal framework for MAR in California is not precisely defined, ReNeM's existing sites—which primarily infiltrate excess stormwater sheet flow runoff—have not been judged to impair or affect water rights. Participants who recharge groundwater as part of ReNeM do not receive any special right to then extract that water (in other words, ReNeM is not the same as groundwater banking). Participation and guidance by members of the University of California at Berkeley have helped clarify the legal standing of ReNeM.

IMPACTS AND OUTCOMES

One project site, Bokariza Ranch, had infiltration benefits of 107 acre-feet (AF), 52 AF and 52 AF for three years of the pilot project (i.e., water years 2018, 2019 and 2020). Based on the formula used, infiltration of 107 AF would have generated a rebate of between US$12,400–$16,500 in 2018.

Improved water quality is a key co-benefit of ReNeM in the Pajaro Valley. Most suitable locations are in an area with elevated concentrations of nitrate, but infiltration of rainwater runoff will help reduce concentration levels over time. UCSC and RCD carry out monitoring of the quality of the water being recharged.

In 2021, the PVWMA Board of Directors voted to formalize and continue the ReNeM program as part of its continued efforts to sustainably manage groundwater resources in the region. At the time of writing, Miller, Fisher, and Kiparsky (2021) also noted that interest by potential project participants exceeded third-party certifiers' capacity to assess site potential. Three active sites are participating in the 2022–2023 water year, and in June 2023, the PVWMA received a US$8.9 million grant from California's Multibenefit Land Repurposing Program. Funds from the grant will be used to cover the costs of development, permitting and design activities for two new ReNeM projects, at least one of which also will be implemented, resulting in infiltration of at least 100 AF per year. The summary of the project released by the program noted how the proposal reflected strong partnerships across varied interest groups (CA MLRP, 2023).

The PVWMA, UCSC and RCD are currently exploring how the ReNeM program might be expanded to, or replicated in, other areas of California experiencing groundwater overdraft. This includes, for example, assessing how to appropriately incentivize landowners in areas where groundwater pumping is paid for differently.

ENABLING FACTORS

External funding for a pilot project was a key enabling factor. Other enabling factors are summarized by category in the table below.

ENABLING FACTORS	
Institutional	PVWMA's financial incentive-based approach allowed them to partner with willing private and public landowners, thereby accessing viable sites that otherwise may not have been available. Third-party certifiers provided capacity to select viable sites, find funding, install the project, and monitor/verify project benefits. They also helped ensure projects met all relevant local, regional, state and national regulations.
Social	Voluntary participation by willing landowners and tenants was necessary for the project to be successful.
Knowledge	Expertise on topography, soil, geology, and groundwater was needed to assess site suitability. Expertise on hydrology was needed to assess annual net infiltration benefits and changes in water quality. Economic expertise was needed to assess costs and benefits and analyze optimal financing incentives for participants.
Technical	Design and construction of the infiltration sites was done by professionals.
Economic	Funding for assessing site suitability, installing sites and conducting research came from a variety of sources. Rebates were provided by PVWMA.
Legal	Guidance from University of California at Berkeley helped clarify the legal basis for ReNeM.

LESSONS LEARNED

The ReNeM project is novel approach to addressing groundwater overdraft for at least two reasons:

1. While common in the energy sector, this may be the first example of rebates on groundwater pumping costs being offered in exchange for installation and maintenance of infiltration sites.
2. Participation of private landowners allows the project to select and install sites in locations that maximize infiltration potential given the hydrologic conditions of the region.

The pilot project's success appears to have relied on outside funding sources (i.e., state and federal agencies, foundations, and universities) that covered most of its costs. This was appropriate at the time, since key partners involved in the project approached it as a pilot research activity. Now that the ReNeM program has been proven to work, future expansions of the ReNeM program, and other programs looking to use a similar approach, should be structured with a view of long-term financial sustainability in mind (for example, through program management costs being covered by key partners or through the rebate mechanism).

Another challenge relates to infiltration performance, which first, is dependent on climatic conditions, and second, as the indicator is "infiltration" as opposed to "recharge," means benefits to the aquifer are uncertain and may not be apparent in the short term.

The potential for scalability in the Pajaro Valley appears to have been demonstrated by the high number of landowners interested in participating in the project. Replicability of the general approach—that is, providing financial incentives for private landowners to participate in a program focused on improving water resources in a given area)—appears entirely plausible. Providing rebates on groundwater pumping fees, however, can only be an incentive to participate if such fees are charged in the first place. For that reason, application of the methods in other geographies would likely require a different financial structure than that used in the Pajaro Valley.

A recharge basin in the Pajaro Valley. © Andy Fisher

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PERU

INVESTING IN NBS FOR WATER SECURITY

Example of the landscape where Infraestructura Natural has been working. © AldoCardenas

INTRODUCTION

Peru is a global leader in scaling up public and private investments in Nature-based Solutions (NbS). In 2010, investments in natural infrastructure for water security totaled less than US$1 million; by 2020, investments grew to almost US$10 million annually. This rapid growth of interest in and commitments for NbS draws from the deep ancestral knowledge and historic practices of the region and responds to the rapidly escalating climate risks that the country faces. Peru's topography varies from arid coastlines, to high Andean peaks, to the Amazon rainforest. Climate change impacts are rapidly and significantly affecting these ecosystems and catalyzing multiple crises. Rising temperatures and extreme weather events, coupled with human-caused deforestation and soil erosion, are triggering an accelerated melting of Peru's glaciers and loss of functioning watersheds. Between 2016 and 2017, the country experienced numerous states of emergency, with droughts and forest fires in Northern Peru followed by floods and landslides along the Pacific coast. These natural disasters caused over US$3 billion in damages (Benites Elorreaga and Gammie, 2021).

As one of the largest coastal desert cities in the world, Peru's capital city, Lima, is among the most water-stressed cities on the planet. The city receives very little annual rainfall and relies on runoff from the Andes for year-round water supplies. During the rainy season, from January to April, there is abundant runoff that fills reservoirs and rivers. Conditions shift in in the dry season, from May to December, when there is little to no rain. During this time reservoir levels drop, and the city must adjust to a water supply deficit.

Engineered gray infrastructure projects have historically been favored to expand water storage and bridge the gap in water supplies in Lima, as well as in other communities and regions around the country. However, policymakers and water managers across the Peru are increasingly turning to both age-old techniques and natural infrastructure to bolster water security. In addition to buffering the effects of climate variability, droughts, and floods, natural infrastructure also complements and improves the effectiveness of gray infrastructure by reducing sedimentation, slowing runoff, and increasing infiltration to mitigate water quality deterioration. Ancestral techniques from pre-Incan and Incan times have assisted community water supplies and agricultural production and have great potential in modern times as well.

Investments in the maintenance and restoration of forests, grasslands, wetlands, and *amunas* (ancient canals that bolster aquifer recharge) are rapidly growing. While most financing prior to 2020 was provided by regional governments and public ministries, water utilities have started to invest in and develop NbS projects to provide greater water security to their customers and communities.

NBS APPROACHES

Across the country, Peru is investing in ancient knowledge and practices to protect high-altitude watersheds, improve hydrologic flows and infiltration, and help adapt to the deepening severity of climate-change-driven droughts and floods (Gies, 2021). These ancient techniques were reliably used as a landscape and agricultural irrigation strategy to slow the movement of water within the soil and allow for the water to resurface downslope after a period of several weeks to several months. Forests, grasslands, and wetlands can effectively slow the flow of water across the landscape and act as sponges, absorbing water during precipitation events and slowly releasing the water throughout the year. In addition to the significant hydrological benefits, these types of Nature-based Solutions can lead to additional social, cultural, and environmental benefits through community engagement and by building landscape systems that can filter contaminants, stabilize soils, and provide habitats for animal and plant diversity.

As Peru deepens investments in NbS as a complement to, or improvement upon, gray infrastructure, the following definitions are useful (as derived directly from Gammie and Bievre, 2015).

- **Gray infrastructure.** Conventional, built infrastructure (e.g., wastewater treatment plants, large projects to divert water from other water-sheds, industrial pollution control technologies, and water conduction pipelines).

- **Natural infrastructure.** Watershed ecosystems—like forests, wetlands, and grasslands—that provide a variety of ecosystem services, or benefits, for water resource management as well as habitat provision, carbon sequestration, pollination services, etc.
- **Green interventions.** A wide range of actions that protect, restore, or enhance watershed ecosystems and/or sustainable land use in a watershed—for example, actions that reduce threats to natural forests, restore wetlands, improve filtration capacity of rangelands, keep cattle away from surface waters, or reduce nutrient runoff of agricultural land.

