UNEP

GREEN INFRASTRUCTURE

GUIDE FOR WATER MANAGEMENT

Ecosystem-based management approaches for
water-related infrastructure projects

UNEP-DHI PARTNERSHIP
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ACKNOWLEDGMENTS

This guide is a product of collective effort by United Nations Environment Programme (UNEP), UNEP-DHI Partnership – Centre on Water and Environment, International Union for Conservation of Nature (IUCN), The Nature Conservancy (TNC) and the World Resources Institute (WRI). The guide's principle authors, contributors, and reviewers are as follows:

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Publication: Green Infrastructure Guide for Water Management: Ecosystem-based management approaches for water-related infrastructure projects
ISBN: 978-92-807-3404-1
Job Number: DEP/1827/NA

Disclaimers

Design and Layout: Paprika-Annecy

This guide is a joint product by following organizations:

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LIST OF ABBREVIATIONS

BCA	Benefit-cost analysis
CBD	Convention on Biological Diversity
CEA	Cost-effectiveness analysis
EPA	U.S. Environmental Protection Agency
GGA	Green-Grey Analysis
IUCN	International Union for Conservation of Nature
NPV	Net Present Value
O&M	Operation and Management
MCA	Multi-criteria analysis
PWD	Portland Water District
TNC	The Nature Conservancy
UNEP	United Nations Environment Programme
USD	U.S. Dollars
WRI	World Resources Institute
WWF	World Wide Fund for Nature/World Wildlife Fund

EXECUTIVE SUMMARY

Green Infrastructure (GI)[1] is becoming increasingly recognized as an important opportunity for addressing the complex challenges of water management. The GI approach refers to the natural or semi-natural systems that provide services for water resources management with equivalent or similar benefits to conventional (built) "grey" water infrastructure.

Typically, GI solutions involve a deliberate and conscious effort to utilize the provision of ecosystem services to provide primary water management benefits, as well as a wide range of secondary co-benefits using a more holistic approach. As a result, GI solutions can be used to support goals in multiple policy areas. For example, floodplains can reduce flood risk and simultaneously improve water quality, recharge groundwater, support fish and wildlife and provide recreational and tourism benefits. While the value and function of grey infrastructure can be expected to depreciate over time, many GI solutions can appreciate in value and function over time as soils and vegetation generate or regenerate.

Green Infrastructure solutions for water management are also at the heart of Ecosystem-based Adaptation – defined as [using] "… *biodiversity and ecosystem services*[2] *as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels*" (UNEP 2010). The capacity of GI to build resilience to climate shocks and variability has already proven to be effective in a multitude of cases around the globe – from conserving mangroves that provide shoreline protection against coastal erosion and storms, to restoring natural floodplains that recharge groundwater and reduce the risk of severe flooding.

The growing interest in GI is being driven by a combination of factors, including the need to improve water management, owing to a growing demand for and a scarcity of freshwater, and the increasing impact of climate change, including extreme events such as floods and droughts. Moreover, spatial planners, engineers and decision-makers are eager to identify and utilize cost effective, long term and environmentally appropriate infrastructure solutions.

This guide addresses one of the main barriers to widespread adoption of GI solutions: a general lack of awareness of the solutions and associated cost-benefits. The illustrative case studies in this guide provide examples of GI options that address water management challenges, while delivering a number of significant co-benefits. These include reafforestation and afforestation (abbreviated in the tables as Re/afforestation), wetland conservation and construction, levee setbacks, flood bypasses and coastal protection, as well as a number of urban oriented options such as green roofs and permeable pavements.

Table 1 provides an overview of GI solutions that are relevant for water resources management and are discussed in this guide. Solutions marked with '*' consist of built or "grey" elements that interact with natural features and seek to enhance their water-related ecosystem services. These are included in this guide to provide an overview of the wide spectrum of GI solutions for water management.

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[1] For the purposes of this publication, the terminology of Green Infrastructure is adopted, while it is acknowledged that the terms *ecological and natural* infrastructure are often used to describe similar approaches.

[2] See more on the definition of ecosystem services on page 10.

Table 1 Green Infrastructure solutions for water resources management

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

The guide also includes an outline methodology for water management options assessment comprised of a number of steps relating to definition of development objectives, specification of investment portfolios, modelling of environmental outcomes and economic evaluation, cost-benefit analysis, as well as risk and uncertainty analysis.

While in some cases planners may directly compare the advantages of "green versus grey" water infrastructure solutions, this guide places greater emphasis on understanding how green solutions can be integrated within an overall system of water management, composed of appropriately sited and designed elements of both green and grey water infrastructure. The methodology, therefore, provides meaningful evaluation of water infrastructure *options* – consisting of green and grey alternatives, or mutually supportive green and grey elements.

