GUIDELINES FOR MAINSTREAMING NATURAL RIVER MANAGEMENT IN WATER SECTOR INVESTMENTS

SEPTEMBER 2021

ASIAN DEVELOPMENT BANK

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FOREWORD

Charting a steady course, Asia and the Pacific has made great strides in poverty reduction and economic growth in the last 50 years. Today, the region is challenged to make further progress, curtail rising inequality, and address large infrastructure deficits, while at the same time minimizing severe declines in natural capital that threaten to constrain future economic growth.

With the coronavirus disease (COVID-19) pandemic highlighting the intrinsic connection of human health to environmental health, the Asian Development Bank (ADB) has deemed it crucial to promote quality infrastructure investments that are green, sustainable, resilient, and inclusive. Through its knowledge and technical support assistance project Protecting and Investing in Natural Capital in Asia and the Pacific (TA 9461), ADB has partnered with the Climate Change Fund and the Global Environment Facility to build the business case for ADB developing member countries to invest in natural capital. Part of the project's output is providing ADB officers with the tools for mainstreaming natural river management (NRM) practices in ADB water sector investments.

In the river and coastal communities of Asia and the Pacific, climate change is intensifying the impacts of extreme weather events such as flooding and landslides. Historically, developing countries have addressed flooding by using hard infrastructure interventions in rivers, which tend to push a river basin onto a development path that may no longer be tenable within the context of a changing climate. This not only requires considerably more investment over time, but may also have unintended negative consequences on the lives of people whose livelihoods depend on the river. To harness the natural ecosystem services inherent in rivers and develop sustainable river management practices, and the concept of natural river was developed.

NRM strives to optimize river use and reduce river-related risks while respecting the natural dynamics and flow of freshwater, sediment and nutrients, and peoples' dependence on these at the basin scale. In the ADB portfolio, NRM provides a basis for embedding a planning process that proactively chooses where to intervene, following a risk-based approach, and where to have the river follow its natural course. It guides the inclusion of nature-based solutions in river projects in close harmony with standard engineering interventions through multi-criteria analysis and cost–benefit analysis. NRM offers ADB officers arguments based on natural river functions for refraining from actions with negative side effects on the upstream and downstream reaches, and for stopping actions that will not be sustainable because of lack of long-term funding for operation and management.

Home to seven major transboundary river basins, Asia and the Pacific presents great potential for expanding NRM investments. It is hoped that this publication, *Guidelines for Mainstreaming Natural River Management in Water Sector Investments*, will provide a useful reference resource for those working on development planning in the region and beyond.

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ABBREVIATIONS

ADB	–	Asian Development Bank
IRBM	–	integrated river basin management
IWRM	–	integrated water resources management
NBS	–	nature-based solutions
NRM	–	natural river management
TRTA	–	transaction technical assistance
UK	–	United Kingdom
US	–	United States

EXECUTIVE SUMMARY

River flooding claims hundreds of lives each year in developing countries in Asia and the Pacific and ruins countless livelihoods. The devastation caused is set to worsen with climate change, as extreme rains gain strength and periods of drought lengthen and become more intense. The region, which leads the rest of the world in population growth rate and average annual rate of economic growth, is challenged to make further progress, improve infrastructure, benefit communities, and reduce poverty, while at the same time preventing or at least minimizing environmental damage. Development, besides being economically and socially beneficial, must be ecologically sound and sustainable. To deal with the problem of river flooding and increase resilience to climate change, the developing member countries of the Asian Development Bank (ADB) need to take a new approach to water management.

The construction of hard or gray infrastructure, such as dams, embankments, canals, dikes, and levees, is often the first line of defense against flooding. Designed to operate within a fixed range of hydrologic conditions, these interventions not only tend to neglect the dynamics and natural functions of rivers but also often give priority to the subsequent (and increasingly expensive) maintenance of the infrastructure over river health. Without proper master planning and with only a short-term focus on return on investment, gray infrastructure can result in natural resource degradation.

The natural river concept was developed as part of an overall approach to harnessing the natural functions of rivers and developing sustainable river management practices, under nature-based solutions (NBS). Natural river management (NRM) is an iterative, science-based, and participatory water resources management approach that leverages the intrinsic abilities of natural river systems to deliver climate resilience at a lower cost while minimizing negative environmental and social impacts. The practice strives to respect the natural dynamics and flow of freshwater, sediment and nutrients, and peoples' dependencies on these at the basin scale.

Drawing heavily on the concepts of ecosystem services, integrated water resources management, and integrated river basin management, NRM does not advocate natural solutions alone. Instead, it serves as a guide in including NBS and nonstructural measures in river projects in close harmony with standard engineered interventions. NRM provides a basis for embedding a planning process of proactively choosing where to intervene, through a risk-based approach, and where to let the river follow its natural course.

This publication, *Guidelines for Mainstreaming Natural River Management in Water Sector Investments*, shows how the NRM approach can be embedded in the ADB project cycle, particularly in three distinct phases: project identification, project preparation, and project implementation.

The **project identification** phase lists interventions that consider the entire river system and such functions as geology, hydrology, sediment transport, morpho-dynamics, water quality, and ecology. Generic objectives are translated into the specific characteristics of each river basin, and both green and gray strategies are evaluated. "Hot spots," or priority areas for action in the river basin, are identified through risk analysis, setting off a more exhaustive process of problem solving and systematic understanding that leads to low-regret and deliberate proposed interventions.

Project preparation requires comprehensive project justification and a clear cost–benefit analysis of the NRM approach, to establish NRM as a means of tackling challenges or achieving a development goal. Relevant stakeholders are identified and consulted at this stage. Project officers are tasked not only with comparing the economic benefits of the NRM approach with those that may be derived from traditional interventions, but also with determining the co-benefits of the approach and its nonmonetary impacts.

A lead agency or a group of agencies oversees NRM **project implementation**. As the approach is largely dictated by the characteristics of the natural system, effective implementation demands a comprehensive set of solutions that encompass social, environmental, engineering, and policy and institutional considerations. Management and maintenance, monitoring and evaluation, capacity building, stakeholder and community involvement, and an enabling institutional environment—all these factors should be taken into account to maximize the usefulness of both green and gray infrastructure.

This publication also contains a summary of structural and nonstructural (or gray and green) measures for dealing with hazards in different sections of rivers. The NRM examples presented here demonstrate that there is no one-size-fits-all solution for riverine concerns. In the Netherlands, different NRM approaches to flood safety were adopted at two rivers, with positive outcomes for both. Creating a side channel at Nijmegen–Lent improved the local discharge capacity of the Waal River, while in Zwolle, widening the IJssel River floodplain provided a buffer for excess water during periods of high river discharge. Both approaches took away space from agriculture, but also offered the opportunity to restore, or even increase, the natural values of the rivers.

Urban centers around the world are applying different NBS to stabilize river flow and mitigate erosion. In Australia, the restoration of the Tomago Wetlands not only created a buffer against flooding and controlled erosion but also improved water quality. While it is beneficial to restore natural river dynamics by partially or fully removing built embankments—as was done at Australia's Upper Drava River and Japan's Moizari River—alternative nature-based bank solutions can be explored. The embankment at the once-volatile Los Angeles River in California used a combination of fixed concrete and natural ingredients, while bioengineering solutions such as wood weaving and regreening were employed in France and Hong Kong, China, respectively.

To maximize navigability, river training structures such as groins and longitudinal dams are alternatives that have been explored at the Jamuna River in Bangladesh (groins), and the River Loire in France and River Waal in the Netherlands (longitudinal dams). These structures have the disadvantage of worsening main channel degradation, but they also increase mid-channel flow to maintain a certain navigational depth. Groin fields are more effective at flow blockage; the area between the bank and a longitudinal dam, on the other hand, offers opportunities for natural development or recreational purposes.

These are just some of the recent advances in knowledge, tools, and assessment methods presented here. It is hoped that by giving ADB teams a more robust understanding of the advantages, technical characteristics, climate resilience aspects, and environmental and socioeconomic impacts of natural river management, this publication will encourage those teams to find ways in which nature-based solutions and natural river management can contribute to the success of their water sector projects.

1 INTRODUCTION

Asia and the Pacific is home to 60% of the world population and generates 60% of global economic growth. The population is growing, and economies are expanding, at rates that are unsurpassed worldwide (ADB 2019a). This growth comes with considerable challenges related to poverty reduction , infrastructure development, and environmental degradation. Rapid expansion of the urban population and high-speed (and often unplanned) infrastructure development exert added pressure on water resources, and make integrated development significantly more complex. Cities and economies have become more vulnerable to water-related disasters as a result. The United Nations Office for Disaster Risk Reduction (UNDRR 2015) reports that floods accounted for 47% of all weather-related disasters worldwide between 1995 and 2015, affecting 2.3 billion people, 95% of them living in the region. These trends are expected to escalate with climate change, their impacts ranging from higher-intensity rainfall to prolonged and more severe drought. To secure economic growth and poverty reduction, the region must take a new approach to water management and become more resilient to climate change.

A recent study by the Organisation for Economic Co-operation Development projects global financing needs for water infrastructure ranging from $6.7 trillion by 2030 to $22.6 trillion by 2050 (OECD 2018). According to the Asian Development Bank (ADB), the Asia and Pacific region will have to invest around $53 billion per year over the 2016–2030 period in climate-proofing water supply and sanitation infrastructure to keep up its growth momentum, reduce poverty, and respond to climate change (ADB 2017b). Amid stiff competition for limited governmental funds, solutions that are cost-effective, besides improving infrastructure services, demonstrating resilience in a changing climate, and contributing to the achievement of social and environmental goals, will have to be developed and deployed worldwide (World Bank 2019).

A growing body of evidence shows that hard infrastructure interventions in rivers can have unintended consequences with the passage of time, ultimately requiring considerably more investments. Infrastructure has traditionally been designed to function within a fixed range of hydrologic conditions. However, within the context of a changing climate, hydrologic assumptions are uncertain and likely to change. Hard infrastructure tends to push a river basin onto a development path that may become untenable as conditions evolve over time. However, deviating from this path or reverting to more natural conditions may become more difficult as considerable changes in land cover, sediment load, and water supply occur.

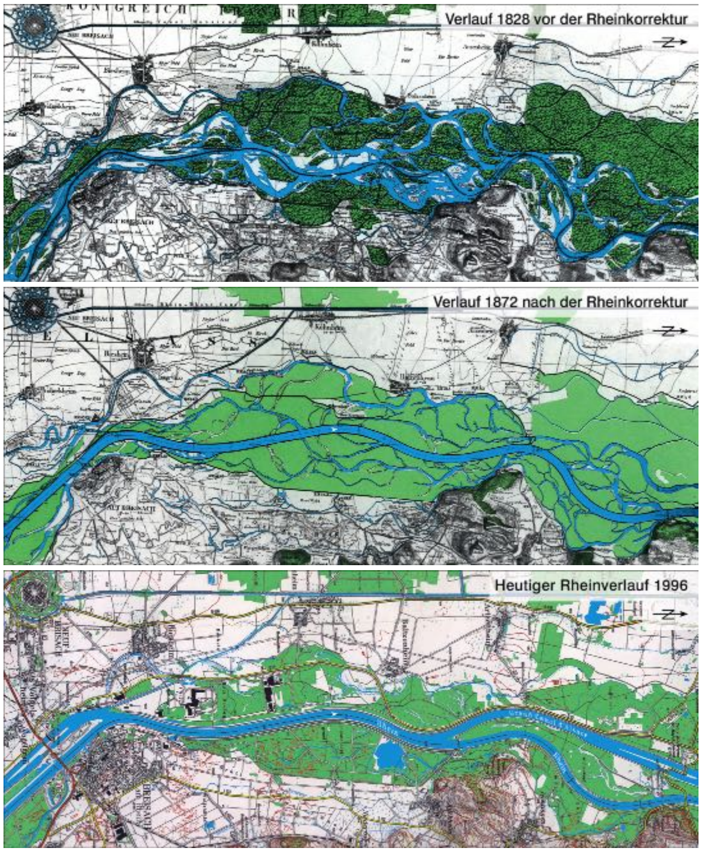
The downside of hard infrastructure is regularly experienced worldwide. For example, the channeling of the Upper Rhine river in Europe at the end of the 19th century seemed an effective option at the time for shortening navigation routes and reducing the risk of flooding (Box 1). Now, nearly 2 centuries later, Germany and the Netherlands are still dealing with the long-term effects of this engineering legacy, such as riverbed incision and lowering of the groundwater table (Schneider 2010).

If not planned, evaluated, designed, and constructed well, the hard infrastructure being developed on a massive scale in the region runs the risk of increasing environmental degradation and misuse of valuable resources such as sand and water. Natural river management (NRM) can build resilience and cost-effectiveness through flexibility, as the ecosystems can adjust on their own to a range of climatic conditions and are less costly to build and maintain. NRM is part of the current global trend of exploring more natural alternatives to complement traditional engineering interventions, in response to natural resource depletion.

Box 1: River Regulation Setbacks on the Upper Rhine

In the 19th century, engineer Johann Gottfried Tulla developed and implemented a plan for regulating the Upper Rhine river in Germany. It was believed then that straightening, narrowing, embanking, and shortening the river would reduce ice jamming, improve navigation, and minimize the adverse effects of flooding. At first, the regulation structures were effective. But then, flow velocity began to increase and channel erosion worsened, resulting in up to 10 meters of bed degradation. Eventually, navigation became nearly impossible. In an effort to solve these problems, the digging of the Grand Canal d'Alsace was begun in the late 1920s and this enormous project was completed after World War II. A series of weirs and sluices managed the water level, making navigation possible again (Knepper 2006). However, diverting the main water flow through the new channel reduced water supply to the Rhine. This caused a dramatic drop in the groundwater level in the area (a new problem), leading to the desiccation of natural and agricultural areas, while increasing flood hazards in the Lower Rhine and the Netherlands during periods of peak discharge (Pinter et al. 2006). Today, several floodplain restoration projects are being carried out to retain water in the area and to delay discharge toward downstream areas, thus mitigating local drought and downstream flood effects.

Maps of the Upper Rhine showing the effects of river regulation

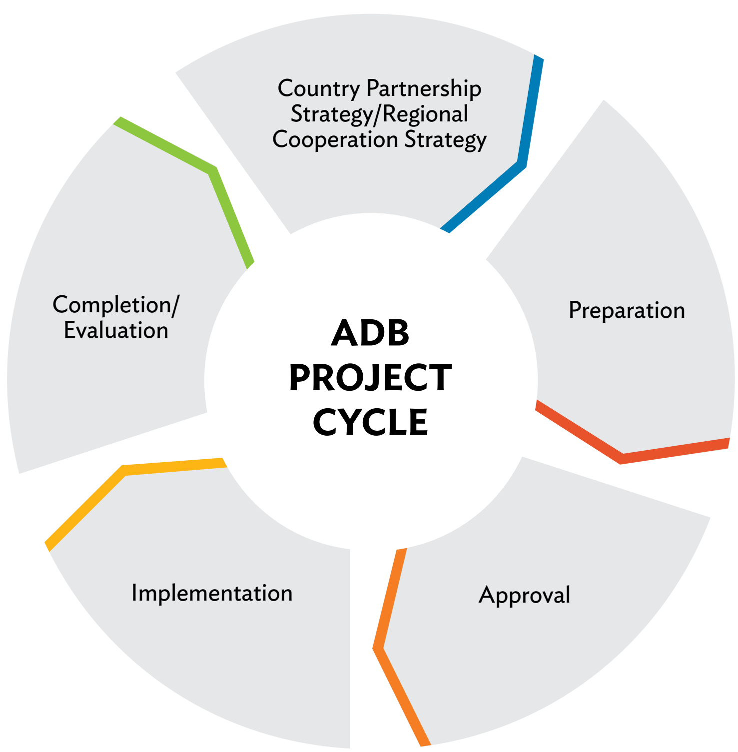


Source: Mäckel and Seidel. 2003.

NRM harnesses the functions of natural river systems to deliver climate-resilient and high-quality services at a lower cost while minimizing negative environmental and social impacts. Natural systems have always been recognized for their ability to deliver key services such as water supply, and flood and drought management. Although traditional hard infrastructure will continue to play a key role in providing services to societies in the face of growing environmental threats, this approach alone can no longer deliver the climate resilience and level of services needed to move forward (SEPA 2016). Combined approaches making use of high-level technical expertise to enhance and nourish natural services in combination with engineered solutions are gaining ground. In addition, the ongoing development of modeling tools and the availability of global data and rapid assessment methods enable water practitioners to understand better the key features of natural systems and to quantify the effects of intended interventions, in order to prepare plans and projects with a degree of rigor similar to that applied when planning traditional infrastructure.

This publication, *Guidelines for Mainstreaming Natural River Management in Water Sector Investments*, presents a step-by-step methodological approach intended to assist ADB project teams in systematically incorporating natural river management approaches into ADB water sector investments. The approach is meant to be embedded in the ADB project cycle (Figure 1 and Table 1) and to be consistent with ADB's water sector objectives and practices. The guidelines provide targeted advice in three distinct phases of the ADB project cycle: **project identification** (Section 4 of this publication), **project preparation** (Section 5), and **project implementation** (Section 6). The aim is to help project teams gain a better understanding of the international, national, and local development objectives and priorities of clients, and to support the identification of ways in which NRM approaches can contribute to the achievement of those objectives and priorities.

Figure 1: ADB Project Cycle



Source: ADB. 2021.

In the **project identification phase**, the guidelines provide project teams with a multidisciplinary checklist (Section 4, Table 8) to help them determine whether and how they can incorporate NRM into the project design. Guided by this checklist, the teams can assess NRM performance against a set of elements including technical, environmental, social, and economic aspects. The project teams will also be able to identify key design elements, as well as any further analysis needed to prepare the project in the next phase.

In the **project preparation phase**, the project teams will draw up the terms of reference for technical assistance to support the analytical work needed to determine whether and how NRM approaches can be incorporated into the project design. The guidelines provide general information and advice that can be useful in preparing the terms of reference.