PROJECT

This case study highlights The Natural Infrastructure for Water Security (NIWS) project, which was made possible by the implementing consortium of organizations, which includes Forest Trends, Consortium for the Sustainable Development of the Andean Ecoregion (CONDESAN), Peruvian Society for Environmental Law (SPDA), EcoDecision, and Imperial College London, with funding from USAID and Canada. The goal of the NIWS project is to:

> **...scale the conservation, restoration and sustainable use of ecosystems and ancestral technologies, in order to reduce water risks, such as droughts, floods and water pollution in Peru. To achieve this objective, NIWS works to improve the enabling conditions for scaling natural water infrastructure approaches, improve the information generated and used for decisions on natural water infrastructure, and develop, secure financing, and facilitate implementation of natural infrastructure projects. Throughout these components, NIWS works to reduce inequalities in water resource management and natural infrastructure solutions** (Elorreaga and Gammie, 2021).

There are five overarching categories of interventions within this project, as described below.

1. **Water sowing and harvesting.** There are a variety of important interventions designed to slow and capture water. Some of these interventions include qochas (permeable micro-reservoirs), infiltration trenches, and terracing. One particularly effective technique focuses on *Amunas*—a Quechua word meaning "to retain"—which are ancient diversion channels that were historically built to convey wet-season flows to infiltration ditches that were constructed laterally across mountainsides. Infiltrated water would re-emerge in small, constructed micro-pools or in natural springs downslope over several weeks or months, and could be used to irrigate agricultural fields. Over the centuries, channels have eroded, and portions are no longer impervious. Restoration of the *amunas* requires re-grouting to convey all the water to the infiltration ditches, to contribute to shallow groundwater tables and baseflow. Today, *amuna*s restoration is focused in river basins that supply water to Lima in an effort to bridge water supply gaps during the dry season (Gies, 2021).
2. **Natural grassland restoration.** *Puna* and *paramo* grassland ecosystems thrive on carbon-rich soils in the high Andes above Lima and in the northern regions of Peru. Many of the grasslands have been degraded from grazing and the increasing impacts of climate change. Removing animals from designated zones, as well as implementing rotational grazing, allows these ecosystems to recover. Then, compacted soils can decompress as soil composition and infiltration capacities improve. With careful and attentive restoration, healthy grasslands help regulate hydrological processes, reduce sediments in the water supply, augment baseflows, and improve water quality—all of which benefits Lima's water supplies.
3. **Hydrological restoration of drained wetlands.** Animal grazing in the uplands was often enabled by altering the landscape to dig surface trenches and drain wetlands. These changes allowed animal to access more land for grazing. Over time, these trenches drained more than wetlands, drawing down localized groundwater tables and

reducing base flows. To restore these hydrological functions, trenches need to be filled in and closed so that wetlands can begin to replenish and recover their full storage capacity and contribute to groundwater baseflows.

4. **Peatland recovery.** Rare, high-altitude tropical peatlands, called *bofedales*, or cushion bogs, are unique to the Andes and are well adapted to tropical mountain conditions of "summer every day and winter every night." They thrive in intense sun, stiff winds, short growing seasons, and seasonal snows (Gies, 2021). Peatlands, including *bofedales*, have a higher percentage of organic matter than other soils, making them unusually good at holding water. In the steep landscape of the Andes, *bofedales* slow water runoff, preventing floods and landslides. As the glaciers that once stored water melt, *bofedales* play an even more important role in holding water for supply in the dry season. They are also biodiversity hotspots, providing food and shelter for birds and mammals, including deer, pumas, Andean foxes, and pampas cats—along with vicuña and guanaco: wild ancestors of domesticated alpacas and llamas.

5. **Forest restoration.** Recognizing a link between conversion of montane rainforests into farmland and a corresponding decline in water quality, reliability, and availability, NbS interventions have focused on restoring the extent and health of upland forests. An initial pilot project pairing forest protection and restoration efforts with a successful financing effort grew from the Andean Amazon town of Moyobamba in northern Peru. Residents agreed to allocate one Peruvian Sol (US$0.33) per household per month into a fund overseen by a local management committee, which was then invested in conservation easements on forest lands and upstream watershed and forest restoration projects. Over time, these funds and investment actions have improved the quality and reliability of Moyobamba's water supply and seeded local economic enterprises such as beekeeping that establish anchors for future sustainable livelihood initiatives. Lessons from this initial pilot project have been applied throughout the country to underscore the importance of montane rainforests to water supplies and the capacity to develop financing techniques that draw on local engagement and scale up investments.

The Mecanismos de Retribución por Servicios Ecosistémicos (Mechanisms of Reward for Ecosystem Services), or MRSE, are directed towards NbS that protect grasslands, shift grazing practices, repair ancient water management systems, and augment groundwater storage and baseflow runoff. While a decade ago it was nearly unheard of to invest public funds in NbS, today in Peru it is required. Over the past several years, Peru has distinguished itself as a leader in NbS investments by passing a series of national laws requiring water utilities to invest a percentage of their customers' bills in "natural infrastructure" (Gies, 2021). As a result, regions on the western slopes of the Andes and coastlines are significantly investing in NbS, and the portfolio of investment funds has grown exponentially over the past several years (Gammie, Benites Elorreaga, and Momiy Hada, 2021).

IMPACTS AND OUTCOMES

Over the last decade, Peru has garnered international attention for leading a paradigm shift in incorporating natural infrastructure as a central solution to water risks. "Natural infrastructure" was recognized in the legal framework that governs Peruvian public investments, and the drinking water sector made significant policy and financial commitments to contribute to natural infrastructure conservation, complementing conventional funding sources for environmental conservation. From 2014 to 2019, more than US$30 million of drinking water tariffs collected by water utilities were committed to innovative financing mechanisms for restoring and conserving ecosystem services (Gammie, Benites Elorreaga, and Momiy Hada, 2021). In 2017, US$2.1 million was executed in investments in natural infrastructure for water security.

With the success of financing, there have been important lessons learned in project development and implementation (Benites Elorreaga and Gammie, 2021).

1. **NbS project execution.** There has been a gap between allocated and executed funds that is due in part to bottlenecks in the public investment process, which delays and encumbers the development and evaluation of projects. Nonetheless, NIWS has assesed a project portfolio of over 50 projects that meet the demand for Nature-based Solutions and natural water infrastructure in Peru, principally through improving water regulation and erosion control (Gammie, Benites Elorreaga, and Momiy Hada, 2021).

2. **Estimating benefits.** Despite having specified hydrological objectives, the projects analyzed lack a consistent approach to describe, quantify, and monitor their impact (i.e., hydrological benefits generated). This is in part because estimating hydrological benefits is more difficult to do for green interventions in the region than for conventional gray infrastructure. Addressing this challenge will require investments in hydrological monitoring networks that prioritize data collection and synthesis on hydrological processes in complex mountain catchments, document variations across regions, and fill data gaps (Gammie, Benites Elorreaga, and Momiy Hada, 2021).

3. **Individualized approach.** An approach to project development and implementation that recognizes the different needs, knowledge, and roles between men and women is essential for the efficacy and sustainability of financing. It can be important, for example, to draw on the experience, knowledge and wisdom of women in developing and implementing natural infrastructure investments.

ENABLING FACTORS

A variety of enabling factors were critical to the development, implementation, and overall performance of this project, which are summarized by category in the table below.

ENABLING FACTORS	
Institutional	National water policies requiring investments in NbS. Expanded support from government officials to water utilities and water managers.
Social	Participation of community members open to share their experiences and wisdom, grounded on their ancestral knowledge and practices. Local communities willing to engage and lead restoration efforts. A shared understanding of the significance of NbS in enhancing both environmental and socioeconomic well-being..
Technical	Commitment of national institutions like the water utility regulator SUNASS, as well as regional and local institutions and water utilities, including SEDAPAL (Lima's municipal water and sewer service), to drive forward the overall system of investments in natural infrastructure. Interest of local communities, small-scale farmers and ranchers in participating in technical trainings. Willingness to shift grazing and livestock management practices. Available portfolios important habitats and biodiversity hotspots to protect, restore, and manage.
Economic	National policies to scale up investments from multiple sectors within Peru and internationally.