Mainstreaming GI solutions as equally relevant water management approaches remains a challenging task, as the economic analysis of GI is relatively new with a lack of historical cost and benefit. On the other hand, there is a wealth of historical cost and benefit data for grey infrastructure. This increases the perceived risk (i.e. uncertainty) associated with GI, and such projects may have to pass a higher threshold in order to be considered. As a result of this uncertainty, GI valuation studies often employ conservative assumptions and produce wide ranges of estimated benefits. Conservative assumptions and the omission of ancillary benefits can lead to the *underestimation* of the value of a GI investment. Even with these limitations, GI can still be demonstrated to be a cost-effective infrastructure alternative in many cases. In time, efforts by economists in this area of research and the benefit of hindsight will lend additional understanding of the real returns provided by GI over time (Schmidt and Mulligan 2013). Also, greater emphasis on the quantification of environmental (and, to the extent possible, social) impacts over the life cycle of water management systems will be necessary to ensure that unintended trade-offs are not created (UNEP 2004a; 2011a; 2012).

The response to water challenges can benefit from a combination of green and grey infrastructure that involves retrofitting GI solutions to grey infrastructure systems in order to improve efficiency. Thus, this guide takes a pragmatic approach to water management and shows that GI not only provides significant water management benefits and co-benefits in a stand-alone manner, but also as a supporting element to existing grey water infrastructure. The most efficient and cost-effective approach can only be found by evaluating all available options, grey and green, based on their suitability to local hydrology, resource availability, climatic conditions and other variables, on a case-by-case basis.

1

INTRODUCTION

Green Infrastructure refers to natural or semi-natural ecosystems that provide water utility services that complement, augment or replace those provided by grey infrastructure.[3] This Green Infrastructure guide shows that viable and cost-effective alternatives to grey infrastructure in management of water resources can result from an increased effort to work with GI.

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In many developed and developing countries, governments, corporations and communities are under constant pressure to rehabilitate and expand water management infrastructures to serve growing demands for water, energy and food. This work is challenged by the negative impacts of floods and droughts, which may be further exacerbated by climate change. Population growth in at-risk areas increases vulnerability to natural disasters, and climate change is forecasted to intensify the frequency and the severity of extreme events in many parts of the world. Hence, risks could rise for those lacking appropriate infrastructure and the means to implement adaptation measures (IPCC 2014).

To date, the most common response to water-management challenges has been increased investment in conventional built or "grey" infrastructure, such as water-treatment plants, dams and levees and the expansion of sewage networks. Fortunately, a growing number of spatial planners, engineers and decision-makers are identifying and utilizing cost effective, long term and environmentally-friendly infrastructure solutions, thus spearheading increased interest in and successful use of GI.

Grey water infrastructure solutions are attractive as they can offer immediate and high visibility impacts. One of the most obvious drawbacks is that grey water infrastructure tends to be capital intensive to build, operate, maintain and replace. Furthermore, as grey infrastructure is often designed to address a specific water management problem (though some grey infrastructure may serve multiple purposes, such as reservoirs that provide water supply, flood control, hydropower, recreation, etc.), it can serve to shift amplified risks to other locations. For example, canalized rivers and urban stormwater infrastructure may cause downstream flooding. An additional drawback, that is often overlooked, is that certain types of infrastructure can actually lead to declines in the quality and quantity of water supply, as a result of ecosystem degradation. For example, conventional flood management infrastructure can disconnect rivers from floodplains and reduce or eliminate services such as flood control, groundwater recharge, pollution control and supply regulation (Opperman 2009).

In recent decades, there has been a dramatic expansion of our understanding of the direct and indirect values to society provided by ecosystems. "Dams and Development: A New Framework for Decision-Making" (WCD 2000), and the subsequent Dams and Development project (UNEP), are some of the first major initiatives to recognize that water infrastructure solutions need improved decision-making and appropriate assessment of existing alternatives, considering the social and environmental dimensions of such infrastructural developments (UNEP 2004b). This understanding underpins a growth in interest and willingness to consider GI as a means of providing water services in more efficient and sustainable ways than grey infrastructure alone.

Green Infrastructure in a Green Economy

Healthy ecosystems and continuous delivery of ecosystem services are at the core of sustainable and resilient economies and growth in the transition to a Green Economy.

UNEP defines a Green Economy as "*(…) one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*" (UNEP 2010). In a Green Economy, the value of nature is fully recognized, and growth is resource efficient and socially inclusive. This includes recognizing not only the monetary and non-monetary value of ecosystem services, but also the costs that society would bear, due to the degradation or loss of ecosystems.