Finally, in the **project implementation phase**, the NRM approaches will be implemented, and their results measured and reported (Section 6, Table 11). Key system indicators will be established to enable decision makers to adapt project implementation in light of emerging issues, and to inform stakeholders about the performance of the NRM approaches.

Table 1: Steps in Mainstreaming Natural River Management into ADB Water Sector Investments

Project Cycle	Main Activities	
Country Partnership Strategy	**Alignment** Align NRM approaches with international, national, and local development objectives	Alignment: Key Aspects
Project Identification Phase	**Screening** Identify the possibility of including NRM in project design	NRM screening tool Project Identification Phase: Key Aspects (Section 4, Table 9)
Project Preparation Phase	**Assessment** Assess the feasibility and impacts of including NRM in project design Describe the rationale for incorporating NRM approaches into the project, as well as the environmental, social, economic, and climate resilience impacts of such use	Technical Assistance TOR (Appendix 1) Project Preparation Phase: Key Aspects (Section 5, Table 10)
Project Implementation Phase	**Implementation** Establish implementation arrangements Identify and provide additional technical support and capacity building, if needed Monitor and communicate the results to decision makers, project beneficiaries, and communities	Project Implementation Phase: Key Aspects (Section 6, Table 11)

ADB = Asian Development Bank, NRM = natural river management, TOR = terms of reference.

Source: ADB. 2019b.

2 NATURAL RIVER MANAGEMENT

A History of River Management

People started channeling water thousands of years ago, and modifying its distribution across the landscape. Hard infrastructure interventions (Box 2) shaped societies by enabling people to live in places that would otherwise lack freshwater, and by making agriculture more productive. As technical capacity increased, hard infrastructure became a feature of water resources management, often focusing on increasing its supply over time and space.

Hard infrastructure is commonly based on assumptions about future climate, such as freshwater demand for domestic or industrial water use, and implemented solely with that perspective in mind (Cosgrove and Loucks 2015). However, as climatic conditions change and development requires multi-objective infrastructure, hard infrastructure may be somewhat limited in providing the desired short-term economic development, and natural system functioning and longer-term consequences may be overlooked. Effective water resources management draws on a multitude of disciplines, such as ecology, morphology, and hydrology, and embraces a multitude of functions. Single-function river management often results in problems in other functions, given the wide range of functions performed by rivers, both upstream and downstream.

The integrated water resources management (IWRM) concept was developed by water practitioners to address the complexities of water resources management. IWRM is aimed at integrating water quantity with water quality, and surface water with groundwater (World Bank n.d.-a). Integrated river basin management (IRBM) is commonly considered as the process that brings all users together and incorporates their needs into river basin management plans by defining their various objectives. Nowadays, flood management also takes different stakeholders and objectives into account through integrated flood risk management (Sayers et al. 2013).

These concepts advocate the inclusion of all functions in water resources management and regard the preservation of natural systems as one of these functions. Natural river management (NRM) (Box 2) places the natural system in a more central role as the main conveyor of all other functions. This perspective links well with the global trend of reconnecting with nature and recognizing its vital importance.

Box 2: Key Definitions

hard and/or gray infrastructure – built structures and mechanical equipment, such as embankments, reservoirs, groins, riprap, pipes, pumps, water treatment plants, and canals

green infrastructure – strategically planned network of natural and seminatural areas that are consciously integrated into spatial planning and territorial development, and are designed and managed to deliver specific infrastructure services and to provide a range of co-benefits in both rural and urban settings (European Commission n.d.)

nature-based solutions – “actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (Cohen-Shacham et al. 2016)

natural river management – iterative, science-based, and participatory water resources management focused on harnessing the functions and services of natural river systems while reducing hazard impact

See also the **Glossary** *included in this publication.*

Source: Browder et al. 2019.

The development of more natural approaches to watershed and river basin management coincides with recent trends in civil engineering that strive toward nature-inclusive design, such as the "building with nature" (de Vriend and van Koningsveld 2012) and "engineering with nature" approaches (Bridges et al. 2018). But in practice, river and coastal management is still dominated by hard infrastructure measures. In general, the construction of revetments, groins, and riprap is still the preferred option for mitigating erosion, and the building of dikes and levees, still the first line of defense against flooding (Bridges et al. 2013).

The implementation of hard infrastructure measures should be approached with caution. Their impacts on the natural system after construction may be large, and is often irreversible. For example, embankments disconnect wetlands and floodplains from sediment, freshwater, and nutrient input. Reduced sediment input results in decreasing land elevation, which heightens susceptibility to flooding when embankments are breached or removed (Auerbach et al. 2015). Upstream embankment and channelization reduce flood retention and increase runoff speed, thus amplifying downstream peak discharge (Acreman, Riddington, and Booker 2003). Mitigating these effects, which occur on large spatial scales, will require new and continuous investment

The Natural River Management Concept

River systems serve nature and people in numerous and vital ways. Natural river management is aimed at harnessing the natural functions of river systems to safeguard the services on which communities depend. NRM is defined in Table 2 as "low-interference management of rivers to optimize river use and reduce river-related risks," such as floods and droughts. The approach draws heavily on the ecosystem services (Silvis and van der Heide 2013), IWRM, and IRBM concepts (e.g., World Bank 2016b; WWF 2016 ; Pegram et al. 2013; Sayers et al. 2013). Therefore, it does not advocate natural solutions alone, but strives to focus river interventions on hot spots through a risk-based approach, and to optimize efforts and resource allocation by implementing a balanced set of interventions (Table 2).

Table 2: Main Characteristics of Natural River Management

Item	Description
DEFINITION	Low-interference management of rivers to optimize river use and to reduce river-related risks, while respecting the nature dynamics and flow of freshwater, sediment, and nutrients, and peoples' dependence on these at the basin scale
AIMS	Facilitate sustainable social and economic development by advocating a short- as well as a long-term perspective on effects on the natural river system Define optimal management strategies and set of interventions for long-term sustainable river management Give guidance on optimizing the engineering process to arrive at a coherent set of interventions that constitutes the best investment option in the whole basin for achieving the desired objectives

Source: ADB. 2019b.

The World Bank forecasts $22.6 trillion in global financing needs by 2050, solely for water supply infrastructure. Amid the tight budget constraints of governments, competing needs, and changes in the hydrologic environment, NRM can provide cost-effective solutions that yield multiple benefits, including monetary as well as nonmarket gains. But harnessing the valuable resources that rivers can offer and reaping the benefits for generations to come requires a shift in the river engineering paradigm. This shift entails a more central role for understanding the dynamics of natural river systems and confining engineered interventions to areas where a positive net benefit can be obtained through damage reduction and co-benefits gained.

In the context of a changing climate and heavily modified river systems, previous assumptions about the behavior of river systems no longer suffice and must give way to dynamic assumptions that are better suited to dealing with future uncertainties (e.g., climate change and socioeconomic development). Hard infrastructure built today may underperform sooner than expected but still influence the future development of the river systems to a large extent. NRM, on the other hand, can build resilience by introducing flexibility, as ecosystems can adjust on their own to a range of climatic conditions and require less capital investment for installation. The idea of making the best use of natural river systems and limiting hard interventions wherever possible has accordingly been gaining ground (Pegram et al. 2013).

Integrating river ecosystems and their functions into water sector projects can reduce costs and limit environmental impacts, while delivering many co-benefits. Though long advocated, making that move now rests on a more robust understanding of the advantages, technical characteristics, and climate resilience aspects of NRM, as well as its environmental and socioeconomic impacts, as a result of recent advances in knowledge, tools, and assessment methods. Moreover, global experience has shown that NRM can also facilitate access to new sources of financing. NRM approaches can be cost-effective and enhance service delivery, while at the same time empowering local communities and increasing infrastructure resilience and flexibility (Table 3).

Table 3: Opportunities Presented by Natural River Management

Project Aspect	Opportunities
TECHNICAL	More resilient infrastructure systems Multifunctional Simpler operation and maintenance options
SOCIAL	Communities empowered through participation Less water and air pollution Lower health care costs Social benefits, such as increased personal well-being
ECONOMIC	Lower implementation costs Multiple monetary and nonmarket benefits Greater access to alternative financing resources
ENVIRONMENTAL	Biodiversity protection Ecosystem conservation and restoration

Source: Browder et al. 2019.

3 ALIGNING NATURAL RIVER MANAGEMENT WITH DEVELOPMENT OBJECTIVES

Strategies and Plans

Project impacts does not manifest itself in a vacuum. Even if a project is designed for a single purpose and addresses a specific problem, how it interacts with other projects in the basin, existing or still being developed, will affect its performance and that of the river system. Many projects are designed without regard to other developments or to climate change effects. The long-term performance of realized infrastructure is therefore rather uncertain. For example, because the Ministry of Agriculture needs water for irrigation, regulating structures are built to direct water to irrigation canals. Sometimes, such regulating structures do not take climate change effects into account in their design, and may already be undersized when they are completed. If the structures are built downstream of an area facing flood risk, upstream flooding may worsen. To prevent flooding, the Ministry of Infrastructure commissions the construction of raised embankments. But these embankments will reduce the flood retention function of the floodplains and may increase flow velocity and intensify erosion. Poor coordination and piecemeal project development around rivers have cascading effects that create the need for continuous investment in those rivers to mitigate the unwarranted consequences of previous projects.

Understanding the development context of a project, and aligning its objectives with national development objectives, is vital to its success. It is also useful to know whether other water infrastructure projects in the area were considered in its development, and whether the cumulative impact of existing and planned water infrastructure is adequately understood. In addition, paying particular attention to the impacts of climate change and considering these impacts in project planning is likely to pay off in the long run.

Every country, as well as every project, is differently positioned and differently resourced. However, for any given project, a better understanding of its overall context—including ongoing development plans, donor involvement, stakeholder engagement, and information about the current and future state of national water systems—can generally be obtained from some key sources:

- National, territorial, and sectoral development plans. National, territorial, and sectoral development plans put forward a set of accepted development objectives and investment programs that are ideally aligned and establish the context for a project. If no development plan is available for a sector or a territory, more efforts will have to be exerted to ascertain the short-term and midterm aspirations and related investments relevant to the project context. For example, the project team may need to get information about the development objectives and portfolio directly from the sector or territory representative. For rivers in particular, river organizations or basin management authorities are sometimes created and will often have basin master plans that state the functions and development objectives of rivers.

- Country partnership strategy. To work with a developing member country, ADB and other donors usually define a medium-term development strategy and operational program, referred to as a country partnership strategy (CPS) by ADB, and as a country partnership framework (CPF) by the World Bank. The CPS, the CPF, and similar cooperation strategies devised by other donors are typically aligned with the country's development plan and poverty reduction goals, and with the priorities of other development partners. Civil society organizations and communities are often consulted to a significant degree in their preparation. These cooperation strategies impart a targeted understanding of the likely medium-term investments, the support provided by development partners to the country, and key stakeholders' views on the ongoing development process, and thus give context to the project.

- Climate action plans. Countries collect analytical work that helps define the state of understanding of climate change impacts on the country in combination with mitigation and adaptation strategies. These documents, consisting of intended nationally determined contributions and national adaptation plans, provide key insights into a country's progression toward understanding and addressing climate change impacts, the funding that is available to it, and key actors in the sector.

Objectives of Natural River Management

In many river basins, management is focused on a single function, or on several functions that are treated hierarchically (e.g., flood protection, irrigation, power generation, navigation). Measures are accordingly designed to provide quick fixes and short-term wins, instead of enabling sustainable and long-term resilience and development. For instance, dam and reservoir construction is a common approach to the problem of water shortages, and embankments are often built to combat flooding. However, in the long term and on a larger spatial scale, both measures reduce the resilience of people and the environment to climate change and new extremes of flooding and drought. The challenge is to facilitate social and economic development in a sustainable manner.

Natural river management can be instrumental in providing short- and long-term perspectives on the effects of development on the natural river system. Whether the river system can adequately provide its functions in the future can thus be determined. But first, clear objectives must be set with respect to the interests of the different stakeholders, river functions, and societal dependence on these functions—a process that ultimately results in minimizing future conflicts over water.

Goals and objectives derived from present strategies and plans set the stage for future projects. Clear objectives are more easily translated into measurable targets and performance indicators for projects. To avoid unintended consequences, NRM advocates several objectives related to river functions. The following river functions may be considered:

- Water supply. There must be enough freshwater supply for domestic, agricultural, and industrial purposes, and it should be of good quality.
- Navigability. Water-borne transport is slow but relatively cheap. It requires great depth of water and a relatively constant water level.
- Hydropower. Falling water is a source of renewable energy. However, the impact of dam building on the natural ecosystem and on other river functions is considerable.
- Food. This refers to the supply of fish and other river-related food sources.
- Nature and recreation. Natural rivers with healthy ecosystems have better water quality and are more resilient to drought and extreme discharge. Notably, disturbances in the natural river system can cause problems for other functions, such as fisheries. A more natural and greener river provides opportunities for tourism and recreation.
- Flood safety. The water levels in a river influence flood safety in the area. Any measure in the river or on the floodplain that accelerates or reduces current velocities can (directly) affect water levels, so this river function should always be considered.

River functions should be reflected either in the project objectives (Table 4) or in the impact assessment, where the impact of the project on specific functions should be evaluated.

Table 4: Some Flood Risk Reduction and Nature Conservation Objectives of Natural River Management Projects

River Function	Objective
Nature	Ensure flows of freshwater and sediment to sustain downstream livelihoods, ecosystem services, and biodiversity
Flood Safety	Decrease the vulnerability of people to flooding through targeted, sustainable, and long-term strategies for each river section
Other Functions	Accommodate other functions but minimize interference with natural river behavior as much as possible

Source: ADB. 2019b.

Differences between Natural River Management and River Engineering

Natural river management differs from traditional river engineering in several respects. Nature-based solutions (NBS) still lag behind in terms of reliability. With regard to risk reduction, the intent is to work toward the same level of performance for both river management approaches, but NRM and NBS are often tested differently. Although the NBS evidence base is rapidly growing, the implementation of these solutions is not yet standard practice and may require extra effort. On the other hand, NBS are considered more adaptive in that they can, for example, adjust by accreting sediment. However, this may also imply that full performance of these solutions will take a longer time to achieve, for example, if vegetation still has to be established. The most promising feature of natural approaches is their ability to deliver various ancillary benefits (co-benefits) in the form of ecosystem services. Generally, this tends to have a positive effect on poorer people, such as fishermen or farmers, who rely more directly on the availability of natural resources. Other differences between the two river management approaches are listed in Table 5.

Table 5: Hard Infrastructure and Natural River Management Approaches Compared

Consideration	Hard Infrastructure	Natural River Management
Reliability	Is able to mitigate mild to extreme hazards and can be tested under a wide range of conditions	Provides less certainty and evidence of performance under full range of conditions
Flexibility	May reduce the adaptive capacity of natural systems by blocking sediment transport; adaptation to other safety levels is often costly	Harnesses and builds on the natural capacity of ecosystems to adapt to changing conditions
Timescales	Is fully functional after construction, but has limited life span	May take time to adjust and become fully functional, but can then function for decades or even centuries
Spatial Scale	Generally exerts negative effects by amplifying flood peaks on a larger scale	Reduces flood peaks on a larger scale by increasing river length and width
Social Inclusiveness	Is more likely to hamper functions that benefit the poor, such as fisheries	Is likely to have positive effects on functions that benefit the poor, such as fisheries
Planning and Implementation	Requires land acquisition in areas where construction will take place	Needs more comprehensive planning at river-basin scale; land ownership or leases should be arranged
Capital Investment and Running Costs	Requires major capital investment but lower maintenance cost	Requires less capital investment but must be closely monitored, and replenished or upgraded
Implementation	Needs a good project implementation agency	Needs a good monitoring body and long-term commitment
Ownership	Is constructed and managed by the infrastructure department	Requires collaboration between the infrastructure and natural resources and environment departments
Co-benefits	Has no clear co-benefits	Benefits fisheries, nature, recreation, and aesthetics

Source: ADB. 2019b.

4 PROJECT IDENTIFICATION

Several aspects and components of river systems must be considered when identifying interventions in river systems in the project identification phase. The basin scale must be taken into account, to start with. A risk-based approach to identifying the priority areas for action in the basin is advocated. Special attention should be given to social inclusiveness, to ensure that resources are distributed equitably among the various social and income groups.

The risk-based approach begins with a risk assessment, which is the process of determining the severity of hazards, the likelihood of their occurrence, and the exposure and vulnerability of people and assets to those hazards (IPCC 2012; UNDRR 2015). To understand how the river system and its attendant risks may evolve in the future, a range of future scenarios can be studied. A scenario is commonly defined as a series of exogenous climatic, socioeconomic, or management-related events marked by uncertainty and affecting the status of the river system or its level of risk. The scenario analysis, in combination with the baseline scenario, shows where deviations from the defined objectives can occur. This type of analysis generates a more comprehensive grasp of the problem and the river system, and enables the development of low-regret and well-thought-out interventions (Table 6). The current and expected impacts of climate change and demographics on the basin must also be understood.

Project objectives can be defined, strategies formulated, and different sets of measures evaluated with the help of several frameworks of analysis (see Appendix 6). Such a stepwise approach can be used to ensure that alternatives go through a well-defined evaluation process, to guide project development and implementation. Project identification must

- take a comprehensive view of the river system and its functions (IRBM and ecosystem services);
- adopt a risk-based approach, considering hazards, exposure, and vulnerability, to guide the identification of investment hot spots;
- be participatory, to ensure stakeholder involvement; and
- compare different strategies, such as green and gray infrastructure measures, to evaluate the return on investment in comparison with gains from feasible alternatives.

Table 6: Main Problems in River Systems and Likely Causes

Problem	Possible Causes
Water Shortage	Decreased rainfall Unsustainable water demand Decreased groundwater storage Upstream measures
Flooding	Increased rainfall Changes in land use Narrow bridges or other obstructions People living on the floodplain
Erosion	Natural erosion (e.g., effect of river meandering) Infrastructure development Increased discharge Quarrying or mining

Source: ADB. 2019b.