Bofedales, or cushion bogs, include low-growing, spongey plants that absorb water and regulate downstream flow during the dry season. © Erica Gies

LESSONS LEARNED

This case study provides several lessons that may be valuable for similar efforts in the future.

1. **Scalability.** Peru provides a compelling and effective example of scaling up financial investments in NbS in response to multiple drivers. First, climate change risks are real and accelerating across the country, requiring immediate and visionary action. The capital city of Lima is considered among the most water-scarce cities in the world and is particularly vulnerable during the six-month dry season. Since the bulk of the city's freshwater supplies derive from Andean runoff, it has become increasingly important to invest in the natural processes that safeguard that runoff. While human and climate change impacts may outpace restoration of natural wetlands, peatlands, and grasslands, overall landscape improvements are complementary companions to gray infrastructure in the near term, and may prove more effective, durable, and resilient in the long term.
2. **Financing.** Peru has seen remarkable growth in financing for natural infrastructure since the mid-2010s. While this success is notable and commendable, the number of implementable projects has not fully utilized available funding. This is in due in part to the process of developing the projects themselves, which involves engaging key stakeholders, crafting project strategies and management structures, and the timeline for implementation. This imbalance also arose from a swift and steep growth in financing relative to a longer timeline required to develop effective and community-supported projects. Additionally, gray infrastructure has historically been the primary solution set for water supply problems, so developing new project management cycles, implementation protocols, and effectiveness monitoring frameworks takes time.
3. **Ancient Cultural Wisdom.** Finally, Peru has a rich cultural history based in creative, extensive, and effective water management systems. From pre-Incan times to Incan architecture and agriculture, the Andes are steeped in cultural traditions and functioning infrastructure that can be revitalized and used today to increase water security.

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UNITED KINGDOM

MANAGING FLOODING WITH COMMUNITIES

The landscape near the Stroud Project area. © PJ Photography

INTRODUCTION

Extensive flooding inundated the Stroud Valleys in 2007, causing widespread damage in communities and across the landscape. Today, climate change is sparking more extreme and unpredictable weather patterns, including more intense precipitation events that eclipse the area's historic built environment's ability to absorb such storms. This trend is expected to continue—and as evidence, some portion of the region has experienced flood conditions every year since 2007 (Stroud District Council, 2023). Several tributaries in the catchment have been characterized as "rapid response catchments," which means that the valleys within the catchment are at increased risk of flash flooding. In response to the overall flood risk, community flood action groups were formed across Stroud Valleys to campaign for better protection for residents and properties.

Stroud Valleys is distinguished by the heritage and aesthetic value of the region, which would be marred by hard-engineered solutions to flooding. In 2012, the UK's Environment Agency commissioned an inquiry and report into the feasibility and potential benefits of implementing Nature-based Solutions, referred to as Natural Flood Management (NFM, or Rural Sustainable Drainage), through the catchment and along the tributaries. The findings of the study showed that the area would be well suited to these techniques, which include working in partnership with community members and landowners to shift management practices in riparian woodlands and on agricultural lands to reduce runoff, slow flows, and reduce downstream flood risks.

NBS APPROACHES

Natural Flood Management (NFM) generally involves storing or slowing of floodwater using techniques that work with natural processes, features and characteristics of the landscape (i.e., the source and pathways of the flood waters). A wide spectrum of techniques exist to accomplish NFM from on-farm use of cover crops or hedgerows to full-scale watershed restoration (The Flood Hub, 2018). NFM can be particularly useful in combination with other hard infrastructure solutions, and can also contribute to improved habitat and increased biodiversity, among other environmental benefits. (SEPA, n.d.; The Flood Hub, 2018). It is also sometimes the only practical and affordable strategy available to many communities.

River restoration, which is the focus of this case study, often involves restoring or returning a river to a more natural state. Additional details of the specific NFM techniques used are provided in the next section.

PROJECT

The Stroud Valleys Natural Flood Management project is a novel effort to reduce flood risk, improve water quality, and recover natural ecological conditions throughout the catchment of the River Frome, in the United Kingdom. The project began in 2014 with a vision:

> **To create a river catchment where water management is fully integrated into land management practices. Where public bodies, private companies and local communities work together to manage water within the landscape, creating valuable habitat for wildlife and people, and limiting flood risk downstream.**

This vision arose from the findings of a 2012 Environment Agency report looking into the feasibility and potential benefits of implementing Natural Flood Management actions through the Frome catchment. The Severn and Wye Regional Flood and Coastal Committee (RFCC) provided funding for a project officer to lead and support project efforts. A partnership between Gloucestershire County Council, The Environment Agency, the RFCC, and Stroud District Council was formalized to implement projects and employ the project officer.

To achieve this vision, landowners, community flood groups, and partner organizations are working together to implement a holistic and comprehensive catchment approach to moderating flood flows and restoring natural patterns of drainage. Collectively, this diverse collective of partners is implementing a wide range of activities across the headwaters and watershed to cumulatively reduce flood risk over time.

NFM techniques have been implemented throughout the catchment with a goal of reducing downstream flood peaks (also characterized as the maximum water height of a flood) and delaying the arrival of the flood peak downstream. These techniques are used to "Slow the Flow" by restricting the progress and speed of water flows across the land and in stream channels. This is achieved using a variety of mechanisms that are implemented singularly or in concert with one another:

1. **Attenuation.** Maintaining the capacity and use of ponds, streams, floodplains, and soils to retain water flows.
2. **Soil infiltration.** Enabling water to slowly seep into the soil and as a result reduce surface runoff. Healthy soil facilitates infiltration and increases the amount of time before saturation is reached.
3. **Large woody debris.** Installing downed trees and large woody structures in channels and gulleys, along with floodplain and riverside vegetation, increases resistance and decreases the speed of water as it flows across the land. In addition, woody debris works to change the physical shape of waterways by pushing flows out of the channels and onto the bank. Different sized logs, branches, and twigs capture silt and sediment and build up soil layers, creating more space for water in a channel. Woody debris also creates pools and riffles, providing habitat refuges for fish, insects, birds, and other wildlife. Overall, placing many debris dams within a defined stretch of stream is more effective than single larger structures.

IMPACTS AND OUTCOMES

Over nearly a decade of collaborative partnerships, Stroud Valleys Natural Flood Management project has reached a number of key achievements.

- Over 900 interventions have been installed throughout the wide Stroud River Frome Catchment.
- Approximately 25% of the entire catchment now drains through NFM features.
- Estimates based on previous large rainfall events suggest that there has been a one-meter reduction in peak river levels on Slad Brook, one of the rapid response streams in the catchment.
- Over 1,000 people from local and national groups have engaged in education around NFM actions.
- Roughly 50 local land managers and contractors have collaborated to implement NFM actions.

In addition, a monitoring network for NFM has been established in Stroud Valleys. Methodologies and survey techniques are being developed in partnership with a range of organizations, including the University of Gloucestershire, the Wildfowl and Wetlands Trust, Gloucestershire Wildlife Trust, and the Environment Agency. Efforts are focused on gathering baseline data to determine how large woody debris structures perform in rain events and how the structures evolve over time. Changes to river habitats and biodiversity are also of interest. Comparison of flows under specific rainfall events offers insights into how effective interventions are in slowing flows and attenuating flood peaks.

ENABLING FACTORS

A variety of enabling factors were critical to the development, implementation and overall success of this project, which are summarized by category in the table on the following page.

ENABLING FACTORS	
Institutional	Multiple local agencies and councils convened a formal partnership to fund and support project implementation. Funded a full-time project officer to invest time and energy in developing community relationships and projects.
Social	Supported through engagement with and participation from a diverse set of stakeholders, including community groups, farmers, local governance, and funders.
Technical	Allowed for experimentation and learning through doing (i.e., a variety of techniques were tried). Developed monitoring protocols that compared similar flood events before and after interventions to learn what works. Redundancy and simplicity were prioritized in project design.
Economic	A project officer dedicated to project implementation has been funded and employed through a partnership of government agencies and councils. The project officer has led implementation efforts and works in close collaboration with community members. Funding investments supported a long view of success and were designed to support small efforts over a long period of time.