The transition to a Green Economy has been widely recognized as one of the pathways to sustainable development. The Rio+20 Conference elevated Green Economy as one of the key features of a sustainable future. Consequently, investments in GI have been identified as one of the main building blocks of a transition to a Green Economy. UNEP's Green Economy Report's Water Chapter emphasizes the significance of investments in ecological (green) infrastructure in reducing the costs and increasing the efficiency of water services delivery (UNEP 2011b).

Despite the numerous benefits of GI, its wider implementation faces a number of challenges, such as

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3 For the purposes of this publication, the terminology of Green Infrastructure is adopted, while it is acknowledged that terms of ecological and natural infrastructure are often used to describe the same or similar approaches. Furthermore it is acknowledged that the present definition of Green Infrastructure is narrower and more focused on the utilitarian services of ecosystems than other widely used definitions (e.g. Naumann et al. 2011). This narrow definition avoids overlaps with the definitions of nature, ecosystems and conservation.

lack of awareness by decision-makers and rigid regulatory or funding policies that stipulate traditional grey approaches. Also, there is a need for agreed methodologies for cost-benefit analyses that would enable a full comparison of grey and green infrastructure options. This guide seeks to address some of these challenges, by:

- Introducing the role of GI in addressing the most common water management challenges
- Providing an overview of GI solutions for water management, along with their direct and auxiliary benefits
- Outlining a stepwise methodology for options assessment of green and grey infrastructure investments to assist implementation
- Providing a brief overview of a number of practical tools to support evaluation of appropriate solutions.

The aim of this guide is to raise awareness of the benefits of GI solutions for water resources management and to provide a basis for informed assessment of options among green and grey infrastructure alternatives. It explores the potential applicability of GI solutions, either as stand-alone solutions or integrated within hybrid approaches (a mutually complimentary mix of green and grey infrastructure). The target audience for the guide is water managers, spatial planners, decision and policy makers, infrastructure engineers, and other stakeholders planning and implementing projects for water management, or those that have a strong interest in such decisions and projects.

The guide contains six chapters. Following this introductory chapter, Chapter 2 provides an overview of the green infrastructure solutions included in the guide. Chapter 3 then describes each GI solution in more detail, including an overview of the most important co-benefits (benefits beyond the delivery of the water-related services). A practical stepwise methodology for assessing and comparing different green and grey infrastructure solutions is presented in Chapter 4, while Chapter 5 provides a brief overview of practical tools to support first steps in the process of identifying and quantifying the benefits and co-benefits. Chapter 6 reflects on main benefits, barriers and the way ahead.

Green Infrastructure and Ecosystem Services

Green Infrastructure solutions are based on the utilization of ecosystem services. Ecosystem services may be defined as “the direct and indirect contributions of ecosystems to human wellbeing” (TEEB 2010). Several classifications of ecosystem services exist including those presented by the Millennium Ecosystem Assessment (MEA 2005), TEEB (TEEB 2010) and the Common International Classification of Ecosystem Services (CICES 2013). In this guide, the TEEB classification is used; it categorizes ecosystem services into the following four groups:

Provisioning Services: ecosystem services that describe the material or energy outputs from ecosystems. They include food, water and other resources.

Regulating Services: services that ecosystems provide by acting as regulators e.g. by regulating the quality of water and soil or by providing flood and disease control.

Cultural Services: nonmaterial benefits that people obtain from ecosystems though spiritual, recreational and aesthetic experiences.

Habitat or Supporting Services: services needed for the production of all other services. They differ from provisioning, regulating and cultural services in that their benefits to people are indirect.

Green Infrastructure solutions are linked to ecosystem service provision in two ways:

Primary service provision: the sub-set of ecosystem services provided by a GI solution that directly complement, augment or replace services provided by water infrastructure.

Co-benefits: All additional/complimentary ecosystem services provided by a GI solution.

2

KEY WATER RESOURCES MANAGEMENT ISSUES ADDRESSED BY GREEN INFRASTRUCTURE SOLUTIONS

2.1 Water supply regulation 14

2.2 Water quality regulation 14

2.3 Moderation of extreme events 15

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This chapter provides a short overview of the key water management issues that can be addressed by utilizing GI. It also points to the relevant GI solutions that can be used to achieve desired improvements. More detailed information on each of the solutions can be found in Chapter 3.

Table 2 offers an overview of all GI solutions included in this guide, and their respective Water Resources Management (WRM) benefits, as well as conventional grey water infrastructure alternatives, all categorized across three overarching areas of water management issues.

Table 2 Overview of GI solutions relevant for water resources management. Solutions marked with '*' consist of built ('grey') elements that interact with natural features and seek to enhance their water-related ecosystem services.

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

It is important to be aware of the fact that utilization of these green infrastructure solutions may impact the ecosystems themselves. For example, a wetland receiving pollution loads that exceed its assimilative capacity may deteriorate and no longer be able to provide purification services. Therefore, sustainable utilization of green infrastructure relies on understanding and respecting the carrying/assimilative capacity or tolerance limit of ecosystems.