A comprehensive understanding of the river system is an essential requirement, to make sure that the management actions taken and the evaluation of possible interventions are well-founded. Water, sediment, and nutrient flows support the existence of ecosystems and the performance of river functions. Interventions and their short- and long-term effects can be assessed if these processes and the characteristics of natural river systems are clearly understood. Distinctions can then also be made between autonomous or natural dynamics and anthropogenically induced changes in natural systems. System analysis, with and without proposed interventions, must be done, to provide a basis for defining the baseline scenario presenting the current state of the river system, as well as future scenarios covering a range of biophysical and socioeconomic conditions.

For river systems, the system analysis involves understanding the following:

- Geology of the area, to distinguish long-term geologic trends from short-term events, climate change effects, and anthropogenic factors;
- Hydrology and meteorology, to explain how fluctuations in rainfall lead to changes in water discharge and levels over time;
- Sediment transport and morpho-dynamics, to predict potential changes in erosion and deposition patterns and bed slope as sediment fluxes change, and the effect on the landscape; and
- Water quality and ecology, including key parameters, habitats, and species in the delivery of certain services, and also the status or health of ecosystems and water quality.

It is important to bear in mind that these matters cannot be dealt with separately. Geology determines the setting of a river basin, which in turn dictates the boundary conditions for all other processes. Hydrology encompasses all factors that govern the rates and patterns of river discharge, such as interception, infiltration, runoff, and evapotranspiration (Lininger and Latrubesse 2016). Hydrology (water flow), sediment transport, and morphology are very closely related. Erosion and sedimentation processes alter the morphology of the river, and thus the conditions that define water flow (hydrodynamics). Conversely, measures that change the flow of water have an effect on the transport of sediment, and hence on river morphology. On top of this feedback loop, ecology is influenced by and influences water flow, sediment transport, and morphology (Crosato 2007).

Rivers generally have three main sections—an upper, a middle, and a lower course (Table 7)—each one defined by specific characteristics (Nichols 2009). A generic description of the dominant processes and flows in each section, indicating the effectiveness of interventions, can therefore be prepared. For example, land use management through revegetation may be an effective measure for holding water and reducing sediment load and peak flows in the upper course, with its small, high-velocity streams, but less effective in the lower course of the river, which is usually flat and slow-flowing. Additionally, the different sections of a river are interconnected; for this reason, an intervention is likely to have a bearing on conditions upstream as well as downstream. Channelizing the midsection, for example, will increase flood peaks downstream (Calow and Petts 1993) (Table 7).

Understanding the behavior of the natural river system enables the study team to anticipate the effects of interventions at different spatial and temporal scales, and to monitor and assess these effects with the help of several indicators. For example, straightening and shortening a channel in the midcourse of a river can have varied impacts. Flow velocity is commonly higher in a straight channel, resulting in elevated flood peaks downstream, which may affect the presence and abundance of grazers, collectors, and other organisms that typically rely on lower flow velocity. These changes can have cascading effects, leading to heavily altered ecosystems in the midcourse. For fishing communities, the changes could be devastating; urban residents, on the other hand, would be only moderately affected. The analysis of the current river system and the proposed interventions will reveal the changes that could take place, their potential drivers, and the river functions that would be affected.

Table 7: General Characteristics of Different River Reaches

Reach	Hydrology	Morphology	Ecology
Upper Course (erosion zone)	High flow velocities Low discharge Small streams Intermittent wet and dry conditions	Steep, V-shaped valleys Rapids Waterfalls	Dense vegetation Coarse organic matter Shredders*
Middle Course (transport zone)	Medium flow velocities Higher discharge	Wider valleys Meanders Oxbow lakes	Less dense vegetation Sunlight for photosynthesis Fine organic matter Grazers** and collectors***
Lower Course (deposition zone)	Low flow velocities Influence of the sea	Wide, flat valleys Floodplains Deltas	Opaque water column Fine organic matter Collectors

* Shredders feed on coarse plant material and break this up into smaller pieces.
** Grazers feed on periphyton (a mix of algae, microbes, and bacteria dependent on light that accumulates on submerged surfaces such as stones, shells, and wood).
*** Collectors filter and catch finer organic matter.
Source: Vannote et al. 1980.

In the project identification phase, ADB normally provides a transaction technical assistance (TRTA) grant to help the government identify and prepare feasible projects. A number of initial analyses are carried out in the early stages of the TRTA study, including an initial poverty and social analysis. Hot spots for action and NRM approaches can be determined at this point, following an assessment of risk and of the bio-geomorphological system (Kondolf, Piégay, and Landon 2002). To come up with projects for a specific river basin, the study team must look into the situation in the basin to obtain a clear awareness of the balance between the different functions and of the region's dependence on the river. Generic objectives must be translated into explicit targets for the basin to suit its specific characteristics.

An NRM project identification checklist (Table 8) was developed to assist the project team in identifying possible NRM approaches. The checklist looks at four main aspects of project preparation: technical, environmental, social, and financing. It lists a series of questions aimed at generating enough information to determine the suitability of NRM approaches for a project. Project team members, together with the client countries, are encouraged to respond to these questions on the basis of existing knowledge and expert judgment. The checklist includes a reminder of the possibility that additional information may have to be gathered to understand better the applicability of NRM approaches to the project. TRTA funds can be used to generate this knowledge, either through a stand-alone study or as part of typical preparatory studies such as feasibility studies, environmental and social impact assessments, or technical assistance studies.

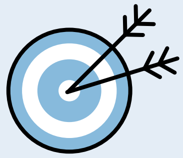
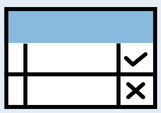
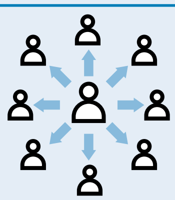
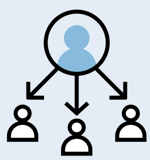
Draft terms of reference for a project preparatory technical assistance study can be found in Appendix 1.

Table 8: Project Officer's Checklist for Identifying Natural River Management Approaches

Project Aspects	Screening Questions	Response
Technical	Would NRM approaches lower the cost, increase the quality, or improve the long-term sustainability of the project?	
	Are NRM approaches included in territorial or sectoral development plans? Are there opportunities to mainstream NRM approaches into territorial and sectoral development plans?	
	Is the current project embedded in a territorial or sectoral development plan? What development objectives have been set for the river basin? Have NRM approaches been considered?	
	How will the project affect the performance of the natural system and the functions of the river? Is there room for improvement in quality, cost, or resilience through the use of NRM approaches? Can negative impacts be further mitigated?	
	What are the co-benefits of the NRM approach?	
	Does the NRM approach result in a more resilient project? Does the NRM approach increase project robustness or flexibility?	
Social	What is the land footprint of the NRM approach? What is the social impact? How are communities, ethnic minorities, and women affected? How are stakeholders affected by NRM approaches?	
	What are the social benefits of the project? How are communities affected by, or involved in the management of, the NRM approach? How is the project perceived by the local community?	
	Are there any local government agencies or civil society organizations to partner with to support the use of NRM approaches?	
	Does the project include schemes where stakeholders can benefit from NRM approaches and negative impacts can be reduced?	
	Will the NRM approach provide environmental or social co-benefits?	
Economic	Will the proposed NRM approach reduce, or at least not significantly increase, the cost of the project?	
	Can the NRM approach be justified in terms of costs, as well as in broader economic terms?	
	Is the NRM approach justified on the basis of monetary and nonmonetary benefits?	
	How does the NRM approach compare with traditional hard infrastructure in terms of costs and benefits?	
Financial	What are the available funding sources and are they secured over time? How diversified are the financing resources (e.g., public funding, private funding)?	
	Is there access to funds for NRM investments? Are there available grants or concessional loans from development partners?	
	Can the NRM approach be financed and sustained over time?	
Next Steps	Is additional information required to better determine whether NRM approaches are suitable for this project? Are there particular considerations that should be included in the TOR for the feasibility study and the ESIA?	

ESIA = environmental and social impact assessment, NRM = natural river management, TOR = terms of reference.
Source: Browder et al. 2019.

Table 9: Project Identification Phase—Key Aspects

	Identified **fit between NRM approaches and national, territorial, and sectoral development objectives**, and the **possible contribution of NRM to the achievement of international development targets** (e.g., Sustainable Development Goals, climate resilience targets)
	**Analysis of the natural system**, using best-practice analytical tools, and identified **potential performance improvements** resulting from the use of NRM approaches, as well as the **environmental, social, and economic impacts** of such use
	Identified **quality and resilience improvements and cost reductions** that can be obtained for the project through the use of NRM approaches
	Identified ways in which NRM approaches can **benefit affected communities and minimize adverse project impacts**, and ways of generating **early community involvement** in the project to facilitate information gathering and promote successful project implementation
	List of **relevant stakeholders** in the design and implementation of NRM approaches, together with the level of importance, influence, and capacity of those stakeholders; a **stakeholder strategy** for the design and implementation of NRM approaches
	Identified **potential for reducing costs and increasing the economic benefits** of the project through the use of NRM approaches; possible **environmental and social co-benefits**, to be studied further during project preparation
	An **institutional framework**, and identified **enabling institutional conditions** for implementing NRM approaches, as well as **institutional and legal constraints and opportunities**
	A **financing strategy** based on an evaluation of funding sources and efforts to obtain funding assistance

NRM = natural river management.
Source: ADB. 2019b.

5 PROJECT PREPARATION

Project Feasibility

A detailed justification for the project is drawn up in the project preparation phase. This involves listing and exploring various intervention strategies and consulting with relevant stakeholders. Assessing the impact of problems without action and after the implementation of the intervention strategies will give a first indication of project costs and return on investment. In this phase, objectives can be translated into quantitative or qualitative targets and performance indicators can be identified.

One of the main challenges when considering NRM approaches is generating the key information required to justify the project in terms of its technical and financial viability and suitability. For example, providing technical and quantitative details about how reforesting upstream watersheds will reduce downstream river runoff and what the return on investment will be in economic terms is still a challenge. Water professionals are working to tackle these challenges by developing case-study evidence, carrying out modeling studies for quantification, and doing on-site monitoring. Earth observation and geospatial information and other global data sources help in making rapid assessments of natural system behavior, identifying areas with high risk and hazard, and thus generating the first perception of present problems and causes, while also directing planning efforts and suitable intervention strategies. These tools can likewise shed light on the actual technical feasibility of both NRM and gray approaches, the cost–benefit analysis, and the environmental and social impacts (Appendix 2 lists global assessment tools). NRM approaches can and should be prepared with the same degree of rigor as gray infrastructure and be held to the same standards. Although knowledge of natural approaches may not be as well developed as that for hard infrastructure, the level of performance for priority objectives, such as flood risk mitigation, can or rather should be the same to allow for a fair comparison and evaluation of green versus gray strategies for reducing risk (Meyer, Priest, and Kuhlicke 2012).

Box 3: Steps in Cost–Benefit Analysis

- Objective. Description of the contribution of the NRM approach to a development objective.
- Define scenarios:
  - » **Baseline.** Development without measures, under autonomous development.
  - » **Climate change.** Development of projections of future flood risk with climate change.
  - » **Socioeconomic.** Development of risk projections with population growth.
- Definition of alternative strategies. Development of alternative strategies, consisting of distinct combinations of measures and variants.
- Definition of effects of alternative strategies. Identification, quantification, and monetization of impacts and co-benefits.
- Definition of costs of alternative strategies, including initial investment costs, operation and maintenance costs, and financing costs.
- Uncertainty/Sensitivity analysis. Identification of key uncertainties and risks, and analysis of their impacts on conclusions.
- Overview of costs and benefits. A general assessment of, and conclusions about, the costs and benefits of harnessing the functions and services of natural river systems while reducing hazard impacts.

Source: ADB. 2019b.

ADB generally uses TRTA funds to finance technical assistance aimed at generating the information required for project preparation. The technical assistance typically produces feasibility studies, cost–benefit analyses, environmental and social impact assessments, resettlement plans, and other safeguard-related documents (Box 3). The type of analytical work required to prepare a project with NRM approaches is case-specific, but key information that is normally needed can be defined. Appendix 1 provides draft terms of reference for activities carried out to explore the suitability of NRM that could be included in the terms of reference for the technical assistance.

The information obtained from the technical assistance study will be included in the technical assistance report. The report contains a comprehensive description of the project—its justification, output and activities, cost and financing, and implementation arrangements—and generally culminates with the President's recommendation. Although the content of the technical assistance report will depend greatly on the project context, a few general recommendations can be made on how to incorporate NRM approaches into the technical assistance report, and these are included below.

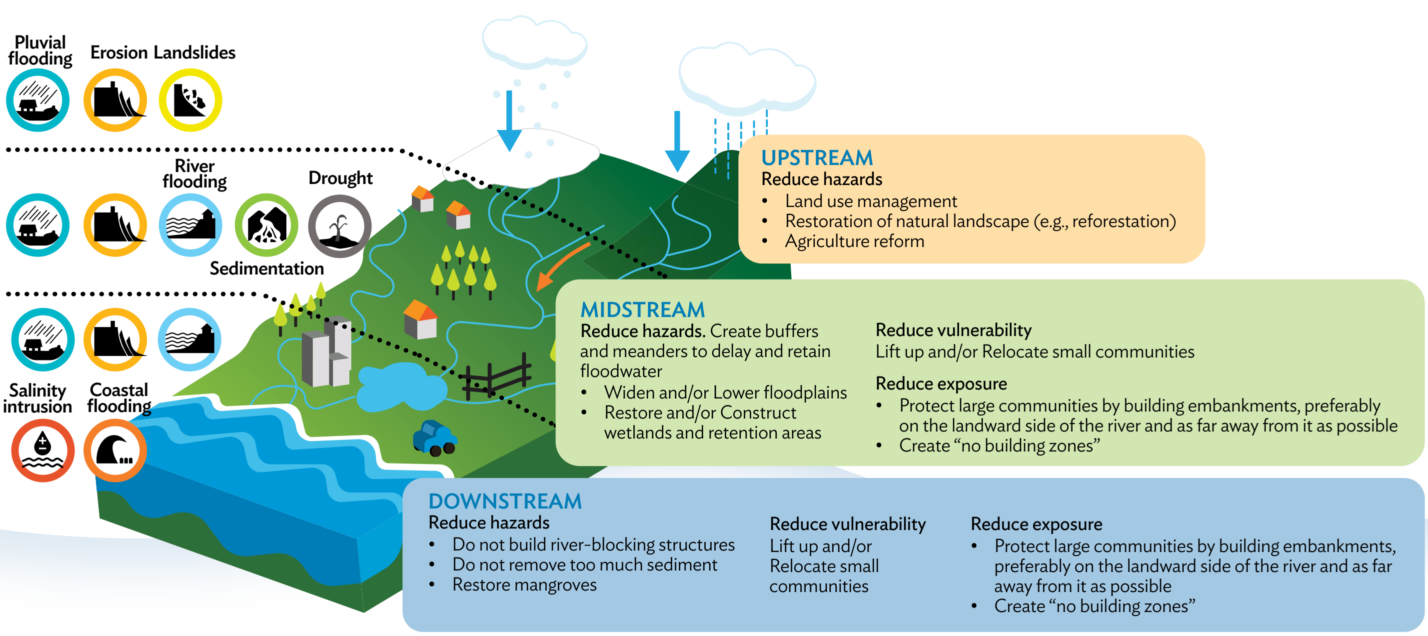
Listing of Interventions

Here, the most common river management measures for specific hazards are summarized. The hazards dealt with include floods, droughts, riverbank erosion, sedimentation in the river channels, and landslides. Both green and gray and structural and nonstructural measures are considered. For each measure, the river section (upper, middle, or lower course) where it would be most effective is indicated (Figure 2). In the upper basin, steep slopes make the area vulnerable to landslides and erosion. Recommended measures for this area, often with few inhabitants, focus on reducing the hazards through land use management. The middle basin is characterized by river meanders and reduced river velocities, causing sedimentation of eroded particles, impeding navigation activities, and possibly increasing flood risk. Communities are often built on riverbanks or on the floodplains, and are thus vulnerable to bank erosion and flooding.

Appropriate measures should pay particular attention not only to reducing the hazard but also to decreasing exposure and vulnerability, for example, through floodplain restoration and relocation of inhabitants. For the midsection, hard measures for reducing hazards, such as embankment hardening, channelizing, or flood wall construction, should have limited use as such measures are likely to increase flood hazards downstream, where population densities are often higher. Therefore, creating space for water retention and slowing current velocity is of utmost importance in the middle basin.

In the lower basin, coastal processes influence the system. Communities that settle close to river mouths are vulnerable to coastal and river flooding and erosion. Ideally, measures in this section should also be aimed at reducing hazard, exposure, and vulnerability. However, lack of space and a growing population may not allow for the relocation of people or for the use of more spacious green measures. Structural hard measures that limit damage may be a more logical choice here. But saving less space for natural dynamics will result in higher costs of hard measures to achieve a similar level of protection. Appendix 5 lists examples of nonstructural or structural and gray or green measures for the dominant hazards in each river section, which are described in detail below.

Figure 2: Natural River Management Measures for Generalized Hazards in Upper, Middle, and Lower River Sections



Source: ADB. 2019b.