LESSONS LEARNED

Strouds Valleys provides several key insights from a concerted community engagement effort to learn how to implement Nature-based Solutions to increase response and resilience to floods that are likely to increase as a result of climate change dynamics. Some important lessons learned include:

1. **Invest time before money.** It takes a significant investment of time to discuss changes to a community member's land, even if the cost of the changes is relatively modest. For example, discussions with a farmer may extend over a year and culminate in a US$2,000 action. Investments in people, skills, and communication can be more important than when investing in large capital efforts. However, this strategy means investors need to be willing to commit to smaller amounts of funding over longer periods of time.

2. **Small actions add up.** Many small interventions lead to larger cumulative changes. Over 50 landowners have participated in projects, and each farmer has different needs, objectives, contributions, and interests. Taking the time to learn what each farmer can contribute is key to fostering engagement and investing in a diversity of approaches and actions.

3. **Redundancy is critical.** Mimic nature's design for repetition and redundancy so that interventions can change, decay, or be absorbed back into the land. The importance is in taking action, even if projects are suboptimal. Eventually, many actions add up to overall changes and improvements.

4. **Respect participants.** Always offer landowners and farmers the first right of refusal and the ability to have an active role in the design and implementation of their actions. This fosters a higher level of ownership and responsibility in the overarching vision.

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UGANDA
SECURING DRINKING WATER THROUGH WETLAND RESTORATION

Landscape around Kemwenge District. © Water for People

INTRODUCTION

Wetlands provide an abundance of resources and services to communities in Uganda and are critical to healthy watersheds. However, wetlands are under threat from the compounding impacts of human activities and climate change. While Uganda has a mostly tropical climate characterized by historically stable rainfall patterns, that is changing. More recently, both the rainy and dry seasons have become more intense, with more precipitation falling and intensifying runoff conditions during wet periods, and harsher and longer droughts occurring during dry seasons. Both swings impact the stability and function of wetlands.

Covering roughly 11% of the country's land area, wetlands provide materials for construction, habitats for fishing, and a source of water for domestic needs. Wetlands are also a physical indication of the presence and movement of groundwater. Depending on the topography and location of wetlands, they can either provide space for surface flows to recharge aquifers and or serve as a place to convey groundwater from beneath the land into streams and marshes. In a tangible and physical sense, wetlands represent a place of connection for ground and surface water, among aquatic and terrestrial habitats, and between the natural environment and human livelihoods. Particularly at this time of shifting climates and water availability in arid and semi-arid environments, the role of wetlands as a source of freshwater is essential.

In 1995, Uganda became the second country in the world, after Canada, to pass a wetlands policy. The National Policy for the Conservation and Management of Wetlands revolves around four principles: sustainability, improving wetlands productivity, diversity, and good governance (Government of Uganda, 2016). Despite the importance of wetlands and the creation of a national policy, degradation of wetlands as a result of population growth and economic development has continued. Activities such as agriculture, animal rearing, sand mining, brickmaking, and commercial planting of high-water-use trees have diminished the quality and quantity of water for local communities. From 1994 to 2008, estimates suggest that wetland areas declined by 30% across the four primary basins within Uganda, including Lake Victoria, Lake Kyoga, Lake Albert, and the Upper Nile (Government of Uganda, 2016).

NBS APPROACHES

Wetlands play an outsized role in sustaining and nourishing a range of functions and services to the health of the land and human communities. Ecologically, wetlands moderate runoff, regulate shallow groundwater tables, filter drinking water supplies, and nourish biodiverse plant and animal populations. From a socioeconomic perspective, wetlands sustain fisheries, medicinal and food plants, materials for construction as a livelihood source, and freshwater sources for communities across the country.

Given both the abundance and critical importance of wetlands to landscape functions, clean drinking water, and food sources, wetland restoration and protection is an essential component of the health and livelihoods of local communities within Uganda. Restoration actions include three sequential and integrated actions: 1) delineating wetland boundaries, 2) removing deleterious impacts such as high-water-use trees, and 3) improving upstream land use practices and hydrologic functions.

PROJECT

For the past decade, Water For People has worked with communities in Kamwenge District of the Lake Albert Water Management Zone to improve Water, Sanitation, and Hygiene (WASH) outcomes. Their work has focused on collaborating with local governments and communities across district and catchment levels to advance stakeholder processes and assess, plan, and implement measures to restore wetlands as an avenue for protecting communities' drinking and domestic water supplies.

Within the country of Uganda, water resources management zones are defined according to hydrological flows, while local district and subcounty governments are politically delineated. Overlapping governance regions and different boundaries can make it difficult to identify which portions of a politically defined subcounty are within a specific water management zone and, therefore, which oversight or management authority should be engaged to implement water supply protection and wetland restoration efforts. To resolve some of this confusion, a distinct and critical cornerstone of this project focused on aligning governance and management area boundaries with WASH-related efforts within catchment areas.

This case study focuses on wetland restoration within the Kamwenge District of Uganda. While most of the district is within the Lake Albert Water Management Zone, a portion of the Biguli Subcounty falls under the Victoria Water Management Zone. Degraded wetland ecosystems in the Kamwenge District were within the recharge areas of existing and planned piped water supply systems and presented significant risks to the reliability and stability of groundwater dependent communities (Mahayni et al., 2021). Agriculture, brickmaking, sand mining, and forestry have contributed to wetland degradation, along with the commercial planting of eucalyptus trees, which drain water from wetlands and shallow groundwater tables and displace native plant species.

Wetlands contribute directly to the quality of WASH services, including drinking water sources, as wetlands filter water as it seeps into groundwater tables or flows as runoff into streams and diversion channels. As a result, the degradation and loss of wetlands due to both human and climate change impacts affect WASH processes and diminish reliable and sustainable access to clean drinking water for local communities. To address this problem, a collaborative effort among Water For People, local district governments, the Albert and Victoria water management zones, and community members coalesced to address and reverse degradation of key wetlands in Biguli Subcounty. Stakeholders developed a coordinated intervention strategy that involved a range of activities, including:

- **Water resources assessments.** An area water resources assessment was conducted, and degradation hotpots were identified for five priority wetlands and across 21 additional wetland systems in the district. These maps were used to familiarize local community and government members with the location and condition of wetlands, as well as to invite and encourage participation in restoration initiatives. Permanent concrete pillars were installed at three wetlands to establish buffer zones within which to avoid harmful activities and to implement planned restoration activities.
- **Community education.** Building from the mapping efforts, additional meetings and site visits with leaders and community members provided descriptive and illustrative information on the hydrological dynamics of wetlands, the importance of groundwater-to-wetland functions, and the impact of wetland degradation on plants and animals as well as on human water supplies. Further educational efforts focused on linking improved agricultural practices with the restoration of soil and improved land conditions.
- **Livelihood initiatives.** Local and regional governments and leaders worked with community members to develop water and soil conservation practices on farms that fostered greater soil health, improved moisture and nutrient retention, reduced erosion, and increased food production resilience in response to water availability fluctuations. Improved farm practices benefited both community members and the health and function of wetlands.
- **Monitoring.** Community members and scientists worked together to set up groundwater monitoring systems to track the response of groundwater levels to restoration activities. Monitoring data served several complimentary purposes, including providing feedback data on the effectiveness of restoration activities to community members and establishing a record of the types of ecological and livelihood improvements that restoration was facilitating.

IMPACTS AND OUTCOMES

From the beginning of this effort, there have been observable improvements in the health of the land and water system that have produced tangible benefits to local communities.

1. **Restored wetlands.** Within one year, five wetlands were fully restored: Rwakasirabo, Kizikibi, Nyakatooma, Kabale, and Keishunga Wetlands in Biguli Subcounty. Each of the wetlands are fully inundated and sustaining wetland plant and animal species. In Kizikibi

Wetlands, mud fish have returned after a period of total extinction and have become a renewed food staple for locally adjacent communities.