2.1 Water supply regulation

Sufficient water supply is a precondition for the functioning of any community, industrial and economic activity, as well as for the health of ecosystems. Grey infrastructure, including water treatment plants and distribution pipes, are essential in providing water to large populations. However, water supplies invariably originate from the broader landscape of watersheds and aquifers, and so natural ecosystems are the foundation of water provision. Therefore, GI solutions that affect hydrological processes such as runoff and infiltration can be the first line of defence for maintaining or enhancing water supplies.

GI can help to:

- Increase/sustain (clean) water supplies by increasing the water infiltration and storage capacity of wetlands/soils and increasing recharge of aquifers.
- Mitigate droughts through the release of water during drought from natural storage features, including soil and groundwater, surface water and aquifers.

GI options for Water supply regulation: Re/afforestation and forest conservation, Reconnecting rivers to floodplains, Wetlands restoration/conservation, Constructing wetlands, Water harvesting, Green spaces and Permeable pavements.

2.2 Water quality regulation

Water purification (filtration and chemical conversion)

Water pollution from both point and non-point sources of nutrients, sediments, heavy metals, persistent organic pollutants (POPs) and waterborne diseases is one of the major challenges in water management. Industrial, commercial or domestic human activities create wastewater that must be treated to avoid water pollution. Typical infrastructure solutions to deal with wastewater from these activities include constructed wastewater treatment facilities. The main source of non-point pollution is diffuse runoff from cultivated or industrial land. Some of the most frequently used infrastructure solutions to these challenges include expanding the water drainage infrastructure to capture polluted runoff and divert it to water treatment plants. A number of GI solutions can be used to provide the service of water purification either as an alternative or supplement to traditional water treatment infrastructure.

GI can help to:

- Purify polluted water from both point and non-point sources by trapping and/or containing sediments, pollutants in sediments, soils and vegetation (filtration and chemical conversion).
- Protect groundwater from contamination by removing sediments, heavy metals and other pollutants from the infiltration water.
- Relieve pressures on existing water treatment infrastructure via bioretention and infiltration practices that support water capture and infiltration, and slow down release of contaminants.

GI options for Water purification: Re/afforestation and forest conservation, Riparian buffers, Reconnecting rivers to floodplains, Wetlands restoration/conservation, Constructing wetlands, Green spaces and Permeable pavements.

Erosion control

Healthy ecosystems may effectively prevent soil erosion and thereby reduce sediment load – and associated pollution - to river systems. While low-lying ecosystems such as wetlands are important "sinks" for sediments (see above), healthy ecosystems on high-gradient terrain, such as forested slopes, effectively protect potential sediment "sources".

GI can help to:

- Stabilize and protect hill slopes, riverbanks and shorelines, thereby reducing erosion and associated pollution, and can bring additional biodiversity benefits and livelihood diversification options.
- Reduce sedimentation in reservoirs, channels and harbours by removing sediments from the inflow. This, in turn, preserves the functionality (e.g. flood control and/or water supply) of grey infrastructure (i.e. dams) and prevents additional costs for dredging.

GI options for Erosion control: Re/afforestation and forest conservation, Riparian buffers and Reconnecting rivers to floodplains.

While excess sediment loads may be harmful to ecosystems, suspended sediments are natural components of healthy aquatic ecosystems. Downstream ecosystems – in particular estuary/coastal wetlands – depend on a sufficient supply of sediments and associated nutrients to maintain their integrity. Furthermore, removing suspended sediment from a river/stream increases the sunlight penetration and the visibility in the water column and thus affects the species composition of the in-stream flora and fauna. Therefore, depriving a river of its sediments may be as detrimental to ecosystem health as excess sediment loads.

Water temperature control

Water temperature directly and indirectly affects aquatic ecosystems and their ability to provide water purification services. Thermal pollution occurs when the natural temperature of a water body is elevated (or sometimes reduced) due to human activities – such as waste heat from industrial activities and deforestation.

GI can help to:

- Reduce temperature of waterways affected by thermal pollution by providing shade.

GI options for Water temperature control: Re/afforestation and forest conservation, Riparian buffers, Reconnecting rivers to floodplains, Wetlands restoration/conservation, Constructing wetlands and Green spaces.

Biological control

Healthy and balanced ecosystems are more capable of controlling pests, invasive species and waterborne diseases. Ecosystems regulate such water pollutants through the activities of predators and parasites. Biological control depends on very sensitive interactions between species and the balance is easily disturbed. Utilization of ecosystems (GI solutions) for biological control in pollution management must therefore be based on solid knowledge about the ecosystem and its assimilative capacity/tolerance.