Use of Natural Materials

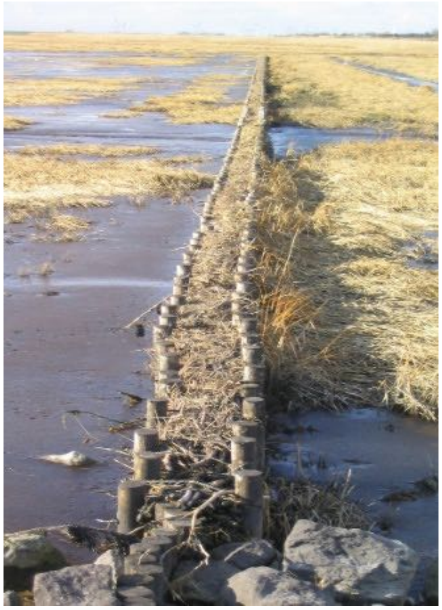
Measures can be implemented in several ways, and with different materials. For example, seawalls, levees, and embankments can be built out of concrete but can also be built from a sand base, with a clay top layer seeded with native grass species or covered with brush mattresses that promote the growth of native vegetation. Using natural and biodegradable materials can potentially result in solutions that can be locally sourced and have a minimal footprint. Logs can be anchored at the base of these embankments so they are protected from fast-flowing debris and also provide a habitat for fish. Another natural bank erosion mitigation measure is anchoring log piles along the banks, to collect drifting materials and build up bank protection. Permeable groins that reduce current speeds to mitigate erosion can be constructed with wooden or bamboo piles. Finally, in urban areas, combining functions, such as designing city parks to function also as storm water buffers or retention areas, can easily make urban spaces greener. Similarly, drainage systems can consist of concrete tubes and culverts but can also be designed to resemble natural creeks in form and function, as in the case of bioswales and wadis (see measures A5.11 and A5.12). Often, bioswales and wadis provide other benefits, such as water purification, biodiversity enhancement, and groundwater infiltration.

Levees and Seawalls Built with Different Materials

Seawall. A seawall in Surigao Del Norte, Philippines built of concrete (photo by ADB).

Dike. A dike made of earthen materials and covered with grass in a Flood Rehabilitation (Flood Control and Irrigation) Project in Bangladesh (photo by ADB).

Groins Made of Different Materials



Timber groins. In Schobüll, Nordfriesland, Germany (photo by Dirk Ingo Franke).

Principles of Infrastructure Development

Instead of placing embankments and levees on natural riverbanks, focusing levee trajectories on the presence of communities and vital infrastructure can enhance safety, lower costs, and conserve valuable natural systems. Infrastructure can be placed on the landward side of natural systems, instead of disconnecting floodplains from the river (Box 4). This way, natural systems, while still functioning properly, can complement gray infrastructure by reducing load on this infrastructure. This may result in lighter structures with lower crest levels. Basic principles for determining the trajectory of hard infrastructure can be summarized as follows:

- Flood protection infrastructure should be focused on areas with high exposure (many people or assets, or both).
- Infrastructure should be placed close to exposed assets and should be aimed at protecting people.
- If possible, a natural buffer should be maintained between infrastructure and hazards.
- Flood protection infrastructure needs to be closed. This often results in enclosed dike rings or units.
- A maintenance budget should always be included.
- Infrastructure should be planned in an integral manner, so that measures at one location do not have adverse effects on other areas (in terms of increased risks or other undesirable effects).
- A multi-hazard risk assessment should be carried out and the protection solutions provided should address all the causes contributing to the listed risks.

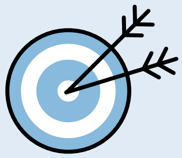
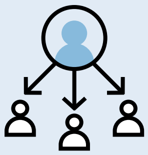
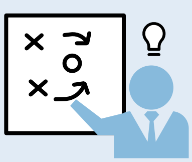
Box 4: Advantages of Situating Embankments Away from the River

Placing infrastructure on the landward side instead of on the high water line or on the river embankment results in several advantages:

- no load exposure under average conditions;
- less load under extreme conditions;
- possibility of building smaller, less robust structures;
- lower construction and maintenance costs (more adaptive to climate change and external changes in storm frequency);
- conservation of natural value;
- more room for natural landscape buildup with sand and mud; and
- less impact on adjacent (unprotected) sections.

Source: ADB. 2019b.

Table 10: Project Preparation Phase—Key Aspects

	**Justification for the use of the NRM approach** to tackle challenges or to achieve a development goal. The NRM approach should be linked to the country partnership agreement, as well as to other relevant ADB strategies or international agreements, such as the Sustainable Development Goals.
	List of **relevant stakeholders** in the NRM approach, including communities and development partners, and their level of importance and influence; a **stakeholder strategy** for implementing the NRM approach .
	List of **fundamental analysis conditions**, including base year, time horizon(s), economic discount rate, and system boundaries. This list should also include the tools and data sets that are available for use in system assessment, base case and reference case evaluation, identification and assessment of measures, and strategy development.
	A clear **cost–benefit analysis** of the NRM approach, including co-benefits and nonmonetary positive impacts. The economic benefits of using the NRM approach should be compared with those derived from the traditional focus on hard infrastructure. Co-benefits should also be compared, if not quantitatively then qualitatively. Attention should be given to social inclusivity. ADB specifies the discount rate to be used for different project types: 9% for most projects and 6% for social sector projects, projects targeting poverty, and projects with environmental benefits.
	The possibility of improving **access to alternative financial resources** through the use of the NRM approach.
	Clear **implementation arrangements** for the NRM approach. NRM approaches may require active community participation in the implementation phase.

Source: ADB. 2019b.

6 PROJECT IMPLEMENTATION

NRM entails a wide-ranging set of solutions that deal with social, environmental, engineering, and policy and institutional concerns. Their effective implementation requires the setting of boundary conditions, including clear implementation plans and provision for capacity-building support. As NRM is largely governed by the natural system, adequate observation and monitoring systems, as well as communication and policy feedback loops, must be in place to detect emerging issues and enable successful adaptation to those issues.

- Implementation arrangements. Adequate implementation arrangements will depend greatly on the existing institutional framework, as well as on the decision makers' appetite for developing an enabling institutional environment for NRM implementation. While a lead agency or group of agencies normally oversees the implementation of NRM approaches, the actual execution of those approaches may entail the participation of broader groups of government organizations, community groups, or civil society organizations, or the private sector. Roles and responsibilities should be clearly defined in the implementation arrangements. The implementing partners should be identified on the basis of their mandate and capacity and the adequacy of their resources, and capacity-building services should be made available to them if necessary.

- Infrastructure maintenance and management. Infrastructure maintenance and management often has no part in financing schemes. But both green and gray infrastructure will not function properly without regular maintenance and management. Financial resources for infrastructure maintenance should be included in the annual budget of the government.

Box 5: Steps in Monitoring

There are many approaches to monitoring, but they all generally include the following elements:

- defining the expected level of performance;
- assessing actual performance;
- identifying variations in performance (underperformance or overperformance); and
- establishing a process of communicating these variations to the appropriate authorities so that the implementation of the natural river management approaches can be adapted to suit emerging realities.

Source: ADB. 2019b.

- Monitoring and evaluation. Monitoring and evaluation activities are aimed at communicating the progress of NRM implementation (Box 5). The monitoring can relate to local, national, and territorial development plans, as well as to key international indicators (e.g., Sustainable Development Goals). Regular monitoring and evaluation of the implementation results is a way of continually improving the implementation process, and reporting on key results indicators to relevant stakeholders. A good indicator is normally specific, measurable, achievable, relevant, and time-bound.

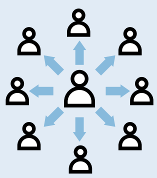
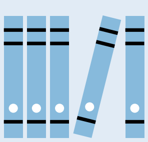
- Capacity building. As the practical applications of NRM continue to increase, implementing agencies, communities, development partners, and contractors are likely to need some degree of capacity building to gain a better appreciation of the NRM concept, its implementation, and the operation and maintenance of NRM approaches. If project size and resources would allow it, implementation could be accompanied with a capacity needs assessment, followed by the preparation of a capacity building plan that clearly identifies the required capacity and the strategy for building capacity for NRM implementation.

- Enabling institutional environment. NRM approaches can be better developed in an enabling environment, where institutions, information, and funding are available, and NRM approaches are routinely considered in their planning. NRM implementation can also be accelerated when accurate information about costs, benefits, and impacts is

available, as financers will then have an analytical basis for investing confidently. In addition, trust in NRM and nature-based approaches must be built among local stakeholders and within the engineering community. Resources must be set aside for monitoring performance in implementing these approaches.

- Stakeholder engagement and community involvement. In some instances, key aspects of the monitoring process are turned into communication products for relevant stakeholders such as policy makers or communities. Regular progress updates have an important role in keeping stakeholders and decision makers engaged. NRM approaches call for a high degree of participation by local communities as these are heavily involved in the project's long-term operations. These approaches could have a large footprint (e.g., watershed restoration), which could involve land acquisition or the modification of land use practices and livelihoods. But if they are properly designed and implemented, NRM approaches should generate social and environmental co-benefits. The correct application of social safeguards is also important in minimizing negative impacts and enhancing project benefits. Stakeholders can be actively involved in the monitoring program through community-based monitoring.

Table 11: Project Implementation Phase—Key Aspects

	**Project evaluation report**
	**Revisited social and environmental impact assessment**, including standards and safeguards relevant to the project
	**Regulatory frameworks,** to sustain and maintain the intervention
	**Implemented measures**
	**Monitoring and evaluation reports**
	**Publications,** to share lessons learned

Source: ADB. 2019b.

7 CONCLUDING REMARKS

Natural river management provides river basin managers, policy makers, and funding agencies with a vision and a rationale for deciding where to spend available funds while optimizing the use of natural functions of rivers. Concepts such as nature-based solutions and ecosystem-based adaptation are gaining popularity. The attention is primarily due to growing awareness of natural values and increased interest in sustainability. In river management, natural functions and community benefits are often lost with the implementation of engineered interventions. To keep a river resilient and adaptive, interventions must be more carefully considered, must integrate a multitude of functions, and must adopt a large time and spatial perspective.

Natural river management offers the flexibility to cope with future uncertainties associated with climate change and socioeconomic developments. This provides opportunities to learn by doing, to overcome technical complexity and the unpredictability of the river response to interventions. In the light of future climate change and related uncertainties, hard infrastructure is seen to be rather rigid and non-adaptable (van Wesenbeeck et al. 2016). Those uncertainties warrant the adoption of a long-term perspective that considers future infrastructure performance under a wide range of possible scenarios. No- or low-regret measures thus receive implementation priority. Nonstructural interventions and nature-based solutions are typically no- or low-regret measures (van Wesenbeeck et al. 2014). The case of the Rhine (Section 1, Box 1) perfectly illustrates this point. If future impacts and the cost of mitigation had been foreseen, channelization might not have been the first choice.

Natural river management provides the basis for starting a planning process that proactively chooses where to intervene, in accordance with a risk-based approach, and where to let the river follow its natural course. By presenting the natural river management concept, and providing an overview of natural river processes and possible measures, this publication aspires to open the door to a well-informed dialogue on such measures. There are basic guidelines on more natural management of rivers (WWF 2016; World Bank 2017a), but more quantitative design criteria for different ecosystems are still lacking. For proper uptake within the community of civil engineers, ecosystems must be merged into standard practice. Traditional civil engineering already advocates taking the natural system into account. Natural river management merely puts the natural system and the long-term sustainability of approaches at the core of project initiation and development. Natural river management aims to give guidance in optimizing the engineering process to achieve a coherent set of interventions that constitute the best investment option in the whole basin for attaining the desired objectives. It therefore aims to define the best set of interventions for long-term sustainable river management.

In practice, natural river management provides arguments based on natural river functioning to refrain from actions with adverse side effects on the upstream and downstream reaches, and to cease actions that will not be sustainable because of lack of long-term funding for operation and management. For example, while the construction of reservoirs is common practice in Southeast Asia at the present time, in the United States and Europe, where the practice was also widespread, authorities have begun to rethink dam projects, remove dams, and restore rivers. This reversal mainly occurs when projects reach the end of their lifetime. Dams and their functions have become obsolete, repair is too costly, and their social and environmental impacts is now considered unacceptable (O'Connor, Duda, and Grant 2015).

Before a decision is made to construct a dam, energy demand and the water shortage problem should be carefully studied. Often, water shortages are largely due to unsustainable water use practices, water-intensive agriculture in inappropriate locations, and deforestation and loss of retention capacity in the basin. In addition, constructing reservoirs in rivers will increase demand and make people more dependent on a surplus of water, and more vulnerable to drought (Di Baldassarre et al. 2018). Similarly, as has been shown in the past, a focus on regulating rivers can become an expensive choice. Taking a long-term perspective and using an approach that is centered on the functioning of the natural river system and the people that live near rivers can prevent mistakes and avoid future costs. We can then all work together toward implementing more sustainable infrastructure.

APPENDIXES

APPENDIX 1: DRAFT TERMS OF REFERENCE FOR TECHNICAL ASSISTANCE

Objective. The objective of this technical assistance activity is to determine whether the proposed Project can benefit from natural river management (NRM) approaches. NRM has been shown to hold the potential for increasing the benefits of projects of this type, generating co-benefits, and improving environmental and social outcomes. The results of this activity will be used in further preparing the proposed Project. The Consultant is expected to deliver the following results, among others:

- Clearer understanding of how incorporating NRM approaches into the proposed Project fits within overall national development objectives, international standards such as the Sustainable Development Goals, and other territorial and sectoral development plans, and the identification of value added.
- Basic understanding of the state of the natural functions of the basin and/or coast, as well as related trends, opportunities, and challenges, and the linking of this information with the process of identifying possible opportunities to use NRM approaches.
- Identification of further information and/or knowledge needed to make informed decisions on NRM approaches.
- Understanding of ongoing and future development, including infrastructure, in the basin and/or coast and its impacts on the natural river system.
- First assessment of the impacts of incorporating NRM approaches into the proposed Project.
- Understanding of the economic impacts of NRM approaches on the proposed Project, including economic costs and benefits, investment and operation and management costs, and co-benefits.
- Identification of additional financing resources available to fund the NRM approaches.
- Taking all of the above into consideration, identification and proposal of options and ultimately design of an NRM approach to be incorporated into the proposed Project.

Proposed positions

Team Leader or Water Resources Manager

- Oversee and coordinate the generation of information and ultimately the design of NRM approaches, if appropriate, and their incorporation into the proposed Project.
- Synthesize information generated by the technical assistance team and distribute it appropriately among the members of the team, the government, the Asian Development Bank (ADB), and other relevant stakeholders.
- Organize stakeholder consultation initiatives and support the government and ADB, where relevant, in implementing those initiatives.
- Make recommendations regarding whether NRM approaches could be incorporated into the proposed Project, and how.

Hydrologist or Modeler

- Design models or run existing models to simulate the river basin and/or coastal zone baseline, ongoing and planned developments, and the proposed NRM approaches.
- Design models or run existing models to simulate the impacts of climate change on the proposed NRM approaches as well as the overall river or coastal system.
- Produce flood and drought maps for current and future scenarios.

- Disseminate the modeling results in a format agreed on with other members of the technical assistance team, to serve as input to further economic, environmental, social, and resilience analysis.
- Present the modeling results to the government, ADB, and other potential stakeholders, in a format relevant to them.

Civil Engineer or Water Resources Manager

- Identify and design NRM approaches that can be incorporated into the proposed Project.
- Assist other members of the technical assistance team in analyzing the economic, environmental, social, and resilience impacts of the proposed NRM approach.
- Prepare standard designs, specifications, and drawings, taking into consideration the input of the other members of the technical assistance team.

Economist

- Identify and estimate the costs and benefits of the NRM approaches and their impacts on the overall performance of the proposed Project.
- Identify co-benefits generated by the NRM approach.
- Apply a cost–benefit and/or cost-effectiveness analysis of the selected NRM approach, if needed.
- Recommend improvements on the basis of the cost–benefit analysis and/or cost-effectiveness analysis, as well as any identified co-benefits.

Environmental Specialist

- Together with the Team Leader and the Civil Engineer, identify the main natural functions of the basin and/or coast, and the associated trends, opportunities, and challenges.
- Together with the Team Leader and the Civil Engineer, identify opportunities to use NRM approaches.
- Identify the climate scenarios and parameters of concern for the proposed Project, and the degree of certainty, assumptions, and limitations of the existing information.
- Review the proposed NRM approaches and their potential environmental impact, and recommend suitable approaches and improvements in the proposed Project.
- Review the proposed Project design, including the NRM approaches, and determine the environmental impact.

Social Specialist

- Review the proposed NRM approaches and analyze the potential social impact; recommend approaches and improvements in the proposed Project.
- Review the proposed Project design, including the NRM approaches, and determine the social impact.

Note: Depending on the specific situation and problem at hand, roles, tasks, and activities may need more elaboration and emphasis.

APPENDIX 2: GLOBAL TOOLS FOR QUICK-SCAN TECHNICAL FEASIBILITY ASSESSMENT

Technical Tools	Information and Links	Assessed Hazards	Pros (+) and Cons (–)
Aqueduct Water Risk Atlas	A compiled map with an overall water risk index. https://wri.org/applications/aqueduct/water-risk-atlas/	Drought and other water-related hazards	– Low resolution
Aqueduct Global Flood Analyzer	River flood risks for different protection levels. https://floods.wri.org/#/	Fluvial flooding	– Not all basins included
Aqua Monitor	Surface water changes along shorelines and in rivers. Assessment of river dynamics and erodible river corridor. https://aqua-monitor.appspot.com/	Erosion	– Quality and period depend on availability of satellite images
MI-SAFE	Influence of coastal vegetation in reducing wave impact. https://fast.openearth.eu/	Waves	– Surges not included

APPENDIX 3: ECONOMIC TOOLS

Economic Tools	Description	Considerations and Requirements	Pros (+) and Cons (–)
Cost-effectiveness analysis (CEA)	Effectiveness is compared: to what extent does an option contribute to the achievement of the defined goal? • Investment costs of each measure are estimated (quick scan: order of magnitude, based on data or expert judgment). • A ratio of the effect obtained for a unit of money given: e.g., how much flood risk protection is delivered for $1?	One **single, clear goal is defined** for the project and the **financially** most attractive alternative must be found. First screening of measures	– Additional benefits of a measure might not be taken into account
Life cycle costing (LCC)	All costs of the asset over its entire lifetime, as well as operation and maintenance and, if relevant, breakdown costs, are compared over a fixed (long) time horizon, e.g., 100 years	The costs of the solution should be known.	
Multi-criteria analysis (MCA)	Semiquantitative analysis and scoring of performance of measures according to multiple criteria based on expert and/or stakeholder opinions (e.g., natural habitat creation, flood risk reduction, costs, cultural heritage preservation)	**Multiple criteria or effects** must be considered. **Increased stakeholder engagement and support** is needed.	+ Very good for engaging stakeholders and increasing support – Qualitative, but relatively subjective, approach
Cost–benefit analysis (CBA)	Project costs are compared with welfare effects and/or benefits. These are determined in relation to a reference situation that includes autonomous development. If possible, all effects should be expressed in monetary terms for comparability. In a quick scan, standard numbers from other studies in similar contexts can give a first insight into the value of certain investments. A full CBA requires more detailed analysis, including the local context, for a limited number of spatially explicit designs, as well as sensitivity analysis of results.	More objective than MCA: all effects considered from the viewpoint of impact on welfare	+ Quantified, more objective overview of costs and benefits; increased comparability – False sense of security through quantitative results

APPENDIX 4: OVERVIEW OF RIVER MEASURES

These measures are described in more detail in Appendix 5. The number stated after each measure is its subsection number in that appendix.