2. **Delineating wetland boundaries.** The boundaries of 26 wetlands have been delineated, and the areas within the boundaries have been described and characterized. Based on this mapping, three wetlands have been fully protected with permanent concrete pillars to allow for restoration and recovery.
3. **Increased government engagement.** As wetlands are recovered, there is growing momentum in district and subcounty local governments to prioritize wetland protection activities. In tandem, communities are taking steps to reduce wetland draining actions and remove eucalyptus plantations that are diverting water from wetland vegetation.
4. **Socioeconomic benefits.** Local communities are directly benefiting from restored ecological functions in the wetlands in a variety of livelihood-enhancing ways. Functioning wetlands produce a number of food products that local communities use, including mud fish, wetland sages and other types of vegetation that can be used for moisture retention and weed and soil erosion control in gardens.
5. **Improvements in aquifer levels.** Groundwater monitoring has provided important hydrological context for wetland restoration activities. Data suggest that groundwater levels are directly responsive to precipitation, rising during the rainy season and dropping during dry periods. This pattern underscores the importance of wetlands in slowing precipitation and retaining water for infiltration into shallow groundwater tables that can enhance water supply resilience during increasingly intense drought periods.
6. **Stability.** Additionally, water sources that are in proximity to restored wetlands are more stable and not as affected by climate change-driven extremes in more intense seasonal precipitation and dry seasons.
7. **Improvements in water quality.** Monitoring data compiled by Water For People illustrates a significant improvement in the quality across water sources in districts with marked improvements in wetland conditions. For example, in the Kamwenge District, the number of water sources with “adequate” ratings for water quality increased from 37% in 2017 to 68% in 2019 (Kanweri, Okettayot, and Nimanya, 2019).

ENABLING FACTORS

Key factors that contributed to the success of this project are outlined in the table below.

ENABLING FACTORS	
Institutional	Strong political leadership and support. Aligning various governance regions (e.g., water management zones, districts and political regions) to ensure broad engagement and representation. Compliance and committed engagement from local communities.
Social	Buy-in from stakeholders early in the process. Diversity of partners, including community members, government officials, leaders, WASH specialists, academics, NGOs, and scientists.
Technical	Investment in the “why.” Maps, assessments and monitoring data illustrated the impacts of degraded wetlands as well as the benefits of improved wetland conditions, which helped local communities engage and contribute to restoration efforts.
Economic	Engagement around farms, agriculture, and fisheries produced economic benefits for local communities.

LESSONS LEARNED

A motivating and energizing outcome of this work emerges from the wetlands themselves. While wetland degradation is extensive, the wetlands responded within six months to restoration efforts—both from removing/preventing causes of impact (e.g., through boundary delineation) and proactive efforts to revive wetland species and functions. Observation and monitoring of wetland recovery provides positive feedback to local communities, leaders, and government bodies; demonstrates deeper climate resilience; enhances adaptation to climate variations; and sparks additional motivation to continue improving wetland conditions and realizing the hydrological, socioeconomic, and ecological benefits. To expand on this work in new areas, there are several key next steps that are particularly relevant.

1. **Capacity building and political will.** For this project, government leadership and engagement was a key component of success in restoring wetlands. Continuing to strengthen collaboration and capacity across government institutions will help to scale up efforts to more wetlands and hasten wetland recovery.
2. **Monitoring.** Groundwater monitoring has also been a critical piece of the project's success by demonstrating the benefits and urgency of continued restoration activities.
3. **Improvement in agricultural practices.** Engaging farmers is a key piece of the strategic process. Offering them alternative livelihood choices as well as options for improving food production, soil health, and slope stability helped to strengthen a connection between wetland conditions and personal and community well-being.

A concrete pillar denotes a protected wetland area.
© Water for People

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Leadership comes in different forms and is key to igniting action and sustained engagement in projects.

ZAMBIA

BUILDING WATER RESILIENCE WITH LOCAL NBS ACTORS

Horticulture demonstration plot for enhanced water productivity in the Kafue River catchment area, Zambia. © NIRAS

INTRODUCTION

Zambia is endowed with an abundance of natural resources. In 2014, according to the Wealth Accounting and Valuation of Ecosystem Services (WAVES) Global Partnership, natural capital accounted for an estimated 40% of the country's wealth, with approximately three-quarters coming from renewable resources (Mubanga, n.d.).

Among those resources are plentiful supplies of arable land and freshwater, which historically have not been fully utilized for agriculture. For example, while 58% of Zambia's area is classified as medium-to-high potential for agriculture, only 15% of that land is currently cultivated. Furthermore, most of the cultivated lands, especially the smallholder farms, operate at very low productivity levels. Even still, agriculture accounts for 19% of Gross Domestic Product and employs three-quarters of the country's population. The economic contributions, however, come from a limited number of medium- and large-scale farms, as approximately 90% of agricultural producers are small-scale subsistence farmers (International Trade Administration, 2022).

In addition to the general need for sustainable development of the agricultural sector, Zambia's water resources—and perhaps even more so, the rural communities that depend on them—are being negatively impacted by both environmental and anthropogenic factors. As a result of climate change, Zambia is experiencing higher temperatures, increased frequency and severity of both droughts and flash flooding, and shifting weather patterns that have impacted the growing season (i.e., the rainy season is starting later and decreasing in duration) (International Trade Administration, 2022; UNDP, n.d.).

These changes are compounded by rapid population growth—the country's population grew 30% from 2000 to 2010—and economic development (Government of the Republic of Zambia, 2020). In the Lower Kafue Catchment, these changes are particularly evident. In addition to being where Lusaka, the country's capital of government and commerce, is located, the Lower Kafue Catchment also is home to over half of the country's population and an estimated one-quarter of the country's small-scale farms (AWARE, 2021).

Leaky weir for enhanced water infiltration in the Kafue River catchment area, Zambia. © NIRAS

Small-scale farmers, the majority of whom rely on the rainfed growing cycle for crop and livestock farming, are particularly vulnerable to the impacts of a changing climate and increased competition from other water users. Finding efficient and sustainable ways to increase resiliency and help farmers adapt to the reality of a shortened rainfed growing season, punctuated by an increasing number of flash floods and extended dry spells, is critical.

NBS APPROACHES

Watershed restoration typically consists of a combination of activities at multiple scales, including at the field, farm, and catchment levels. Activities may include a mix of NbS, capacity-building and infrastructure investments to improve environmental and socioeconomic conditions. In addition to increasing water retention capacity throughout the catchment, watershed restoration can also contribute to water security by protecting surface and groundwater sources and enhancing water quality.

PROJECT

The Accelerate Water and Agricultural Resources Efficiency (AWARE) program in Zambia is focused on sustainable water resource management (including development of a national water management strategy and local water user groups), improved catchment health, and increased on-farm water availability for small-scale farmers in the Lower Kafue Sub-catchment. The project, which began in 2019, is funded by the European Union (EU) and German Federal Ministry for Economic Cooperation and Development (GIZ), and supported in-country by the Ministry of Water Development and Sanitation (MWDS) and the Ministry of Agriculture (MoA). The total cost of the project is EUR 17.2 million.

Spearheaded by four water user associations, the project is participatory and community-focused to ensure that activities build on local experience and help build additional capacity. Catchment restoration activities include tree planting, trench digging, gully rehabilitation and installation of soil bunds. Demonstration sites and technical trainings provide opportunities for small-scale farmers. In total, 32 demonstration sites were developed to showcase a variety of technical options for improving on-farm water use efficiency and water harvesting. Options for improving on-farm water use include mulching, cover crops and drip irrigation, while water-harvesting techniques include rooftop rainwater harvesting systems, permeable weirs and measures for improving groundwater recharge for shallow wells (Deutsche Gesellschaft für and Internationale Zusammenarbeit (GIZ) GmbH, 2021).

IMPACTS AND OUTCOMES

To date, over 46 million liters of water-harvesting capacity has been installed, and over 11,000 small-scale farmers (more than half of whom are women) have received training, with 94.5% of farmers rating the training as highly useful. Furthermore, 63% stated that they are applying what they learned on their own farm, and 70% reported increased yield after implementing techniques learned in the training (GIZ 2023; Niras, n.d.).

Local residents are also involved in catchment restoration—over 800 residents have helped plant 100,000 trees, construct 80,000 soil bunds and dig over 8,000 trenches, all of which will help improve water infiltration and recharge (GIZ, 2023).

ENABLING FACTORS

A variety of enabling factors were critical to the development, implementation, and overall success of this project, which are summarized by category in the table below.

ENABLING FACTORS	
Institutional	Developed a national water strategy. Formed four water user associations to support more decentralized management of water resources.
Social	Used a participatory, community-focused approach. Leveraged local knowledge and experience to develop activities. Selected activities promoted both improved environmental and socioeconomic well-being.
Technical	Established 32 demonstration sites. Provided technical trainings to small-scale farmers.

LESSONS LEARNED

This case study provides a number of lessons that may be valuable for similar efforts in the future.