GI can help to:

- Reduce pollution caused by pests, invasive species and waterborne diseases.

GI options for Biological control: Re/afforestation and forest conservation, Riparian buffers, Reconnecting rivers to floodplains, Wetlands restoration/conservation and Constructing wetlands.

2.3 Moderation of extreme events

Riverine flood control

Floods are one of the most common and costly natural disasters. Traditional flood management infrastructure solutions rely on engineered solutions such as dams, levees and floodwalls. While these solutions are essential to safety in many locations, they can be expensive and can shift flood risk to other locations. Further, engineered solutions can contribute to a false sense of security and, when coupled with inappropriate land-use patterns - such as dense housing within deep floodplains - can actually contribute to greater losses when they fail. Floodplains are among the most productive ecosystems. Hence, engineered solutions that focus on severing the connection between rivers and floodplains have contributed to a great loss of ecosystem services from river-floodplain systems, such as productive fisheries. A number of GI solutions can contribute to moderation of flood events by increasing the ability of the landscape to store water or by increasing the ability of channels to convey floodwaters. On a watershed level, better forest and wetland management uses the natural ability of ecosystems to retain water, slowing down and absorbing some of the storm runoff. Forests also help to stabilize banks, reducing the impacts of flooding, land erosion and landslides. In urban areas, green roofs, permeable pavements and green spaces help to absorb water, facilitate infiltration and minimize stormwater runoff. This, in turn, reduces or prevents sewer system overflows and flooding and relieves the load on existing flood management infrastructures. Along rivers, floodplains can increase channels' abilities to convey water and reduce pressure on levees.

GI can help to:

- Increase water storage capacity in watershed and urban areas and thus reduce downstream flooding
- Reduce flow velocity of flood waters
- Create space/room for the river (e.g. increase channel conveyance)

GI options for Riverine flood control: Re/afforestation and forest conservation, Riparian buffers, Reconnecting rivers to floodplains, Wetlands restoration/conservation, Constructing wetlands and Establishing flood bypasses.

Urban stormwater runoff

In urban environments, stormwater runoff can be a major cause of deterioration of waterways. The storm runoff flushes pollutants from surrounding areas into waterways and can cause overflow of combined sewers. Standard grey infrastructure solutions to these challenges, including expansion of water drainage infrastructure, can in some instances further exacerbate the problem (e.g. where greater amounts of water are simply drawn in from larger areas).

GI can help to:

- Reduce the risk of sewer overflow and contamination of water by facilitating infiltration and storage of stormwater, thereby minimizing excessive stormwater runoff

GI options for Urban stormwater runoff: Green roofs; Green spaces; Water harvesting and Permeable pavements.

Coastal flood protection

Temporary extreme sea levels, and associated coastal storms, and surges can result in coastal flooding and cause widespread damage to human construction, livelihoods and ecosystems. As a result of climate change, the projected sea rise may further expose coastal areas to damage by higher water tables and higher extreme water levels, shoreline erosion, inundation of low lying areas and saltwater intrusion (UNEP and SEI 2010). This calls for wider implementation of coastal protection measures, an area where GI can play a significant role.

By functioning as buffer zones, coastal ecosystems such as mangrove forests, coastal marshes and barrier reefs, can often provide the same benefits as conventional grey solutions in the form of dykes and levees (DG Environment 2011) and protect coastal areas from erosion and inundation (saltwater intrusion) during large storms.

GI can help to:

- Reduce coastal (shoreline) erosion through creation of natural breakwaters that can absorb the energy of waves
- Prevent saltwater intrusion by storing stormwater and reducing inundation

GI options for Coastal flood protection: Protecting/Restoring mangroves, coastal marshes and dunes; Protecting/restoring reefs (coral/oyster).