Measure	River Section	Structural/ Nonstructural	Green/Gray	Co-benefits
FLOODING				
Meander restoration (A5.1)	Middle	Structural	Green	• Decreased erosion • Improved water quality • Natural value • Aesthetic value
Side channel creation/Revival (A5.2)	Middle/Lower	Structural	Green	• Decreased bed degradation • Natural value
Floodplain widening/Restoration (A5.3)	Middle/Lower	Structural	Green	• Natural value • Aesthetic value • Decreased bed degradation
Floodplain lowering (A5.4)	Middle/Lower	Structural	Green	• Decreased bed degradation • Natural value
Channel deepening (A5.5)	Middle/Lower	Structural	Gray	• Potential flexibility • Increased conveyance capacity
Embankments (A5.6)	Urban/Middle/ Lower	Structural	Depending on execution	• Natural value • Constant fairway • Aesthetic value
Partial/Full embankment removal (A5.7)	Urban/Middle/ Lower	Structural	Depending on execution	• Natural value • Decreased erosion • Aesthetic value
Summer and winter dikes (A5.8)	Middle/Lower	Structural	Gray	Fertile sediment deposition
Wetlands and mangroves (A5.9)	Middle/Lower	Structural	Green	• Recreational value • Natural value • Water quality
Dam/Reservoir construction (A5.10)	Upper/Middle	Structural	Gray	• Water supply • Electricity • Navigability
Urban drainage systems (A5.11)	Urban	Structural	Depending on execution	• (Possibly) Green option • No-regret option
Wadi's/Bioswales (A5.12)	Urban	Structural	Green	• Decreased urban heat effect • Aesthetic value
Construction of retention areas (A5.13)	Urban/Middle/ Lower	Structural	Depending on execution	• Natural value • Recreational value • Water storage • Decrease urban heat effect
Building codes/Zonation (A5.14)	Urban	Nonstructural		• Natural value • Recreational value
Early warning system (A5.15)	All sections	Nonstructural		No-regret option
Removal of obstacles (A5.16)	All sections	Structural	Green	Natural value

Measure	River Section	Structural/ Nonstructural	Green/ Gray	Co-benefits
Lifting up/Relocation of Communities (A5.17)	Middle/Lower	Structural	Gray	• Natural value • Recreational value • Water supply
Land use management (A5.18)	All sections	Nonstructural		Natural value
DROUGHT				
Dam and/or Reservoir construction (A5.10)	Upper/Middle	Structural	Gray	• Water supply • Electricity • Navigability
Wadis and/or Bioswales (A5.12)	Urban	Structural	Green	• Decreased urban heat effect • Aesthetic value
Construction of retention areas (A5.13)	Urban/Middle/ Lower	Structural	Depending on execution	• Natural value • Recreational value • Water storage • Decreased urban heat effect
LANDSLIDES				
Land use management (A5.18)	All sections	Nonstructural		Natural value
Restoration of natural forests (A5.19)	Upper	Structural	Green	• Natural value • Recreational value
EROSION				
Meander restoration (A5.1)	Middle	Structural	Green	• Decreased erosion • Improved water quality • Natural value • Aesthetic value
Partial and/or Full embankment removal (A5.7)	Urban/Middle/ Lower	Structural	Depending on execution	• Natural value • Decreased erosion • Aesthetic value
Floodplain lowering (A5.4)	Middle/Lower	Structural	Green	• Decreased bed degradation • Natural value
Wetlands and mangroves (A5.9)	Middle/Lower	Structural	Green	• Recreational value • Natural value • Water quality
Land use management (A5.18)	All sections	Nonstructural		Natural value
SEDIMENTATION				
Channel deepening (A5.5)	Middle/Lower	Structural	Gray	• Potential flexibility • Increased conveyance capacity
River training with groins (A5.20)	Middle/Lower	Structural	Gray	
River training with longitudinal dams (A5.21)	Middle/Lower	Structural	Gray	• No flow blocking during periods of high discharge • Improved natural value compared with groins (A5.20)
Channelization and/or Normalization (A5.22)	Middle/Lower	Structural	Gray	• Increased fairway depth • Increased conveyance capacity • Land gain

APPENDIX 5: NATURAL RIVER MANAGEMENT APPROACHES—SOME EXAMPLES

A5.1 Meander Restoration

Driver: Flood retention
Where: Middle course

Functions
- Flood safety
- Nature preservation

Co-benefits
- Decreased erosion (restored sediment balance)
- Aesthetic value
- Improved water quality

Disadvantages
- Need for space
- Need for enforcement

Detailed description
A river meander is a U-bend formed by the river, allowing it to decrease water velocity. In the past, river meanders were cut off to straighten rivers and facilitate shipping or gain land for cultivation, among other reasons. Meander restoration can involve creating a new meandering course or reconnecting cut-off meanders. As the length of the river increases, its storage capacity also increases; flow velocities, on the other hand, decrease, thus lowering downstream flood levels. Meander restoration often also has a positive effect on sedimentation, slowing down bed degradation, as well as on biodiversity, by providing a range of aquatic and riparian landscapes (Noviandi, Kaswanto, and Arifin 2017).

Short-term effects
Meander restoration increases buffer capacity, thus lowering flood levels. Because of the increased river length, the water level slope decreases.

Long-term effects
The decrease in slope leads to lower flow velocities and increased sedimentation. In time, the river will adjust to the new slope by raising its bed levels. This will also cause water levels to rise. Dredging may eventually be needed to keep riverbed and water levels low.

Operation and maintenance requirements
Restored meanders generally do not require maintenance. However, a meander that is artificially created may need maintenance to keep the entrance open (dredging). Before construction, it is advisable to do research into natural river behavior.

Examples
- Floodplain restoration and reconnection of oxbows in the Morava River, Slovak Republic
  European Commission (2015b)
- Restoration of winding streams in the Shibetsu River, Hokkaido, Japan
  Hokkaido Regional Development Bureau, Japan (n.d.)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$	+

A5.2 Side Channel Creation/Revival

Driver: Flood retention
Where: Middle course and/or Lower course

Function

Flood safety

Co-benefits

- Decreased bed degradation
- Possibility of restoring natural values

Disadvantage

Need for space

Description of the measure

A side channel or bypass is constructed or reconnected to increase local discharge capacity. This measure is especially effective in reducing local water levels, and when no storage is added, the direct downstream effects are marginal. A side channel requires space, but it also offers opportunities for recreation or the restoration of natural values.

Short-term effects

A side channel effectively increases discharge capacity. Therefore, local flood levels decrease. The effect on downstream water levels, however, is negligible.

Long-term effects

As with the construction of an extra channel, flow velocities generally decrease, and certain locations become subject to increased sedimentation. This will most likely occur at the entrance to the side channel. Also, a sedimentation front will develop in the main channel at the upstream end of the measure and will progress in a downstream direction. Dredging may be required to prevent an increase in bed levels. Sedimentation in the side channel itself is often prevented through the construction of a (submerged) sill that blocks sediment supply.

Operation and maintenance requirements

Maintenance requirements depend greatly on the construction method.

Examples

- Construction of a side channel at Nijmegen Lent, Netherlands
  Ruimte voor de Waal Nijmegen (Room for the River Waal Nijmegen) (n.d.-b)
- Reconnection of a side channel in the Danube River, Hungary
  REFORM (2010b)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (-, 0, +)
$$$	$	+

A5.3 Floodplain Widening/Restoration

Driver: Flood retention and/or Nature preservation
Where: Middle course and/or Lower course

Function
- Flood safety
- Nature preservation

Co-benefit
Aesthetic value

Disadvantages
- Need for enforcement
- Need for maintenance
- Need for space

Description of the measure
Floodplains are areas that are regularly flooded by the river, and thus provide a buffer for excess water during periods of high discharge. Many floodplains have been taken over by urban development or agriculture. Others have been disconnected from rivers by channelization. Restoring floodplain width increases buffer capacity and surface roughness, leading to the reduction of peak flows and the detention of peak discharge. Wider floodplains also increase the natural value of the river by giving more room to floodplain forests and associated species. This measure is often less suitable in urban areas, where space availability is low. In agricultural areas, on the other hand, land acquisition costs may be high. But floodplain reconnection has been used in combination with certain types of agriculture in some parts of the world to reduce flood risk and improve agriculture productivity, and may have similarly positive effects elsewhere.

Short-term effects
Local floodplain widening increases local discharge capacity and thus lowers local water levels during periods of high discharge. The exact level of discharge at which the effect becomes visible depends on the level at which floodplains are naturally flooded ("bankfull" discharge). The measure can be combined with floodplain lowering (A5.4).

Long-term effects
Over time, the lowering effect on the water level may decrease on account of sedimentation upstream of the widened floodplain. Floodplain widening reduces discharge through the main channel, resulting in the long term in sedimentation (bed level increase) in the channel, and therefore also some increase in water levels upstream. Whether or not the net effect is a lower water level throughout the reach depends on local characteristics and requires research before the measure is implemented.

Operation and maintenance requirements
Floodplain widening often involves the reversion of urban or agricultural areas to a floodplain function. Enforcement may be needed to maintain that function.

Examples
- Restoration of floodplains in the River IJssel, Netherlands
- Floodplain restoration in the Danube River, Hungary
  Interreg–Danube Transnational Programme, Hungary (n.d.)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$	+

A5.4 Floodplain Lowering

Driver: Flood retention
Where: Middle course and/or Lower course

Function
Flood safety

Co-benefits
- Decreased bed degradation
- Possibility of restoring natural values

Disadvantages
- Need for regular maintenance
- Need for space

Description of the measure
Lowering the floodplain increases local discharge capacity, and thus decreases local and upstream flood levels. If the storage area also increases as a result of the use of this measure, downstream water levels may decrease as well. However, this depends on the nature of the measure and the roughness of the floodplain.

Short-term effects
Because the local discharge capacity or the storage capacity increases, there is a reduction in local water levels at high discharge. Downstream water levels may also decrease, depending on the increase in storage capacity. Additionally, decreased erosion (or even deposition) occurs in the main channel. During periods of high discharge, more water is conveyed over the floodplains, decreasing erosion in the main channel bed and increasing sediment deposition on the floodplain.

Long-term effects
This measure increases sedimentation on the floodplain and decreases erosion or even deposition in the main channel. There are two main long-term effects:

- The floodplain level increases again. The rate of change depends on factors like the amount of floodplain lowering, floodplain roughness, sediment load in the river, and "bankfull" discharge (the flow that fills a channel without flooding). The bankfull discharge increases and discharge capacity decreases again over time.
- The main channel bed level stabilizes or increases. Local sedimentation (often at the upstream boundary of the measure) is unfavorable to navigability as water depth decreases, and dredging may be required to restore the original water depth. Over time, the sedimentation front will spread downstream, raising the bed level and water level.

In other words, the river will often restore itself to its original state. Regular maintenance will therefore be required to ensure a decrease in water level.

Operation and maintenance requirements
Since the river deposits sediment at its floodplains, floodplain lowering will require regular maintenance. Its frequency will depend on the floodplain roughness, the amount of sediment carried by the river, and the amount of floodplain lowering itself.

Example
Floodplain lowering in Meers, Meuse River, Netherlands
REFORM (2010a)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$$	+

A5.5 Channel Deepening

Driver: Navigability and/or Flood retention
Where: Middle course and/or Lower course

Functions
- Navigability
- Flood safety

Co-benefit
Potential flexibility

Disadvantage
Need for regular maintenance (dredging)

Detailed description
Local channels are deepened mostly to increase the water depth at navigation bottlenecks. This measure can be used to lower flood levels, but this is not common practice. Maintaining a lowered bed level over a large extent results in upstream and downstream erosion, endangering the stability of upstream structures, and lowering groundwater levels. Channel deepening can be achieved through dredging or through the installation of a fixed bed layer in an outer bend, to deepen the inner bend. Dredging is a relatively cheap and flexible measure, but installing a fixed layer is costly and this channel deepening measure is inflexible. On the other hand, while maintenance will be needed to keep the bed at a lower level, as the river will restore its local sediment balance by filling up the deepened part, the fixed layer is not likely to require much maintenance effort, but it can cause navigation problems when water levels are low. Whether or not the implementation of a fixed layer will have the desired effect will depend on local river geometry and sediment transport characteristics.

Short-term effects (of continuous dredging in an alluvial river)
Water depth in the deepened stretch increases, allowing larger ships to pass. Sedimentation in the deepened part also increases, slowly raising the local bed level again. At the same time, bed erosion increases both upstream and downstream of the deepened stretch.

Long-term effects (of continuous dredging in an alluvial river)
If dredging is continuous, the upstream and downstream riverbed degrades until the sediment balance is restored. Ultimately, upstream erosion will result in a lowered riverbed and lowered water levels. The length of the affected river stretch can be calculated on the basis of representative discharge, bed slope, grain size characteristics, and flow velocity. It should be noted that lower river levels will also result in lower surrounding groundwater levels, which may be unfavorable to agriculture and nature.

Operation and maintenance requirements
A river main channel can be deepened in a flexible way (through dredging) or permanently (through the installation of a local fixed layer). If dredging is used, regular maintenance dredging will probably have to be done to ensure that the bed level stays below the required minimum bed level.

Examples
- Jakarta Emergency Dredging Initiative in Indonesia
  World Bank (2014)
- Longitudinal dams in the Waal River, Netherlands (see A5.21)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$	$$	0

A5.6 Embankments

Driver: Erosion mitigation and/or Flood protection
Where: Middle course and/or lower course and/or urban

Functions
- Flood safety
- Erosion reduction

Co-benefits
- Possibility of restoring natural values
- Aesthetic value
- Constant fairway

Disadvantage
Possibility of increased degradation

Description of the measure
A riverbank represents the boundary between the main channel and its floodplains, which is regularly breached under high flow conditions. Riverbanks have a dynamic location and shape, determined by natural sedimentation and erosion processes. Rivers are often embanked to protect adjacent lands from flooding as well as erosion and to provide a fixed river channel for navigation. While restoring natural dynamics through the partial or full removal of built embankments (A5.7) is a favorable option, alternative nature-based bank solutions, such as earth banks, wood stabilization measures, or the introduction of certain grass species, may be considered if strong constraints (lack of space) exist. A more flexible stabilization solution is the "falling apron" approach, which entails dumping (stone) blocks on the bank slope. When the bank is eroded, the blocks fall down the slope, automatically forming a protective layer to inhibit erosion. For flood protection, constructing summer and winter dikes (A5.8) is a more flexible solution to consider.

Short-term effects
Erosion or overflow of riverbanks is limited. A "soft" embankment will improve habitat conditions. If vegetation develops on the bank, this will be an additional (natural) inhibitor of erosion.

Long-term effects
Bed erosion in the main channel often increases, depending on the design of the bank fixation. This may threaten the stability of the new bank fixation, especially if a hard solution is chosen.

Operation and maintenance requirements
The maintenance requirements of bank protection depend on the location and type of the protection. In general, a hard (concrete) protection is more vulnerable to toe scour, so regular inspection and maintenance is needed. Softer solutions, such as wooden sheets or permeable riprap, are just as vulnerable but cheaper to maintain or replace. For nature-based solutions, maintenance requirements are often less, especially for natural riverbanks, where vegetation can develop and root systems increase soil strength against erosion (Rinaldi and Darby 2008).

Examples
- Wood-weaving stabilization in the Hermance River
  European Commission (2015a)
- Fixed embankments in the Los Angeles River
  Los Angeles River Revitalization, California, US (n.d.-b)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	0

A5.7 Partial/Full Embankment Removal

Driver: Flood retention
Where: Upper and/or Middle and/or Lower course

Functions
- Flood safety
- Nature

Co-benefits
- Decreased erosion (restored sediment balance)
- Aesthetic value

Disadvantage
Possibility of higher bed levels

Description of the measure
Artificial embankments are built along rivers to prevent flooding and erosion of adjacent lands. Fixing the banks limits the natural meandering of the river, which would lead to river degradation, increased flow velocities, and decreased biodiversity. Forcing the river into a smaller main channel will increase riverbed incision and lower river and groundwater levels (REFORM 2015b). Lateral connection to the floodplains is inhibited by embankments, leading to a lower storage capacity.

Partially or fully removing embankments restores the natural dynamics of rivers. Diverting overflow away from valuable assets on the embanked riverside is an additional benefit. Bank removal is a prerequisite for other measures, such as re-meandering or reconnecting floodplains (A5.3). "Green alternatives" for present embankments, such as natural sloping green banks, are preferable, but gray embankments may be unavoidable if there are strong hydrologic constraints.