1. **Capacity-building.** Technical trainings increased local knowledge and empowered farmers to make changes to their own practices. Involving community members in catchment restoration activities increased local awareness, knowledge and skills.
2. **Complementary activities.** Nature-based Solutions were implemented in tandem with infrastructure and institutional activities.
3. **Resilience.** Increased resilience for both the watershed catchment and small-scale farmers. Improved watershed health supports biodiversity, improves water quality and reduces flood risk, among other environmental benefits. Small-scale farmers have increased knowledge and improved techniques for sustainable and efficient farming along with increased water supplies.
4. **Scalability.** Similar activities could be implemented in other catchments both in Zambia and elsewhere.

Onlookers observe a demonstration plot farmed with NbS techniques to increase water efficiency. © NIRAS

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SOUTH AFRICA

RESTORING NATURAL VEGETATION FOR ENHANCED WATER SUPPLY

The landscape around Cape Town, South Africa. © Roshni Lodhia

INTRODUCTION

Cape Town, the legislative capital of South Africa, is home to over 4.7 million people (Western Cape Government, 2021). A record-setting drought, lasting from 2015 to 2018, saw the city and its residents facing severe water shortages and approaching " day zero" conditions—when municipal water would have to shut down. Severe water restrictions and an increase in tariffs combined with drought-easing rains allowed Cape Town to narrowly avoid "day zero," but the threat still looms since demand continues to exceed supply. The realities of climate change in the form of decreasing rainfall and increasing temperatures, and population growth, however, make another water shortage crisis under current conditions not only possible, but likely (City of Cape Town, n.d.; Hill-Lewis, 2023).

Water security continues to be a priority for the city and its environs, particularly in light of climate change, as 95% of the city's water is shared with agriculture and nearby municipalities, and comes from a complex of six rainfed dams (OECD, 2021). While demand-side strategies provide a short-term solution, supply-side solutions are also needed in order to meet the region's future water needs. More typical supply-side strategies favor gray infrastructure like the construction of new dams, renovation of existing dams to expand reservoir capacity, water reuse and seawater desalination, and others. Given the heavy reliance on rainfall for supply, another option in this context involves a Nature-based Solution (NbS)—catchment management.

In South Africa, alien invasive plants (AIP), including pines, gums and wattles, are a major threat to water supply and water security. Alien invasive plants, through their excess uptake and evapotranspiration as compared with native flora, negatively impact over two-thirds of the Western Cape Water Supply System (WCWSS), which serves Cape Town and the surrounding areas. In addition to crowding out native fauna, AIPs increase fire intensity and alter habitat, soil ecology, biodiversity, river flow and aquifer recharge. Water consumption by AIPs is estimated to decrease water supply available to WCWSS by up to 55 billion liters per year, which would cover Cape Town's water needs for approximately two months of the year (or one-sixth of total annual water use). In addition to the substantial impact on water supply already created by AIPs, an additional concern is that the plants are spreading at a rate of 5–10% per year. If no actions were taken, estimated annual water loss across the study area would likely double within 30 years (South African Department of Forestry, Fisheries and the Environment, n.d.; The Nature Conservancy, 2018). This threat, on top of climate change impacts and population growth, puts the region at increasing risk for water shortages.

NBS APPROACHES

Ecological infrastructure is the "natural functioning ecosystem that generates and/or delivers valuable services to people, such as freshwater, climate regulation, soil formation and disaster risk reduction" (South African Department of Forestry, Fisheries and the Environment, 2022). Ecological infrastructure is also known to deliver co-benefits such as valuable services to the environment and wildlife. Restoration of ecological infrastructure, therefore, focuses on improving and/or rehabilitating natural ecosystems that have become degraded or destroyed as a result of anthropogenic activity. More specifically, this case study focuses on an effective approach that removes alien, invasive vegetation species in order to allow for native revegetation to repopulate an area.

PROJECT

In 2018, the Greater Cape Town Water Fund (GCTWF) was launched by The Nature Conservancy (TNC) and the City of Cape Town with support from a coalition of public agencies, private entities and non-governmental organizations. The primary function of the fund is to acquire and pool investments from multiple funders and downstream water users, and use that funding to coordinate and implement upstream restoration and/or conservation to improve water quality and/or quantity. In the case of the GCTWF, the primary activity funded will be removal and management of AIPs in seven priority sub-catchments.

Catchment management is not a novel idea in South Africa, as AIPs have been removed and controlled in protected areas and mountain catchments for decades. Since 1995, when the Working for Water program began, it has cleared AIPs from more than 3.6 million hectares (Department of Forestry, Fisheries and the Environment, 2021), but the rate at which plants are spreading is greater than the rate of control—particularly in remote mountainous areas, which are more difficult to access. In addition to increasing water security and providing co-benefits, catchment restoration was ultimately implemented over alternatives because of its cost-effectiveness—“supplying water at one-tenth the unit cost of alternative options” (The Nature Conservancy, 2018).

In addition to involvement of TNC and the City of Cape Town, a multi-stakeholder steering committee consisting of representatives of government agencies, private sector entities, and NGOs was formed. The steering committee is also supported by three technical work groups (i.e., data and ops, monitoring and evaluation, and sustainable finance).

Conservation technician ascends a rope after a long day removing invasive species from steep terrain. © Roshni Lodhia

The business case assessment estimated that up to 55 billion liters of water could be conserved annually through AIP removal and management on 53,400 hectares, which would require an investment of US$25.5 million (in 2018 dollars). To date, 70% of the funding for the high impact phase has been secured (L. Stafford, Personal Communication, July 2023). To protect this investment, funding must be secured for long-term follow-up and maintenance over the next 25 years. If continued maintenance does not occur, the cleared areas will become covered again.

IMPACTS AND OUTCOMES

The overarching goal of the GCTWF is to increase long-term water security for the City of Cape Town in a way that also provides ecological and social co-benefits. Given the large number of benefits provided by the fund, they have been loosely grouped into three categories: environmental, social and economic.

In the last four years, AIPs have been removed from almost 30,000 hectares, or approximately 55% of the total project goal of 54,300 hectares. Follow-up clearing has also occurred on over 11,000 hectares in order to prevent AIPs from reestablishing in the future. As mentioned previously, AIP removal was substantially more cost-effective than the next best water supply alternative, providing water at one-tenth the cost. To date, 15.2 billion liters of water have been reclaimed per year through the removal of AIPs (42 million liters per day).

In addition to increasing water supply and water security, removal of AIPs will help protect threatened communities of native plants, 70% of which are endemic to the region. The natural vegetation—called fynbos—depends on fires every 10 to 15 years to persist. AIPs are also fire-adapted, but cause larger uncontrolled blazes compared to the native plants. Removal of the AIPs substantially decreases wildfire risk in priority sub-catchments and the surrounding settlements.

Economic benefits of the project included both direct contributions to the local economy and avoided costs of alternative water sources. The GCTWF has created 787 green job opportunities, of which 151 are for high-angle technicians deployed to work in remote mountainous terrain—the biggest operation of its kind in South Africa.

ENABLING FACTORS

A variety of enabling factors were critical to the development and creation of the GCTWF, which are summarized by category in the table below.

ENABLING FACTORS	
Institutional	Created public-private partnership with clear governance structure that includes steering committee and technical working groups. Decreased reliance on government funding and increases likelihood of reliable, sufficient funds. Removed bureaucratic barriers, provides greater transparency and promotes adaptive management. Provided opportunities for collaborative planning and prioritization across previously "siloed" entities.
Social	Included a diverse set of stakeholders and funders. Job opportunities. Skills development. Helped to alleviate poverty.
Technical	Leveraged TNC and South African government entities' working knowledge of water funds and AIP removal/management, respectively, to create a community of practice. Drew on partners' expertise in fundraising, financial modeling, scenario modeling and online visual platform development. Required knowledge in plant identification, chainsaw use, herbicide use, site management, health and safety, and skills for camping/survival in remote mountain regions. Utilized high-altitude rope technicians with special training to remove AIPs in remote and rugged terrain. Supported a training program for people from local communities.
Economic	Utilized funding from a diverse set of donors, including philanthropic organizations, corporations, and the City of Cape Town. Cost-effective means of augmenting water supply. Shared implementation resources between the partners, and ownership of the work through the water fund structure.

LESSONS LEARNED

While efforts are ongoing, the GCTWF already can provide a number of lessons that may be valuable for similar efforts in the future.

1. **Quantifying benefits.** Conducting a business case assessment of alternatives for increasing water security and water supply prior to investing resulted in selection of the most cost-effective option (and also the one that likely provided the most co-benefits, and showed who benefited and by how much). Establishing the business case

was essential to bringing several key partners on board and securing long-term funding.