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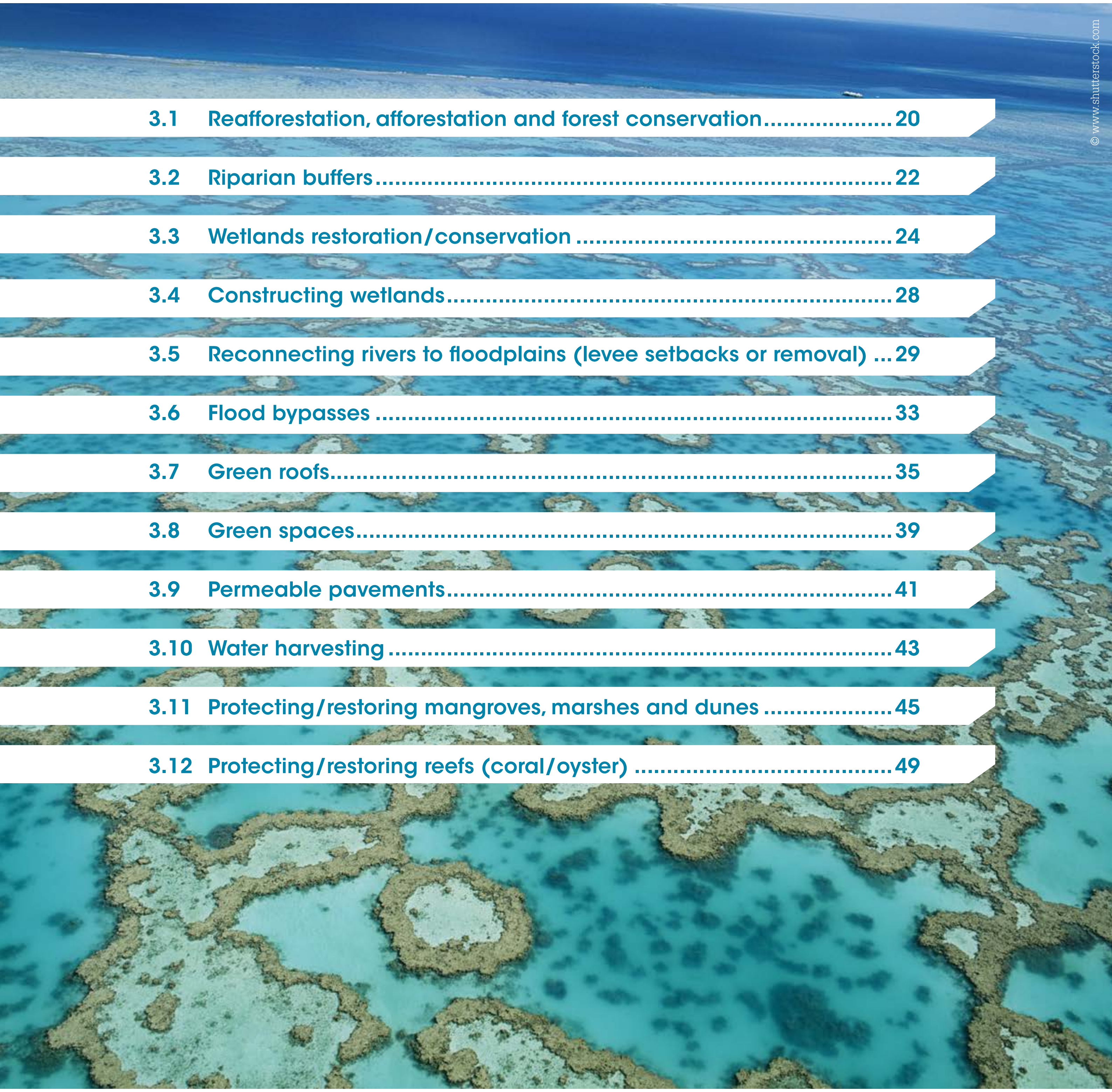
GREEN INFRASTRUCTURE SOLUTIONS FOR WATER MANAGEMENT



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This chapter introduces all GI solutions in more detail, giving an account of the main water management benefits, co-benefits and cost examples/considerations for each of the GI solutions.

All the GI solutions included in this guide utilize the provision of ecosystem services in delivery of both water management and auxiliary benefits described in this chapter. They do so in following ways:

1. Through primary water management-relevant ecosystem services provision, which can then complement, augment or replace services provided by grey water infrastructure, helping to solve the water management challenges;
2. Through delivery of additional ecosystem services, these form the basis for a number of co-benefits beyond the water sector.

Table 3 provides a summary of these ecosystem services for the GI solutions included in this guide, based on TEEB classification.

Table 3 Ecosystem services provided by GI solutions. Blue cells mark services directly related to water management issues while light blue mark co-benefits. Icon design: Jan Sasse for TEEB.

	Ecosystem services (TEEB classification)																
	Provisional				Regulating							Supporting		Cultural			
	Water supply	Food production	Raw materials	Medicinal resources	Temperature control	Carbon Sequestration + storage	Moderation of extreme events	Water purification	Erosion control (incl. shoreline)	Pollination	Biological control	Habitats for species	Maintenance of genetic diversity	Recreation	Tourism	Aesthetic/cultural value	Spiritual experience
GI solution																	
Re/afforestation and forest conservation	■	▨	▨	▨	■	▨	■	■	■	▨	■	▨	▨	▨	▨	▨	▨
Riparian buffers		▨	▨	▨	■	▨	■	■	■	▨	■	▨	▨	▨	▨	▨	▨
Wetlands restoration/ conservation	■	▨	▨	▨	■	▨	■	■	▨	▨	■	▨	▨	▨	▨	▨	▨
Constructing wetlands	■				■	▨	■	■	▨								
Reconnecting rivers to floodplains	■	▨	▨	▨	■	▨	■	■	■	▨	■	▨	▨	▨	▨	▨	▨
Establishing flood bypasses							■					▨		▨		▨	
Water harvesting	■						■		▨							▨	
Green roofs		▨			▨		■			▨		▨				▨	
Green spaces (Bioretention and infiltration)	■	▨			■		■	■	▨			▨		▨		▨	
Permeable pavements	■						■	■	▨								
Protecting/restoring mangroves, marshes and dunes		▨	▨	▨	▨		■		▨	▨	▨	▨	▨	▨	▨	▨	▨
Protecting/restoring reefs (coral/oyster)		▨					■		▨		▨	▨	▨	▨	▨	▨	▨