Short-term effects
Removing (high) embankments increases storage, thereby lowering water levels downstream. The increased variety of flow regimes allows different habitat types to develop, improving the natural as well as the aesthetic value of the river. But removing embankments also results in a wider and more shallow river, unfavorable to navigation.

Long-term effects
Earlier flooding of the floodplains decreases bed erosion during periods of high discharge, when erosion is often most severe. The bed level stabilizes or even increases as a result. In the long term, increased deposition may raise water levels locally.

Operation and maintenance requirements
Increased sedimentation may create a need for regular dredging. How often this will have to be done will depend on local characteristics.

Examples
- Upper Drava River in Austria
  REFORM (2015a)
- Moizari River in Japan
  Foundation for Riverfront Improvement and Restoration, Japan (n.d.)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$	$	+

A5.8 Summer and Winter Dikes

Driver: Flood protection
Where: Middle course and/or Lower course

Function
Flood safety

Co-benefit
Fertile sediment deposition

Disadvantages
- Possibility of increased erosion in case of heightening
- More settlements built close to the river because of increased feeling of safety
- Greater damage in case of flooding

Description of the measure
Overall, giving space to the river by allowing it to meander and overflow onto its floodplains is the cheapest and most sustainable strategy. However, many densely populated areas have space constraints and need structural dikes or embankments to mitigate flood risk. A more flexible structural solution to consider is constructing summer and winter dikes. Summer dikes protect floodplain areas from frequent flooding while allowing overflow up to the winter dike during extreme events. Allowing this lateral connection to the floodplain increases storage capacity during extreme events and reduces the risk of extreme water levels downstream. An additional benefit to be derived from this measure is the periodic influx of fertile sediments and their incorporation into the floodplains. The area between the summer and winter dikes is often put to temporary use, for agricultural or other purposes. Dikes can also be covered with grasses and herbs to improve the landscape and natural values.

Short-term effects
Dike construction or heightening reduces local flood risk.

Long-term effects
In the long term, dike construction leads to the so-called "levee effect." Higher dikes increase feelings of safety, such that more people build settlements and businesses behind the dike. Damage in case of dike failure thus becomes more likely. From a morphological standpoint, dikes often limit the natural movement of rivers. Their location therefore merits careful consideration.

Operation and maintenance requirements
Dikes need regular inspection and maintenance in case of (toe) scour, or piping or dike instability.

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$$	–

A5.9 Wetlands and Mangroves

Driver: Flood retention and/or Erosion reduction
Where: Middle course and/or Lower course

Functions
- Flood safety
- Erosion reduction

Co-benefits
- Restoration of natural values
- Restoration of recreational values
- Water quality improvement

Disadvantage
Need for space

Detailed description
Wetlands are natural retention areas along rivers acting as buffers by soaking up and storing a significant amount of floodwater. Wetlands also control erosion and improve water quality. Coastal wetlands and mangroves likewise serve as storm surge protectors in extreme weather events and mitigate coastal erosion. In many areas, wetland encroachment by urban and agricultural development activities reduces buffer capacity. Restoring natural wetlands moderates local erosion and flood frequency and intensity downstream, and has the added benefit of improving water quality.

Short-term effects
Restored wetlands and mangroves require some time to establish.

Long-term effects
Once established, these wetlands provide an additional buffer that can potentially reduce water levels downstream. There may be less local erosion and water quality may improve.

Operation and maintenance requirements
Established wetlands and mangroves generally require little maintenance.

Examples
- Minnesota State Wetland Program in the US
  Minnesota Department of Natural Resources, US (n.d.)
- Tomago Wetland restoration in Australia
  University of New South Wales Water Research Laboratory (n.d.)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	+

A5.10 Dam/Reservoir Construction

Driver: Flood retention and/or Water collection
Where: Upper course and/or Middle course

Functions
- Flood safety
- Water supply

Co-benefits
- Electricity from hydropower
- Increased water supply
- Controlled water levels for navigation
- Recreation values

Disadvantages
- Ecosystem disruption
- Sediment supply disruption
- Flooding of land behind dam
- Continued unsustainable water use

Description of the measure
Dams can be constructed in a river to restrict the flow of water. Conventional dams retain water, and the resulting reservoir can be used to control flooding and to provide water for industrial, agricultural, and residential use. Often, dams are combined with a hydropower plant to meet electricity demand. To minimize the long-term ecological and sediment transport consequences of conventional dam construction, "dry dams" may be considered. These dams operate only under high-flow conditions and hold excess water for 24–48 hours before slowly releasing the stored water to prevent excess flooding downstream.

Short-term effects
In the short term, a dam can be used to dampen the effects of high discharge.

Long-term effects
The construction of dams and reservoirs generally makes people more dependent on water availability throughout the year, and less able to cope with periods of drought. Over time, sediment supplied by the river is trapped behind conventional dams, so that the reservoir slowly fills up. The capacity of the reservoir is thus reduced and there is less sediment supply downstream, increasing problems related to subsidence and sea level rise.

Operation and maintenance requirements
Dams often have a life span of about 50–60 years. After this they can become inefficient or unsafe, and require expensive maintenance measures. This expense and the enormous impact on the ecosystem explain the growing trend of dam removal in the European Union and the United States (O'Connor, Duda, and Grant 2015).

Examples
- Masudagawa "Dry" Dam in Shimane Prefecture
  Shimane Prefectural Government, Japan (n.d.)
- San Roque Dam in the Philippines
  Wikipedia (2020)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$$$	–

A5.11 Urban Drainage Systems

Driver: Flood retention

Where: Urban areas

Functions

- Flood safety (pluvial flood prevention)
- Water supply

Co-benefits

- No-regret measure
- Possibility of green solutions

Disadvantages

- Expensive measure
- Need for maintenance

Description of the measure

Urban flooding can be reduced with the help of urban storm water drainage systems designed to increase water retention, improve drainage capacity, and decrease direct runoff. Green solutions can take the place of several components of these systems:

- **Source control.** Restricting or slowing down the inflow to the actual drainage system can control storm water discharge at the source. Green roofs, wadis (A5.12), infiltration trenches, or vegetated surfaces can be used for this purpose. These measures are intended to slow down direct runoff and increase infiltration capacity so that groundwater is replenished.
- **Drainage system.** The transport of water to storage basins, rivers, or other locations through the drainage system can be slowed down and the volume reduced through the replacement of artificial pipes with greener solutions such as bioswales, rain gardens, or open water systems. These measures also improve water quality and increase infiltration.
- **Storage components.** Storage components lower the load on the drainage system. Storage facilities can be relatively small (e.g., water butts and small-scale wadis [A5.12]) or large (e.g., ponds and retention basins [A5.13]).

Besides these components, filter components can be designed to improve water quality. The design possibilities for an urban drainage system range from gray to green. Complete guidance on the construction of urban drainage systems is provided by the Construction Industry Research and Information Association (Woods Ballard et al. 2015).

Short-term effects

Damage from pluvial flooding decreases because of the controls placed on water storage and drainage.

Long-term effects

If the design includes increased drainage capacity, groundwater is replenished, thus reducing severe drought and soil subsidence.

Operation and maintenance requirements

The drainage system will require regular maintenance, depending on the type of system.

Examples

- Sustainable storm water management in Fornebu, Norway
  European Commission (2015c)
- Improvement of the drainage system in Metro Manilla
  World Bank (2017b)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$$	+

A5.12 Wadis/Bioswales

Driver: Flood retention

Where: Urban areas

Functions

- Flood safety
- Water supply

Co-benefits

- Increased water availability
- Decreased urban heat effect
- Aesthetic value

Disadvantage

Need for space

Description of the measure

In many cities, a large fraction of the surface consists of impermeable materials (asphalt, concrete). This prevents (pluvial) water from being absorbed into the soil, and thus reduces the natural storage capacity of the area and increases direct runoff and pluvial flood levels in urban areas. Larger artificial drainage systems are intended to accommodate the discharge requirements, which could otherwise worsen flooding downstream from the city.

Wadis and bioswales are green solutions designed to collect runoff and slow down its transport to the main drainage systems or open water, and therefore reduce the overall load on the system. They are usually covered with specific types of vegetation to enhance infiltration and water quality (Boogaard, Jeurink, and Gels 2003). Some systems are designed to include additional storage areas. Common co-benefits of these systems are increased aesthetic value and, when the systems are more widely applied, reduced effect of urban heat islands.

Short-term effects

A wadi/bioswale increases storage capacity and reduces the load on artificial drainage systems, thereby decreasing (pluvial) flooding in an urban area.

Long-term effects

The increased infiltration capacity limits groundwater lowering and drought effects during periods with little precipitation.

Operation and maintenance requirements

To maintain infiltration capacity, vegetation maintenance is required. Generally, annual or semiannual maintenance is sufficient. Maintenance consists of mowing and removal of unwanted vegetation types. The removal of matter that prevents infiltration (leaves, waste) should also be part of the maintenance scheme.

Example

Wadis in urban areas in Northern Europe
Backhaus and Fryd (2013)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	+

A5.13 Construction of Retention Areas

Driver: Flood retention
Where: Middle and/or Lower course and/or Urban areas

Functions
- Flood safety
- Water supply

Co-benefits
- Possibility of restoring natural values
- Possibility of restoring recreational values
- Water storage and supply benefits
- Decreased urban heat effect
- Increased water supply

Disadvantage
Need for space

Detailed description
In many cities, a large fraction of the surface consists of impermeable materials (asphalt, concrete). This prevents (pluvial) water from being absorbed into the soil, and thus reduces the natural storage capacity of the area and increases direct runoff and pluvial flood levels in urban areas. Urban retention areas are designed to store water during (extreme) rainfall events. Retention areas are often ponds with additional storage capacity but can also consist of a (vegetated) depression, which is usually dry but allows for storage and infiltration during heavy precipitation. This measure is made greener through the addition of vegetation to improve permeability.

Fluvial retention areas are often designed to store water during extreme discharge events. Increased storage during the first stage of the flood wave has negligible effect, while storage just before the top of the wave gives maximum effect (Jansen et al. 1994), because of retardation of storage. The moment of inflow of a retention area can be taken into account in the design of the area. Additionally, the location of a fluvial retention area should be considered. The retention area lowers the water level for areas downstream, so for maximum effect, a retention area should be installed upstream of vulnerable areas. A fluvial retention area can be combined with natural retention areas like wetlands to increase capacity and make it a greener measure.

Operation and maintenance requirements
A retention area generally requires little maintenance. If there is always water in the retention area, measures may be needed to ensure water quality. Also, the outlet should be checked regularly (for example, after a flooding event or once a year) to prevent vegetation or waste from blocking the outlet.

Examples
- Urban retention area in Fourth Ward Park, Atlanta, Georgia, US
  Urbanland (2020)
- Fluvial retention area in Volkerak-Zoommeer, Netherlands
  Rijkswaterstaat (n.d.)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	0/+

A5.14 Building codes/Zonation

Driver: Flood safety
Where: Urban areas

Function
Flood safety

Co-benefits
- Possibility of restoring natural value
- Possibility of restoring recreational value

Description of the measure

The implementation of building codes and/or zonation is a land use management measure focused on residential areas. By implementing building codes, local authorities can decide which buildings and land uses are allowed near the river. This ensures that houses and important buildings are located outside the reach of a flood, so the risk of flooding is reduced. (Note that the local authorities must determine which flood levels are considered in the zonation.) There are several ways of implementing zonation, ranging from loose enforcement, which applies only to the construction of new houses and buildings, to strict enforcement, which transforms existing land use. The impact and costs of this measure depend on the exact approach used and on the characteristics of the area. No-building zones can be transferred to floodplains with alternative functions, such as agriculture or nature reserve.

Short-term effects
Flood risk and amount of damage during a flood are reduced.

Long-term effects
The advantage of zoning is that it keeps people and assets further away from the hazard. It therefore reduces exposure in both the short and the long term. For retention areas (A5.13) or for floodplain reconnection (A5.3), zoning measures are often required.

Operation and maintenance requirements
This measure needs enforcement, to make sure that residents comply with the zonation.

Examples
- Change in building codes for hazard reduction in the Philippines
  World Bank (2016a)
- Relocation to reduce flood risk in Kinston, North Carolina, US
  FEMA, US (2005)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$–$$$	$	–

A5.15 Early Warning System

Driver: Flood protection
Where: Throughout the catchment area

Function
Flood safety

Co-benefit
No-regret measure

Description of the measure
When an area is prone to flooding, but population density or economic value is low, the decision can be made not to invest in structural flood protection measures. In this case, a flood early warning system can be a suitable intervention to prevent casualties or economic damage. In densely populated (urban) areas, such a system can be set up to mitigate economic damage from flooding. The advantage of an early warning system is that the negative effects of flooding are decreased, while the river system remains unchanged. Also, this is a relatively cheap measure. An early warning system often combines an extensive monitoring system with a runoff model (Plate 2007). Depending on the scale of the catchment and location within the catchment, including the upstream sub-catchments within the monitoring and modeling system is advisable.

Short-term effects
An early warning system limits economic damage and casualties from flooding.

Long-term effects
This is a no-regret measure with no effect on the riverine system.

Operation and maintenance requirements
An early warning system is often based on a network of observations or on a model. After setup, little maintenance is required except for the maintenance of measurement equipment or the updating of the model in case of changes in the system.

Examples
- Flood early warning system in Metro Manila, Philippines
- Community-based warning system in India
  UNFCCC (n.d.)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	+

A5.16 Removal of obstacles

Driver: Flood retention
Where: Throughout the catchment area

Function
Flood safety

Co-benefit
Possibility of restoring natural values

Disadvantage
Need for regular maintenance

Description of the measure
Obstacles in the flow area can consist of objects in the main channel (bridge pillars, piers, groins), or on the floodplain (bridge pillars, buildings, vegetation). Removing at least part of these obstacles increases local conveyance capacity, leading to lower water levels locally.

Increasing the smoothness of the floodplain or main channel increases local discharge capacity and leads to lowered local water levels. At the same time, decreased wave damping increases downstream water levels. The lowering of local water levels results in a steeper water level gradient, with the possible effect of increasing upstream erosion, thereby endangering upstream construction works such as bridge piers.

The removal of obstacles is advised mainly at locations where discharge capacity needs to be increased but the available space is limited.

Short-term effects
The local water level is lowered as conveyance capacity increases. Downstream flood levels increase because of the increased speed of flood wave propagation.

Long-term effects
A lower water level always leads to a steeper water level gradient, thereby increasing upstream erosion.

Operation and maintenance requirements
If floodplain smoothing through the removal of vegetation is done, regular maintenance is needed to keep the floodplain smooth. But in the case of bridge pier removal , for example, no further maintenance is required..

Examples
- Removal of an artificial elevated area from the floodplain of the Rhine River, Netherlands
  Ruimte voor de Waal Nijmegen (2018)
- Cheonggyecheon River Restoration, Republic of Korea
  World Bank (n.d.-b)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$	$	+

A5.17 Lifting Up/Relocation of Communities

Driver: Flood safety

Where: Middle course and/or Lower course

Function

Flood safety

Disadvantages

- Need for space
- Need for enforcement

Detailed description

Communities on floodplains are susceptible to flooding. Relocating these communities to safer areas reduces their overall exposure to the hazard. However, if there is resistance to the move or not enough space for relocation, housing on stilts or on constructed mounds may be built to lift up the communities.

Short-term effects

Applying this measure instantly reduces community exposure and vulnerability to flooding.

Operation and maintenance requirements

Relocating communities is costly and would require incentives and continuous enforcement. Lifting up communities would require regular inspection and maintenance in case of structural instability of the mounds and stilts.

Example

Overdiepse Polder in the Netherlands

Ruimte voor de Waal Nijmegen (Room for the River Waal Nijmegen) (n.d.-a)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$$	–

A5.18 Land Use Management

Driver: Flood retention and/or Soil stability

Where: Throughout the catchment area

Functions

- Flood safety
- Erosion reduction

Co-benefit

Possibility of restoring natural values

Disadvantage

Need for enforcement

Detailed description

Freshwater in the river comes from direct runoff and groundwater (base flow). Flood events are often caused by heavy precipitation in the upper / middle river course and the corresponding increased direct runoff. Direct runoff and infiltration are negatively related: if the infiltration capacity is low, direct runoff increases. The ratio between the two depends on, among others, the soil composition, soil state, and vegetation coverage. Hard surfaces such as concrete and asphalt diminish infiltration and thereby increase direct runoff and flood levels due to precipitation events. Vegetation intercepts precipitation, thereby increasing infiltration capacity and decreasing direct runoff. Therefore, land use management including agricultural reform is very effective in reducing flood levels, provided that it is implemented on a large scale. Both fluvial and pluvial flood levels are reduced with effective land use management.

Land use management can be applied throughout the catchment, especially in the higher and middle course. In urban areas, removing hard surfaces where possible is an effective measure for increasing infiltration and reducing pluvial flooding.

Short-term effects

Land use management is often applied, with the aim of increasing water storage, thus decreasing both pluvial and fluvial flooding.

Long-term effects

The long-term effects of altered land use management will depend on the nature of this measure.

Operation and maintenance requirements

Land use management requires enforcement to ensure that the land is used as planned.

Examples

- Land use planning in the Netherlands and the People's Republic of China
  Harbers et al. (2017)
- Reforestation as flood management measure in the United Kingdom
  Forest Research, UK (2020)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	+

A5.19 Restoration of Natural Forests

Driver: Landslide prevention
Where: Upper course

Function
Hill slope stability

Co-benefits
- Restoration of natural values
- Restoration of recreational values

Disadvantage
Need for space

Description of the measure
Natural forests are disappearing to make room for settlements and agricultural land. In areas with steep slopes, this activity increases the risk of landslides, which deposit large amounts of sediment in the river. Restoring natural forests prevents landslides not only by reinforcing soil and removing excess soil moisture but also by directly obstructing smaller slides and rock falls. This has the effect of reducing sediment concentration in the downstream river.

Short-term effects
Restored forests may require some time to establish.

Long-term effects
Established forests reduce landslide risk, and thus the amount of sediment deposited in the river.