2. **Co-ownership.** The pace and scale of catchment management, which in this case was primarily AIP removal, can be increased using a public-private partnership approach.

3. **Public-private partnership.** Investment by both the City of Cape Town and the private sector through TNC ensured shared responsibility and commitment to the project's success.

4. **Collaboration.** Partnership between private and public entities allowed for utilization of innovative governance and finance mechanisms, and leveraged the unique skills and expertise of project partners.

5. **Monitoring and adaptive management.** The Greater Cape Town Water Fund Decision Support Tool provides 1) tracking of progress relative to project goals; 2) in-field activity coordination; 3) planning to optimize water yield gains; and 4) benefit validation.

6. **Resilience.** Removal of AIPs not only increases water supply; it also prevents the loss of future supply through continued growth of AIPs and protects native biodiversity. Furthermore, alternatives for increasing water security such as developing new or expanding existing reservoirs may be less reliable in the face of climate change—without sufficient precipitation, these options would fail to increase supply.

Cut invasive pine trees on the side of a steep hill following AIP removal. © Roshni Lodhia

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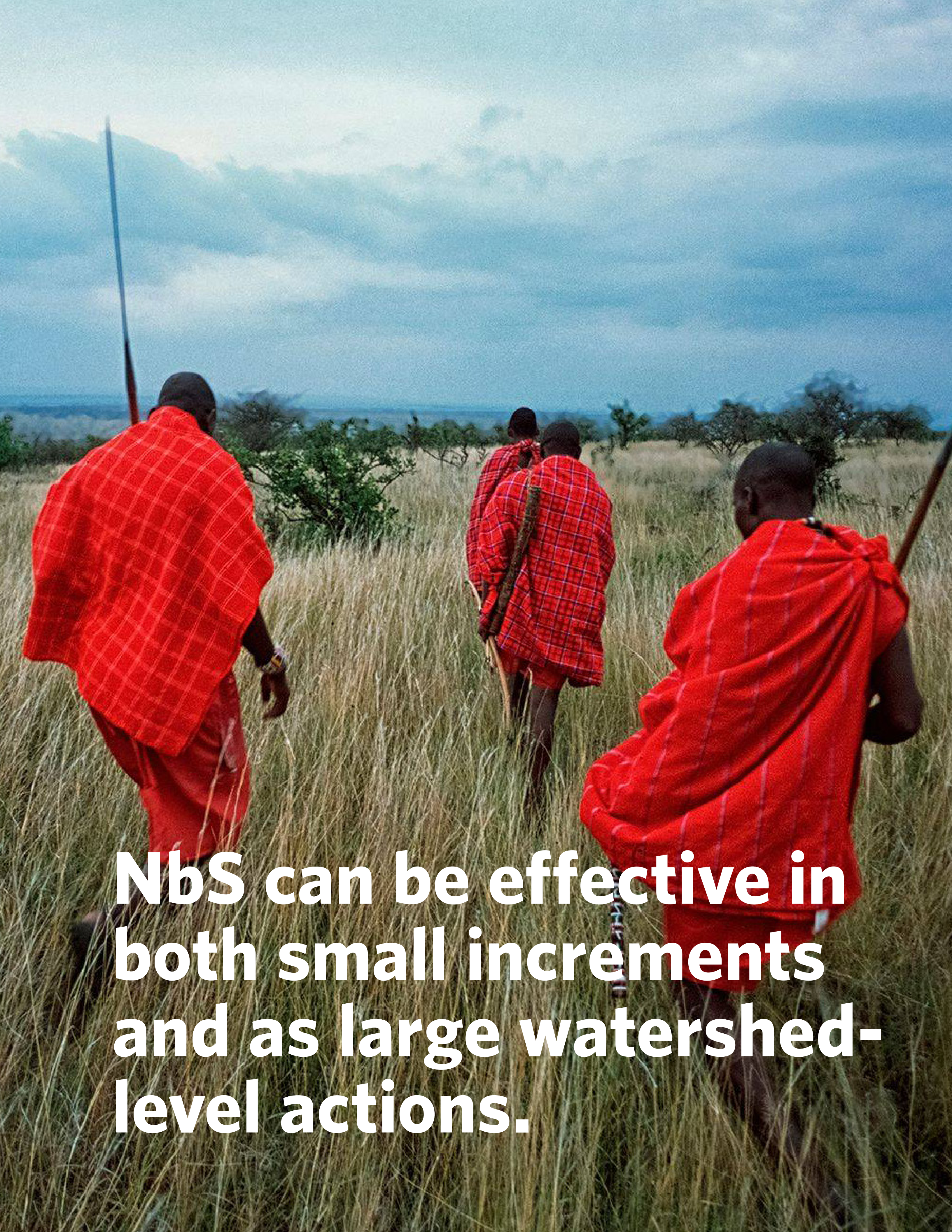
NbS can be effective in both small increments and as large watershed-level actions.

COLOMBO, SRI LANKA
RESTORING FLOODPLAINS FOR FLOOD PROTECTION

View of Colombo from above. © Martin Seemungal

INTRODUCTION

Colombo is Sri Lanka's capital and most populous city—home to an estimated one-quarter of the island country's 22.2 million inhabitants (Department of Census and Statistics, 2023; Perera, 2018). The city's location, along a low-lying river estuary in a region that receives substantial and intense precipitation (an average of 2,400mm per year, much of which falls during monsoon season), makes it particularly vulnerable to flooding. In recent years, these risks have been exacerbated by rapid economic development and urbanization as well as climate change. Since the 1980s an estimated 60% of Colombo's wetlands, which help manage and disperse water from heavy precipitation events, have been degraded or destroyed, primarily as a result of infilling (Cobra Collective, n.d.). Across a similar timeframe, average annual rainfall in Colombo has increased, and climate change predictions suggest both the frequency and intensity of extreme precipitation events to be higher in the future (The World Bank, 2018a).

Beddagana Sanctuary and boardwalk, one of the wetland restoration projects. © Priyanie Amerasinghe, 2022

A flood in 2010 displaced more than a quarter-million of the city's residents and caused an estimated US$100 million in damages (Perera, 2018; Times Online, 2010). On the heels of that natural disaster, the Government of Sri Lanka asked the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR) to conduct a technical assessment of Colombo's flood risk and the range of benefits, including reduced flood risk, that wetlands provide. Findings from that study concluded that wetlands play a key role in flood prevention for the city—during a major storm event, they have the capacity to retain up to 39% of flood waters—and need to be included as part of any flood management strategy the city adopts (The World Bank, 2018a).

Nandya Thalyta Yuwono, the World Bank team leader for the Metro Colombo Urban Development Project (MCUDP), said, "The hydrological model provided damning evidence that even if we installed drainage tunnels, pumping stations and improved canal diversion throughout the city, we still couldn't keep Colombo completely safe from a major flood without preserving the wetlands" (Rajapakse et al., 2022). Not only did the study determine that the city's wetlands are a critical component of flood management, but it also concluded that failure to protect remaining wetlands from further degradation or infilling would likely result in substantial economic losses for the city (i.e., 1% of its gross domestic product annually) due to flooding and related damages (The World Bank, 2018b).

NBS APPROACHES

Wetlands provide a wide range of provisioning services, including flood regulation. Nature-based Solutions (NbS) include development, revitalization, restoration, protection, and/or sustainable management of wetlands. These activities can not only support increased resilience to flooding, but also help address a variety of other socioeconomic and environmental challenges.

Key recommendations for managing and protecting the urban wetlands of Colombo, Sri Lanka from the World Bank's technical assessment were threefold. The first recommendation was to develop legal protections for the wetlands, including classifying them as no-development zones and formally integrating them into urban planning and design. Another recommendation was to create a network of public wetland parks that allow managed access and provide educational and recreational opportunities. The final recommendation involved developing incentives for community and private sector participation in wetland restoration and management (Rozenberg et al., 2015).