As mentioned earlier, utilization of GI solutions may impact the very ecosystems that they draw upon to provide water management benefits. Therefore, sustainable utilization of GI relies on understanding and respecting the carrying/assimilative capacities or tolerance limits of ecosystems, which vary greatly with types of ecosystems and local contexts, and must always be assessed on a case-by-case basis.

3.1 Reafforestation, afforestation and forest conservation

Description

Reafforestation and afforestation refer to to activities where trees are established on lands with no forest cover.[4] The concept of reafforestation is usually used in reference to areas where there was recent forest cover. For areas without an historical record of forest cover, the planting of trees is referred to as afforestation (IPCC 2000). The activities could also include making a conscious decision to maintain forests on lands that would otherwise be handed over for other types of land development, as part of targeted water management interventions.

Benefits

Primary

Reafforestation and afforestation activities, as well as existing forests, can help to reduce the occurrence and intensity of floods. Many communities are already harnessing the water benefits of forests. Forest areas in the upper watersheds can help retain water and stabilize slopes, thereby reducing the risks and disaster caused by storms. Deforestation is a major cause of land degradation and soil erosion. With soil erosion, its ability to store and retain water diminishes, which contributes to higher risks of flooding, as the soils are no longer able to reduce the rate and volume of runoff that occur in the event of heavy rainfall and storms. While increase in forest cover is unlikely to significantly affect outcomes of strong flood events in big watersheds or strong, low frequency floods in smaller rivers, it can have a high impact on reducing minor to moderate floods in relatively small and medium-sized watersheds.

Trees intercept rainfall and increase infiltration, and the ability of soils in forest areas to store more water and release it through evaporation helps in regulating the water quantity during extreme weather events (CNT & American Rivers 2010). However, intensive reafforestion/afforestation activities may reduce the local total annual runoff and groundwater recharge due to increased water loss through evapotranspiration. Thus, there is a trade-off between a more constant supply of water and a reduction in total available water volume. Planting tree species particularly adapted to the local climate and hydrology can help to predict the impacts on groundwater recharge with higher certainty and thus provide greater choices of the most appropriate interventions.

Forests can also reduce the likelihood (or frequency) of landslides, mudflows and avalanches, which can cause extensive damage to infrastructure and inhabited areas vulnerable to floods (EC 2011).

Establishing or conserving forests (but also promoting other sustainable land use activities in the watershed) can contribute to improving water quality. Forests improve water quality by reducing sediment in water bodies and trapping or filtering other water pollutants. Along the shores of water bodies, the roots help to stabilize banks against erosion. Forest cover is also an effective way to prevent other pollutants from draining into the watercourse and regulating sediment flow, if distributed throughout the upstream watershed e.g. drinking water supply reservoir (FAO, 2008). Such measures to ensure a high quality drinking water supply have already been put in place in a number of countries across the globe - a third of the world's hundred largest cities rely on forested protected areas for their drinking water. In fact, well-managed forests often provide clean water at costs lower than those of treatment plants (TEEB 2009).

Forests and riparian buffers in particular, also help to mitigate thermal pollution by providing shade to the streams (see next chapter on Riparian buffers).

Co-benefits

Forests are among GI solutions with the greatest environmental and socio-economic co-benefits. In addition to the immediate benefits that forests have in regulating water quantity and quality, they can also function as carbon sinks, increase pollination for nearby agricultural fields, improve air quality, regulate local climate (including cooling) and help preserve biodiversity. For example, a study from Cascine Park in Florence, Italy, shows that the urban park forest maintained its ability to remove air pollutants over a period of 19 years, removing about 72.4 kg per hectare per year, despite some tree losses due to logging and extreme weather events. Harmful pollutants removed included O_3, CO, SO_2, NO_2, and particulate pollutants, as well as CO_2 (TEEB 2011). Increasing forest cover can also open up possibilities for alternative livelihoods and income

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[4] For the purposes of this report, the cut-off time between afforestation and reafforestation activities will not be of significance, as both refer to activity of establishing trees on land without present tree cover.

opportunities through agroforestry, ecotourism and a range of other forest products.