Operation and maintenance requirements
An established forest has generally low maintenance requirements.

Example
Reforestation of the Regent in Sierra Leone
United Nations Mission in Sierra Leone (2018)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$	$	+

A5.20 River Training with Groins

Driver: Navigation and/or Bank stabilization
Where: Middle course and/or Lower course

Function
Navigability

Co-benefit
Constant fairway

Disadvantages
- Increased flood levels
- Increased main channel degradation

Description of the measure
The implementation of groins is usually intended to increase midchannel flow to maintain a certain navigation depth, or fixate the riverbank. Groins can be divided into open or closed structures. Closed structures generally consist of a soil body with a revetment on top. Open structures, often composed of a row of wooden piles, allow water to flow through at all stages of discharge. These structures add resistance, thereby absorbing part of the energy of the flow. Consequently, the sediment transport capacity is reduced locally, and sedimentation increases, as a result of which the riverbank stabilizes. Because of the low velocity gradient (slowing down local erosion and sedimentation rates), in combination with the low implementation costs, this is an attractive and rather flexible option. Closed groins are less flexible and generally result in increased local scour, but are less vulnerable to damage from boats and floating trees.

Short-term effects
Both open and closed structures reduce transport capacity near the banks, thereby fixing the main-channel bank. Because of increased flow resistance or even flow blocking, local and upstream water levels increase during periods of low as well as high discharge.

Long-term effects
Forcing more momentum to the middle of the main channel increases the sediment transport capacity in the main channel, leading to enhanced bed degradation. Ultimately, this leads to lowered water levels, reducing flood risk but also threatening the stability of infrastructure, bridge piers, and the groins themselves, and lowering the groundwater table.

Operation and maintenance requirements
Groins are relatively expensive structures. Construction and design require a great deal of study. Attention should be paid to the toe levels (considering scour), crest levels (considering flow blockage during high discharge), slopes (considering energy losses during overflow), and distance between and length of the groins (considering resulting flow patterns between the groins and in the channel). After implementation, closed groins will require little maintenance if there is limited scour at the toe. Open structures are more vulnerable and will require more maintenance.

Examples
- Groins for navigability purposes in the Rivers Waal, Ijssel, and Neder-Rijn, Netherlands
  Rijkswaterstaat (Directorate-General for Public Works and Water Management),
  Ministry of Infrastructure and Water Management, Netherlands (2017)
- (Permeable) Groins for bank fixation in the Jamuna River, Bangladesh

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$	–

A5.21 River Training with Longitudinal Dams

Driver: Navigation and/or Bank stabilization
Where: Middle course and/or Lower course

Function
Navigability

Co-benefits
- No blockage of flow during high discharge
- More favorable for natural values compared with groins

Disadvantage
Increased main channel degradation

Description of the measure
Longitudinal training dams are often said to replace the function of classical groin fields (De Ruijsscher, Naqshband, and Hoitink 2018). Longitudinal training dams mainly fulfill the following functions:

- increasing water depth in the fairway during periods of low discharge;
- increasing discharge capacity during high flows;
- creating ecologically favorable habitats behind the dams; and
- minimizing main-channel bed degradation.

Just like groins, longitudinal training dams often reach a crest just above the low-discharge water level. However, because of better alignment with the flow, the increase in the water level caused by flow blockage is lower than that for groins. The area between the longitudinal training dams and the bank offers opportunities for nature development or recreational purposes (Collas et al. 2018).

Short-term effects
Depending on the design of the side-channel inlet, a larger portion of the discharge during periods of low flow is forced through the main channel, thus increasing the fairway depth. Moreover, the bank behind the longitudinal training dam is less vulnerable to erosion, as near-bank flow velocity effectively decreases.

Long-term effects
The high-water level increases as a result of increased flow resistance, but the effect is less profound than that for groins. Also, main-channel bed degradation is expected to be smaller.

Operation and maintenance requirements
Like groins, large-scale longitudinal training dams are expensive structures to realize and design requires a great deal of study. After implementation, however, little maintenance is required.

Examples
- Longitudinal training dams for navigational purposes in the River Waal, Netherlands
  De Ruijsscher, Naqshband, and Hoitink (2018)
- Longitudinal training dams for navigational purposes in the River Loire, France

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$	–

A5.22 Channelization/Normalization

Driver: River stabilization

Where: Middle course and/or Lower course

Function

Navigability

Co-benefits

- Increased fairway depth
- Increased conveyance capacity (a common co-benefit)
- Land gain

Disadvantages

- Increased riverbed erosion
- Higher flood peaks downstream
- Loss of natural value

Description of the measure

Each natural river channel (system) is dynamic, moving and shifting in time. These river dynamics may conflict with human interests, by blocking water inlets and threatening infrastructure or settlements. In such cases, river channelization, that is, fixation and often straightening of the main channel, can be considered.

Short-term effects

Channel straightening and fixation increases the area of available land, which can be used for agricultural or economic purposes. Channel straightening decreases the length of the river, while often increasing conveyance capacity. The propagation speed of a flood wave therefore increases. In combination with a loss of storage capacity, this leads to higher water levels downstream of the measure.

Long-term effects

The loss of floodplain area leads to severe bed degradation in the main channel, threatening the stability of dikes, bridge piers, and other infrastructure.

Operation and maintenance requirements

When a new alignment is designed, it should be kept in mind that a straight channel with uniform cross sections is never stable. Any disturbance will create a helical flow pattern, leading to a pattern of banks within the main channel. The design of a fixed river channel should consider local characteristics, such as sediment load, grain size, typical discharge and discharge variation, and flow velocities (Jansen et al. 1994). After the measure is implemented, the riverbed and banks must be maintained to reduce bed erosion.

Examples

- Channelization of the German Rhine in the 19th century (see Box 1)
- Channelization of the Los Angeles River
  Los Angeles River Revitalization, California, US (n.d.-a)

Implementation Costs ($–$$$)	Maintenance Costs ($–$$$)	Is It Green? (–, 0, +)
$$$	$	–

APPENDIX 6: PLANNING APPROACHES

A process-based approach is essential to the success of projects. Such an approach has several crucial elements, such as getting all stakeholders involved, setting clear objectives, defining measurable targets, and evaluating alternative measures. These steps are closely related to those in earlier documents on flood risk management (FRM) (Sayers et al. 2013), integrated water resources management (IWRM) (World Bank 2016b), and the implementation of nature-based flood protection measures (World Bank 2017a).

In general, integrated river basin management (IRBM) is focused more on the organization of the process of developing basin plans and less on the implementation of measures (Pegram et al. 2013). Also, IRBM and project planning are very closely linked with IWRM. IWRM frameworks are therefore used often in this publication. Following a specific systematic approach ensures that no steps or actions are accidentally omitted.

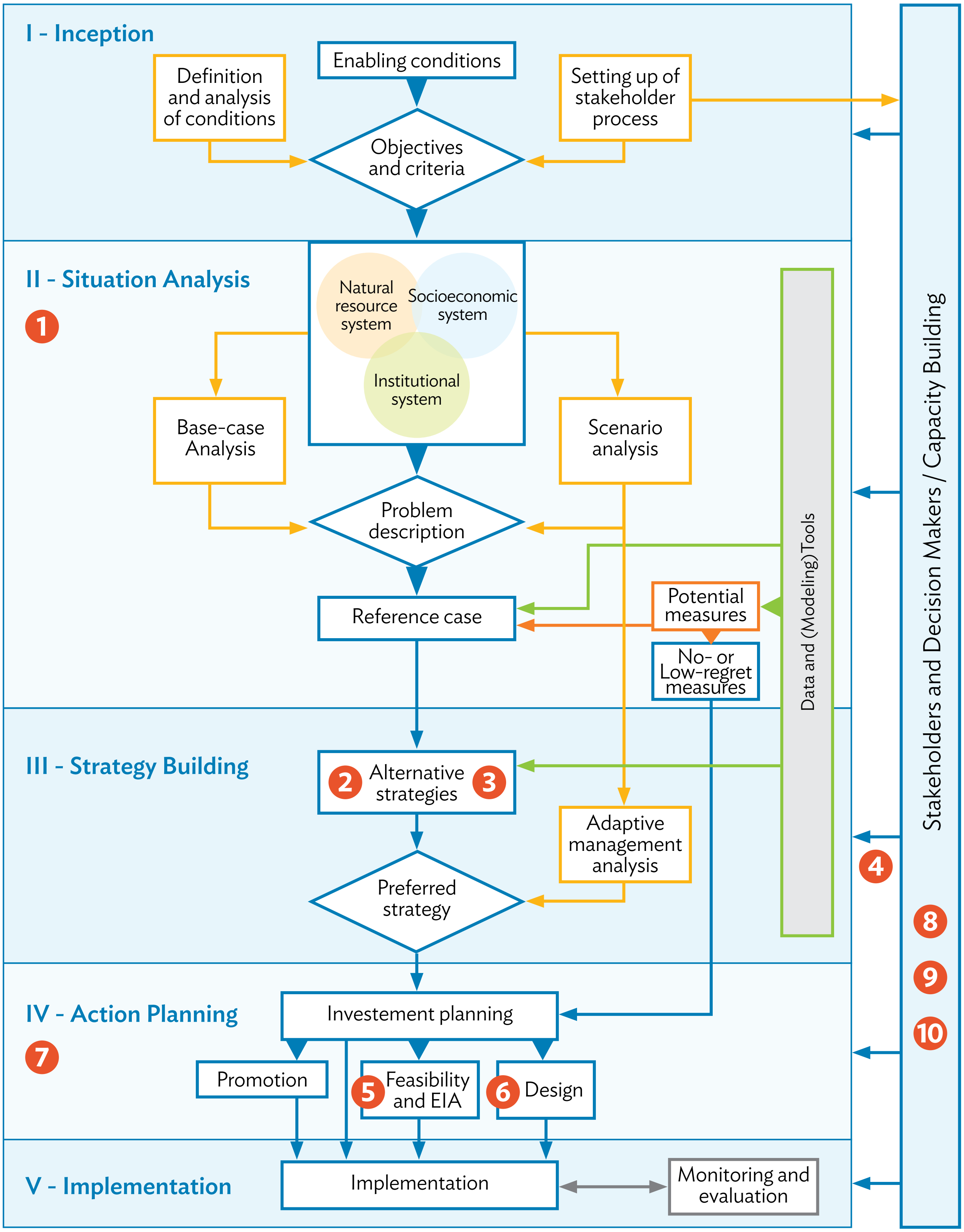
This publication is centered on several overlapping and crucial steps in all these frameworks and provides more detailed guidance on how these steps should be implemented to optimize (natural) river management.

Planning Frameworks for Water Management

USE: Flood Risk Management
PLANNING CYCLE:

Source: ADB; Sayers et al. 2013.

USE: Integrated Water Resources Management
PLANNING CYCLE:



EIA = environmental impact assessment.
Source: World Bank 2016b.

USE: Nature-Based Solutions

PLANNING CYCLE:

Ecosystem aspects | Output

	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
	Define problem, project scope, and objectives	Define financing strategy	Assess ecosystem, hazards, and risks	Develop nature-based risk management strategy	Estimate costs, benefits, and effectiveness	Select, plan, and design the intervention	Implement the project	Monitor and maintain the project, use experience to inform future practices
Ecosystem aspects	Scale of natural system, available data, problem solving	Local investment in intervention, green financing	Ecosystem presence, health, and functioning	Ecosystem potential, action identification	Effectiveness of ecosystem measure	Green and hybrid action design	Conservation, restoration, or establishment of ecosystem elemeants	Monitoring of ecosystem performance, resilience, and stability
Output	• Stakeholder meetings • Maps of areas of interest • Project objectives	• Meeting to identify funders • Budget estimate • Overview of resources	• Risk maps • Ecosystem and land-use maps • Flood zone maps	• Cost–benefit analysis	• List of measures • Strategy map • Stakeholder meetings	• Selection • Design • Impact assessment • Monitoring plan	• Measures implemented • Regulatory frameworks • Measure lifetime	• Monitoring reports • Adaptation if targets are not met

Project Implementation Timeline →

Source: World Bank. 2017a.

GLOSSARY

base flow – the portion of water in a stream or river that is fed by delayed pathways

basin – *see* **river basin**

coastal erosion – the loss of coastal land due to the net removal of sediment or bedrock from the shoreline

delta – an area of low, flat land where a river divides into several smaller rivers before flowing into the sea

dredging – the removal of sediment from the riverbed or from the bottom of other bodies of water

erosion – geological process in which earthen materials (e.g., soil, rock, or dissolved materials) are worn away and transported by natural processes such as wind and water actions

gray solution/measure – *see* **hard solution/measure**

green solution/measure – a structural measure making use of natural or man-made materials to reduce disaster risks and impacts, by working with and enhancing natural (hydrologic) processes, including infiltration, runoff, and purification processes

hard solution/measure – a disaster risk and impact reduction measure relying purely on man-made engineering structures

nonstructural measure – a measure intended to reduce disaster risks and impacts by using knowledge, practice, or agreement, particularly through policies and laws, public awareness raising, training, and education, instead of physical structures

peak flow – the maximum instantaneous discharge of a stream or river at a given location

permeability – a measure of the ability of a porous material (e.g., rock or soil) to allow fluids to pass through it via an interconnected network of pores and cracks

riparian – relating to or living or located on the banks of a natural watercourse

river basin – an area of land where precipitation accumulates and drains off into the river and its tributaries

runoff – *see* **surface runoff**

sedimentation – the settling of particles in suspension

structural measure – physical construction to avoid or reduce the possible impact of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems

subsidence – the gradual sinking or settling of land to a lower level than the surrounding area

surface runoff – the flow of water that occurs when excess stormwater, meltwater, or water from other sources flows across the surface of the earth

REFERENCES

Acreman, M. C., R. Riddington, and D. J. Booker. 2003. Hydrological Impacts of Floodplain Restoration: A Case Study of the River Cherwell, UK. *Hydrology and Earth System Sciences.* 7 (1). pp. 75–85. https://hess.copernicus.org/articles/7/75/2003/hess-7-75-2003.pdf.

Asian Development Bank (ADB). 2008. ADB Photo Library. *Women feeding a cow in Bangladesh. Flood Rehabilitation (Flood Control and Irrigation) Project*. Bangladesh.

———.2017a. ADB Flicker photo. *Project Numbers: 46420-002; 43407-014; 43300-013. An ADB funded sea wall in Barangay Katipunan, Pilar, Surigao Del Norte*. Philippines. 46420-002: KALAHI-CIDSS National Community-Driven Developm... | Flickr.

———. 2017b. *Meeting Asia's Infrastructure Needs*. Manila. https://dx.doi.org/10.22617/FLS168388-2.

———. 2019a. *Annual Report 2018*. Manila. http://dx.doi.org/10.22617/FLS190058.

———. 2019b. *Protecting and Investing in Natural Capital in Asia and the Pacific: Guidelines for Mainstreaming Natural River Management in ADB Water Sector Investments Consultant's Report*. https://www.adb.org/sites/default/files/project-documents/50159/50159-001-tacr-en_2.pdf.

———.2021. Public Sector (Sovereign) Financing. Manila. https://www.adb.org/what-we-do/public-sector-financing/project-cycle#:~:text=The%20various%20stages%20from%20country%20programming%20to%20project,Policy.%20ADB%20provides%20financing%20for%20projects%20that%20.

Auerbach, L. W., S. L. Goodbred Jr., D. R. Mondal, C. A. Wilson, K. R. Ahmed, K. Roy, M. S. Steckler, C. Small, J. M. Gilligan, and B. A. Ackerly. 2015. Flood Risk of Natural and Embanked Landscapes on the Ganges–Brahmaputra Tidal Delta Plain. *Nature Climate Change.* 5 (2). pp. 153–157. https://doi.org/10.1038/nclimate2472.

Backhaus, Antje, and Ole Fryd. 2013. The Aesthetic Performance of Urban Landscape-Based Stormwater Management Systems: A Review of twenty projects in Northern Europe. *Journal of Landscape Architecture.* 8 (2). pp. 52–63. https://www.tandfonline.com/doi/full/10.1080/18626033.2013.864130.

Boogaard, F., N. Jeurink, and J. H. B. Gels. 2003. Vooronderzoek natuurvriendelijke wadi's: Inrichting, functioneren en beheer [Research in Nature-Friendly Wadis: Establishment, Function, and Management]. Utrecht: Foundation for Applied Water Research (STOWA). https://edepot.wur.nl/118748.

Bridges, T. S., E. M. Bourne, J. K. King, H. K. Kuzmitski, E. B. Moynihan, and B. C. Suedel. 2018. *Engineering with Nature: An Atlas.* Vicksburg, Mississippi: US Army Engineer Research and Development Center.

Bridges, T. S., R. Henn, S. Komlos, D. Scerno, T. V. Wamsley, and K. White. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures.* Washington, DC: US Army Corps of Engineers.

Browder, G, S. Ozment, I. Rehberger Bescos, T. Gartner, G.-M. Lange. 2019. *Integrating Green and Gray: Creating Next Generation Infrastructure.* Washington, DC: World Bank and World Resources Institute. https://openknowledge.worldbank.org/handle/10986/31430.

Calow, P., and G. E. Petts, eds. 1993. *The Rivers Handbook Volume 1.* Oxford: Blackwell Scientific Publications.

Cambridge Dictionary. Delta. n.d. https://dictionary.cambridge.org/us/dictionary/english/delta.

Cohen-Shacham, E., G. Walters, C. Janzen, and S. Maginnis, eds. 2016. *Nature-Based Solutions to Address Global Societal Challenges.* Gland, Switzerland: International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.

Collas, F. P. L., A.D. Buijse, L. van den Heuvel, N. van Kessel, M. Schoor, H. Eerden, and R. S. E. W. Leuven. 2018. Longitudinal Training Dams Mitigate Effects of Shipping on Environmental Conditions and Fish Density in the Littoral Zone of the River Rhine. *Science of the Total Environment.* 619–620. pp. 1183v1193. https://www.sciencedirect.com/science/article/abs/pii/S0048969717330176?via%3Dihub.