PROJECT

In 2012, the MCUDP was initiated as a joint effort of the Government of Sri Lanka and the International Bank for Reconstruction and Development (IBRD) of the World Bank Group. These two entities are also the project funders, contributing one-third and two-thirds (as a loan), respectively, of the US$321 million total project costs. The objectives of the project are:

> **To (i) reduce flooding in the catchment of the Colombo water basin, and (ii) strengthen the capacity of local authorities in the Colombo Metropolitan Area (CMA) to rehabilitate, improve and maintain local infrastructure and services through selected demonstration investments (The World Bank, 2014).**

The project combined environmental science and engineering with stakeholder engagement in a two-pronged approach that focused on rehabilitation and protection of Colombo's remaining wetlands, as well as installation of hard infrastructure (i.e., pumping stations and tunnels) to help manage floodwater. Recognizing that there was a need to increase the overall awareness of the role urban wetlands play in the well-being of Colombo residents, the project also created public wetlands parks that showcased the many co-benefits of wetland restoration.

IMPACTS AND OUTCOMES

As the project continues, much of the metropolitan area will see the benefits of increased flood protection. While the overarching goal of the MCUDP is to reduce the risk of catastrophic flooding in Colombo,

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the wetland rehabilitation portion of the project provides a multitude of co-benefits, which are loosely grouped into three categories: environmental, social, and economic.

Additional environmental benefits include protection of the wetlands' rich biodiversity by restoring and protecting habitat for the 280+ wildlife and 250+ plant species that reside there, including a number of endangered species (Rozenberg et al., 2015). The wetlands also help treat wastewater, sequester carbon, maintain air quality (absorbing up to 90% of the city's greenhouse gas emissions) and provide temperature control (during the hottest times of the day, the wetlands and areas around them are, on average, 10°C cooler than non-pervious areas of the city) (Rajapakse et al., 2022; Wetlands International, 2020).

Some, but not all, of the socioeconomic benefits include:

- Avoided economic losses as a result of flooding;
- Increased revenue from tourism and recreation (up to an estimated US$13 million per year) (The World Bank, 2018a);

- Recreational and educational opportunities for residents and visitors;
- Continued opportunities for Colombo's urban poor to utilize the wetlands food and supplemental income (e.g., cultivating rice, subsistence fishing and picking herbs), which benefits an estimated 60% of such households (The World Bank, 2018b);
- Health benefits from improved air and water quality;
- Reduced energy costs for air conditioning (over 50% of metro area benefitted from "natural air conditioning") (The World Bank, 2022); and
- Increased property values (77% of respondents to a beneficiary survey for the three public parks indicated their properties had a higher value as a result of urban improvements) (The World Bank, 2022).

More broadly, in 2018, Colombo became the first world capital to receive accreditation as an International Wetland City by the Ramsar Convention on Wetlands. Because of the success of the MCUDP, the Government of Sri Lanka plans to support wetland preservation across the country. As of early 2022, 49 development plans for wetland conservation had been approved, and 21 more were being developed (Rajapakse et al., 2022).

According to The World Bank Implementation and Results Report, the project was completed in 2021 (the original date was 2017) and was under budget—using only US$253 million, or 79% of the original budget (The World Bank, 2022).

ENABLING FACTORS

A variety of enabling factors were critical to the development, implementation and overall success of this project, which are summarized by category in the table below.

ENABLING FACTORS	
Institutional	Initiated, supported and funded by the federal government.
Social	Conducted a social assessment that included stakeholder engagement and consultations with community groups. Based on that information, developed a management framework to identify and minimize/mitigate project impacts.
Technical	Supported by The World Bank and involved scenario modeling and quantification of economic benefits (and co-benefits) of wetland conservation. Used external consultants to design, implement and manage many of the rehabilitation activities.
Economic	Two-thirds of total project costs were covered by a loan from the World Bank.

LESSONS LEARNED

This case study provides a number of lessons that may be valuable for similar efforts in the future.

1. **Enhanced Awareness.** A contributing factor to loss of wetlands in and around Colombo was a general lack of awareness of the many benefits provided by urban wetlands. Identification and quantification of those benefits in the technical assessment served as a first step. Additional steps included funding community organizations to implement projects in which "communities are empowered to conserve the environment while engaging in their livelihoods" (UNDP, 2022), and developing public parks with enhanced educational and recreational opportunities. This multi-pronged approach has helped build broad support for Colombo's wetlands (The World

Bank, 2018a). Continued public interest and support also is essential to the long-term sustainability of the wetland parks, as funds were only available to establish the parks and will therefore be needed to maintain them.

2. **Resilience.** In the face of climate change, urban wetlands support resilience in a number of ways—both during extreme events, in the case of reduced flood risk, but also on a daily basis in the form of temperature regulation, carbon sequestration and improved air quality, among others.

3. **Scalability.** The government of Sri Lanka is supporting wetland conservation initiatives across the country and has hosted collaborative knowledge-sharing events with representatives of the Maldives interested in implementing similar initiatives in their country.

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In addition to localized benefits, Nature-based Solutions can help achieve global goals of water and food security, climate change mitigation and biodiversity.

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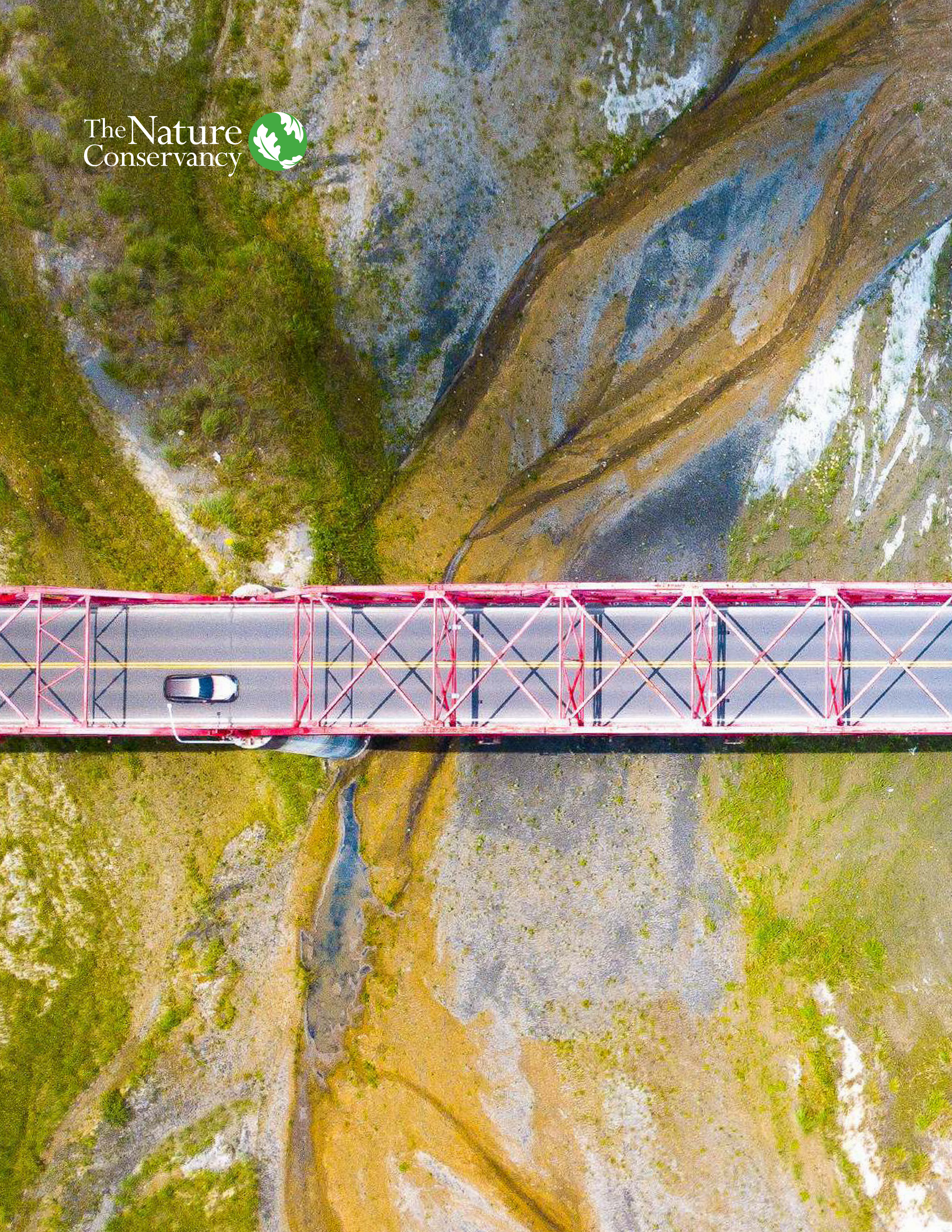
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