Cosgrove, W. J., and D. P. Loucks. 2015. Water Management: Current and Future Challenges and Research Directions. *Water Resources Research.* 51 (6). pp. 4823–4839. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014WR016869.

Crosato, Alessandra. 2007. River Morphodynamics: Morphological Response at the Reach Scale. *Lecture Notes LN381.* Delft, Netherlands: IHE Delft Institute for Water Education.

De Ruijsscher, T., S. Naqshband, and T. Hoitink. 2018. Flow Bifurcation at a Longitudinal Training Dam: Effects on Local Morphology. In A. Paquier and N. Rivière, eds. River Flow 2018 - Ninth International Conference on Fluvial Hydraulics [05020] (E3S Web of Conferences, Vol. 40). EDP Sciences. https://doi.org/10.1051/e3sconf/20184005020.

de Vriend, H. J., and M. van Koningsveld. 2012. *Building with Nature: Thinking, Acting and Interacting Differently.* Dordrecht, Netherlands: EcoShape, Building with Nature.

Di Baldassarre, G., N. Wanders, A. AghaKouchak, L. Kuil, S. Rangecroft, T. I. E. Veldkamp, M. Garcia, P. R. van Oel, K. Breinl, and A. F. Van Loon. 2018. Water Shortages Worsened by Reservoir Effects. *Nature Sustainability.* 1 (11). pp. 617–622.

European Commission. 2015a. Natural Water Retention Measures: Natural Bank Stabilization. Catalog. http://nwrm.eu/measure/bank-stabilisation.

———. 2015b. Natural Water Retention Measures: Restoration of Oxbows and Floodplains on the Morava River, Slovakia. Case study. http://nwrm.eu/case-study/restoration-oxbows-and-floodplains-morava-river-slovakia.

———. 2015c. Natural Water Retention Measures: Sustainable Storm Water and Green Infrastructure Management in Fornebu, Norway. Case study. http://nwrm.eu/sites/default/files/case_studies_ressources/cs-nor-01-final_version.pdf.

———. n.d. Ecosystem Services and Green Infrastructure. https://ec.europa.eu/environment/nature/ecosystems/index_en.htm (accessed 9 September 2019).

Federal Emergency Management Agency (FEMA). 2005. Innovative Floodplain Management. *Best Practices Portfolio.* https://www.hsdl.org/?view&did=7048.

———.2009. *Engineering with Nature: Alternative Techniques to Riprap Bank Stabilization.* https://www.fema.gov/pdf/about/regions/regionx/ Engineering_With_Nature_Web.pdf.

Forbes, H., K. Ball, and F. McLay. 2016. *Natural Flood Management Handbook.* Stirling, Scotland: Scottish Environment Protection Agency.

Forest Research, Forestry Commission, UK. 2020. Slowing the Flow at Pickering: About the Project. https://www.forestresearch.gov.uk/research/slowing-the-flow-at-pickering/.

Foundation for Riverfront Improvement and Restoration, Japan. n.d. Restoration of Moizari River. http://www.a-rr.net/jp/en/waterside/domestic/docs/03-0005Eng.pdf.

Franke Dirk Ingo. 2006. Photo. Timber groins. In Schobüll, Nordfriesland, Germany, File:Schobuellbuhne042006.jpg - Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Schobuellbuhne042006.jpg.

Harbers A., D. Evers, T. Dassen, M. de Jong, and L. Sun. 2017. *Innovating Spatial Planning in China: Dutch Planning Experience in View of Chinese Challenges and Opportunities.* Japan. n.d. The Hague: PBL Netherlands Environmental Assessment Agency.

Hokkaido Regional Development Bureau, Japan. n.d. Restoration of the Shibetsu River. http://www.a-rr.net/jp/en/waterside/domestic/docs/03-0006Eng.pdf.

Intergovernmental Panel on Climate Change (IPCC). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Report edited by C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, and P. M. Midgley. England: Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf.

Interreg–Danube Transnational Programme, Hungary. n.d. Danube Floodplain, Approved Projects. http://www.interreg-danube.eu/approved-projects/danube-floodplain.

International Water Association. Sedimentation Processes. 2021. https://www.iwapublishing.com/news/sedimentation-processes#:~:text=Sedimentation%20is%20the%20process%20of,treatment%20is%20known%20as%20sludge.

Jansen, P. Ph., L. van Bendegom, J. van den Berg, M. de Vries, and A. Zanen, eds. 1994. *Principles of River Engineering: The Non-tidal Alluvial River.* Delft, Netherlands: Delftse Uitgevers Maatschappij.

Knepper, T. P., ed. 2006. *The Rhine.* Vol. 5. Germany: Springer-Verlag Berlin and Heidelberg.

Kondolf, G. M., H. Piégay, and N. Landon. 2002. Channel Response to Increased and Decreased Bedload Supply from Land Use Change: Contrasts between Two Catchments. *Geomorphology.* 45 (1–2). p p. 35–51.

Lininger, K. B., and E. M. Latrubesse. 2016. Flooding Hydrology and Peak Discharge Attenuation along the Middle Araguaia River in Central Brazil. *Catena.* 143. pp. 90–101.

Los Angeles River Revitalization, California, US. n.d.-a. About the LA River. https://www.lariver.org/blog/about-la-river.

———. n.d.-b. LA River Ecosystem Restoration. http://lariver.org/blog/la-river-ecosystem-restoration.

Mäckel, Rüdiger and Seidel, Jochen. 2003. Stromregulierung des Oberrheins. In: Nationalatlas Bundesrepublik Deutschland/ 2. – Relief, Boden und Wasser / Institut für Länderkunde, Leipzig (Hrsg.). Mitherausgegeben von Herbert Liedtke, Roland Mäusbacher und Karl-Heinz Schmidt. Heidelberg, Berlin: Spektrum Akademischer Verlag, 2003, S. 93.

Meyer, V., S. Priest, and C. Kuhlicke. 2012. Economic Evaluation of Structural and Non-structural Flood Risk Management Measures: Examples from the Mulde River. *Natural Hazards.* 62 (2). pp. 301–324.

Minnesota Department of Natural Resources, US. n.d. Wetlands Programs: Wetland Review and Conservation Planning. https://www.dnr.state.mn.us/eco/wetlands/index.html.

Merriam-Webster. n.d. https://www.merriam-webster.com/dictionary/riparian.

National Geographic. Erosion. n.d. https://www.nationalgeographic.org/encyclopedia/erosion/.

National Oceanic and Atmospheric Administration. 2021. National Ocean Service. What is Dredging. https://oceanservice.noaa.gov/facts/dredging.html#:~:text=Dredging%20is%20the%20removal%20of,gradually%20fills%20channels%20and%20harbors.

National Oceanic and Atmospheric Administration. n.d. What is subsidence-Land subsidence is a gradual settling or sudden sinking of the Earth's surface. https://oceanservice.noaa.gov/facts/subsidence.html.

Nichols, G. 2009. *Sedimentology and Stratigraphy.* 2nd ed. New Jersey: John Wiley & Sons.

Noviandi, T. U. Z., R. L. Kaswanto, and H. S. Arifin. 2017. Riparian Landscape Management in the Midstream of Ciliwung River as Supporting Water Sensitive Cities Program with Priority of Productive Landscape. *IOP Conference Series: Earth and Environmental Science.* 91 (1). 012033.

O'Connor, J. E., J. J. Duda, and G. E. Grant. 2015. 1000 Dams Down and Counting. *Science.* 348 (6234; 1 May). pp. 496–497.

Organisation for Economic Co-operation and Development (OECD). 2018. *Financing Water: Investing in Sustainable Growth.* OECD Environment Policy Paper No. 11. Paris. https://www.oecd.org/water/Policy-Paper-Financing-Water-Investing-in-Sustainable-Growth.pdf.

Pegram, G., L. Yuanyuan, T. Le Quesne, R. Speed, L. Jianqiang, and S. Fuxin. 2013. *River Basin Planning: Principles, Procedures and Approaches for Strategic Basin Planning.* Paris: UNESCO.

Pinter, N., R. R. van der Ploeg, P. Schweigert, and G. Hoefer. 2006. Flood Magnification on the River Rhine. *Hydrological Processes.* 20 (1). pp. 147–164.

Plate, E. 2007. Early Warning and Flood Forecasting for Large Rivers with the Lower Mekong as Example. *Journal of Hydro-environment Research.* 1 (2007). pp. 80–94.

REFORM (REstoring rivers FOR effective catchment Management). 2010a. Meers – Floodplain Lowering. Case study. http://wiki.reformrivers.eu/index.php/Meers_-_Floodplain_lowering (last modified 24 November).

———. 2010b. Vén Duna – Side Arm Reopening. Case study. http://wiki.reformrivers.eu/index.php/V%C3%A9n_Duna_-_side_arm_reopening (last modified 13 July).

———. 2015a. Drava – Kleblach. Case study. http://wiki.reformrivers.eu/index.php/Drava_-_Kleblach (last modified 15 December).

———. 2015b. Main page. http://wiki.reformrivers.eu/index.php/Main_Page (last modified 18 December).

Remondi, F., P. Burlando, and D. Vollmer. 2016. Exploring the Hydrological Impact of Increasing Urbanisation on a Tropical River Catchment of the Metropolitan Jakarta, Indonesia. *Sustainable Cities and Society.* 20. pp. 210–221.

Rijkswaterstaat (Directorate-General for Public Works and Water Management), Ministry of Infrastructure and Water Management, Netherlands. 2017. O zit dat zo: hoe kribben ontstonden [Oh well it is : How groins were created]. News release, 14 December. https://www.rijkswaterstaat.nl/nieuws/2017/12/o-zit-dat-zo-hoe-kribben-ontstonden.aspx.

———. n.d. Zoommeer. https://www.rijkswaterstaat.nl/water/vaarwegenoverzicht/zoommeer/index.aspx.

Rinaldi, M., and S. E. Darby. 2008. Modelling River-Bank-Erosion Processes and Mass Failure Mechanisms: Progress towards Fully Coupled Simulations. In: H. Habersack, H. Piégay, and M. Rinaldi, eds. Gravel-Bed Rivers 6: From Process Understanding to River Restoration. Series Developments in Earth Surface Processes, 11. Netherlands: Elsevier.

Ruimte voor de Waal Nijmegen [Room for the River Waal, Nijmegen, Netherlands]. 2018. Obstakelverwijdering Nederrijn Elst, gemeente Rhenen [Obstacle removal Nederrijn Elst, municipality of Rhenen]. https://climate-adapt.eea.europa.eu/metadata/case-studies/room-for-the-river-waal-2013-protecting-the-city-of-nijmegen.

———. n.d.-a. In het Ruimte voor de Rivier project in de Overdiepse Polde [In the Room for the River Project in the Overdiepse Polder Nature Preserve]. Photo archives. https://www.ruimtevoorderivier.nl/river-widening-overdiepse-polder/.

———. n.d.-b. Room for the River Waal: The Project. http://www.ruimtevoordewaal.nl/en/room-for-the-river-waal.

Sayers, P., Y. Li, G. Galloway, E. Penning-Rowsell, F. Shen, K. Wen, Y. Chen, and T. Le Quesne. 2013. *Flood Risk Management: A Strategic Approach*. Paris: UNESCO.

Schneider, E. 2010. Floodplain Restoration of Large European rivers, with Examples from the Rhine and the Danube. In M. Eiseltová, ed. *Restoration of Lakes, Streams, Floodplains, and Bogs in Europe.* Dordrecht: Springer Netherlands.

Scottish Environment Protection Agency (SEPA). 2016. *Natural Flood Management Handbook.* Edinburgh. https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf.

Shimane Prefectural Government, Japan. n.d. Masuda River Dam (Running Water Type). https://www.pref.shimane.lg.jp/kasen/dam/masudagawa/.

Silvis, H. J., and C. M. van der Heide. 2013. *Economic Viewpoints on Ecosystem Services.* Wageningen University, The Netherlands.

United Nations Office for Disaster Risk Reduction (UNISDR). 2017. Words into Action Guidelines: National Disaster Risk Assessment-Hazard Specific Risk Assessment. https://www.unisdr.org/files/52828_07coastalerosionhazardandriskassess.pdf

United Nations (UN). *Sustainable Development Goals.* 2019. https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 28 February).

United Nations Economic and Social Commission for Western Asia. 2020. https://www.unescwa.org/peak-flow.

United Nations Framework Convention on Climate Change (UNFCCC). n.d. Community-based flood early-warning system | India. Climate Action, United Nations Climate Change. https://unfccc.int/climate-action/momentum-for-change/activity-database/community-based-flood-early-warning-system-india.

United Nations Mission in Sierra Leone. 2018. Reforesting Regent: World Environment Day 2018 in Sierra Leone. https://unsierraleone.exposure.co/reforesting-regent.

United Nations Office for Disaster Risk Reduction (UNDRR). 2015. *Sendai Framework for Disaster Risk Reduction 2015–2030*. Geneva.

———. n.d. Structural and non-structural measures. https://www.undrr.org/terminology/structural-and-non-structural-measures#:~:text=Non%2Dstructural%20measures%20are%20measures,awareness%20raising%2C%20training%20and%20education.

University of New South Wales (NSW) Water Research Laboratory, Sydney, Australia. n.d. Tomago Wetland Restoration Project. http://www.wrl.unsw.edu.au/research/tomago-wetland-restoration-project.

Urbanland. 2020. ULI Urban Open Space Awards Finalist: Historic Fourth Ward Park—Phase I, Atlanta, Georgia - Urban Land Magazine. https://urbanland.uli.org/planning-design/uli-urban-open-space-finalist-historic-fourth-ward-park/

USGS. Watersheds and Drainage Basins. n.d. https://www.usgs.gov/special-topic/water-science-school/science/watersheds-and-drainage-basins?qt-science_center_objects=0#qt-science_center_objects.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences.* 37 (1). pp. 130–137.

van Wesenbeeck, B. K., S. Ijff, B. Jongman, S. A. B. Balog, S. M. Kaupa, L. V. Bosche, G.-M. Lange, N. B. Holm-Nielsen, H. Nieboer, Y. Taishi, P. H. Kurukulasuriya, and I. Meliane. 2017. *Implementing Nature Based Flood Protection: Principles and Implementation Guidance.* Washington, DC: World Bank Group.

van Wesenbeeck, B. K., J. P. M. Mulder, M. Marchand, D. J. Reed, M. B. de Vries, H. J. de Vriend, and P. M. J. Herman. 2014. Damming Deltas: A Practice of the Past? Towards Nature-Based Flood Defenses. *Estuarine, Coastal and Shelf Science.* 140. pp. 1–6.

van Wesenbeeck, B. K., M. D. van der Meulen, C. Pesch, H. J. de Vriend, and M. B. de Vries. 2016. Nature-Based Approaches in Coastal Flood Risk Management: Physical Restrictions and Engineering Challenges. In F. G. Renaud, K. Sudmeier-Rieux, M. Estrella, and U. Nehren, eds. *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice.* Cham, Switzerland: Springer International Publishing.

Wikipedia. San Roque Dam (Philippines). 2020. https://en.wikipedia.org/wiki/San_Roque_Dam_(Philippines) (last updated 1 October).

Woods Ballard, B., S. Wilson, H. Udale-Clarke, S. Illman, T. Scott, R. Ashley, and R. Kellagher. 2015. *The SuDS Manual.* London: Construction Industry Research and Information Association (CIRIA). https://www.ciria.org/ItemDetail?iProductCode=C753&Category=BOOK&WebsiteKey=3f18c87a-d62b-4eca-8ef4-9b09309c1c91.

World Bank. 2014. FAQ: Jakarta Emergency Dredging Initiative Project. Brief . 10 July. https://www.worldbank.org/en/country/indonesia/brief/jakarta-emergency-dredging-initiative-project-overall-project-scope-and-implementation.

———.2016a. Mainstreaming Risk Reduction in the National Building Code: Protecting Lives and Property from Disaster Risk in the Philippines. Feature story. 27 June. http://www.worldbank.org/en/news/feature/2016/06/27/mainstreaming-risk-reduction-in-the-national-building-code.

———. 2016b. *Philippines: Integrated Water Resources Management Planning Guidelines*. World Bank Office Manila.

———. 2017a. Implementing Nature-Based Flood Protection: Principles and Implementation Guidance. Washington, DC: World Bank. http://documents1.worldbank.org/curated/en/739421509427698706/pdf/Implementing-nature-based-flood-protection-principles-and-implementation-guidance.pdf.

———. 2017b. Project Highlights: Metro Manila Flood Management. Brief . 29 September. https://www.worldbank.org/en/country/philippines/brief/project-highlights-metro-manila-flood-management.

———. 2019. *Lifelines: The Resilient Infrastructure Opportunity.* Washington, DC. http://documents1.worldbank.org/curated/en/775891600098079887/pdf/Lifelines-The-Resilient-Infrastructure-Opportunity.pdf.

———. n.d.-a. Integrated River Basin Management: From Concepts to Good Practice. Brief 41150. http://documents1.worldbank.org/curated/en/965371468340137430/pdf/411500Intro0to1mgmt0NOTE1101PUBLIC1.pdf.

———. n.d.-b. Seoul: Cheonggyecheon River Restoration. Case study. https://urban-regeneration.worldbank.org/Seoul.

World Wildlife Fund (WWF). 2016 . *Natural and Nature-Based Flood Management: A Green Guide.* Washington, DC.

Guidelines for Mainstreaming Natural River Management in Water Sector Investments

The natural river management (NRM) approach is designed to harness the natural functions of river systems so they sustainably provide important services such as water supply and flood and drought management. Drawing heavily on the concepts of ecosystem services, integrated water resources management, and integrated river basin management, NRM aims to harmonize nature-based solutions and nonstructural measures with engineering interventions. This publication explains the value of NRM and provides step-by-step guidance on how the approach can be systematically integrated into water sector investments.

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