Costs

The primary costs of establishing forests include the cost of land, purchasing seeds or saplings and tree planting (Foster et al. 2011). Reafforestation can also take place through natural regeneration. Just like any infrastructure investment, opportunity costs and ongoing maintenance needs should be considered, in addition to the initial cost of investment in GI. The costs of reafforestation/afforestation or forest conservation activities are usually directly dependent on existing alternatives for land use and vary greatly depending on the location.

For example, lands in or near major urban centres are likely to be more costly to use for such purposes than those in more remote areas due to demands for competing land uses. They may also yield larger benefits. In the city of San Diego, USA, it was estimated that in 2002 the stormwater retention capacity of the urban forest was 2 million cubic meters. If this forest were lost, it is estimated that providing the same benefit through built infrastructure would cost approximately USD 160 million (American Forests 2003).

An important cost consideration is also time lag, which can be substantial for reforestation/afforestation projects, increasing the overall project costs (TEEB 2009). This makes a particularly strong case for forest conservation as one of the priority interventions to maintain water services provided by trees. Trees take time to mature and be able to deliver the full range of services, in contrast to grey infrastructure, which begins operation as soon as it is created. This can also cause afforestation activities to be evaluated negatively, compared to traditional solutions. Forests are also exposed to a number of less predictable risks that can compromise delivery of water benefits and require additional investment – e.g. wildfires, change in ecosystem services due to climate change and pests. The exact costs of GI activities within afforestation or forest conservation are location specific and dependent on a wide range of variables. The data on exact costs is sparse, but a recent database with 127 GI projects from the European Union found that the costs for reafforestation/afforestation projects ranged from USD 1,300 to USD 2,500 per hectare of forest (Naumann et al. 2011).

Where standing forests are a source of delivery of these benefits, and where land development activities threaten the continuity of these, an "action" for these communities to take is to conserve strategic networks of those forests that are most important for the provision of water. Part of that means making sure timber operations are conducted in a way that don't degrade water resources, choosing alternative land development options, and making a strategic decision to forego potential investments returns to preserve forest cover and associated ecosystem service delivery. Water funds, operating based on the principles of payment for ecosystem services (PES), is just one example of possible approaches to preserve forest ecosystem services (See text Box 5).[5]

Reafforestation, afforestation and forest conservation	
Water management benefits	**Co-benefits**
• Riverine flood control • Water supply regulation (including drought mitigation) • Water purification and biological control • Water temperature control • Erosion control (Reduced risks of landslides, mudflows and avalanches)	• Carbon sequestration • Biodiversity benefits (incl. pollination) • Improved air quality • Climate regulation • Recreational, tourism and alternative livelihood possibilities

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[5] Water funds are financial mechanisms, often operating as public-private partnerships, investing in activities that help to maintain water related ecosystem services in watersheds, while also helping to deliver socio-economic benefits to the communities upstream (Russi et al. 2013). Water funds typically operate on the principles of payments for ecosystem services, where the funds receive financial resources from main water services users, and invest them directly in activities that support conservation and continuous delivery of ecosystem services in the watershed (TNC 2013).

Box 1. Fondo de Agua por la Vida y l Sostenibilidad (FAVS) – Water Fund for Life and Sustainability

The East Cauca Valley Water Fund in Colombia was established in 2009 and is overseen by the Cauca Valley's sugar cane producers association (ASOCANA), sugar cane growers association (PROCANA), each watershed's local environmental authority, Vallenpaz (a peace and justice organization) and The Nature Conservancy (TNC).

The sugar cane producers in the region rely on a regular supply of clean water for their production activities. To ensure a long-term supply of water ecosystem services, the private sector sugar cane growers and producers came together and committed an investment of USD 10 million over five years to finance sustainable projects across seven watersheds.

Payments for water services are calculated based on hectares and tonnes of sugar cane produced, while investments have gone to such activities as changing land use or intensity, fencing, silvopastoral systems, forest enrichment and restoration.

Source: TNC (2013).

3.2 Riparian buffers

Description

Riparian buffers are vegetated, often forested, areas ("strips") adjacent to streams, rivers, lakes and other waterways protecting aquatic environments from the impacts of surrounding land use (Enanga et al. 2010). Use of riparian buffers to maintain water quality in streams and rivers is considered to be a best forest and conservation management practice in many countries and is mandatory in some areas.

Benefits

Primary

Riparian buffers help to maintain water quality in waterways by protecting streams from non-point source pollution (e.g. from surrounding agricultural activities). Riparian vegetation cover prevents sediments, as well as such pollutants as nitrogen, phosphorus and others from entering water through biological (e.g. nutrient uptake by riparian vegetation) and physical-chemical (e.g. nutrient absorption for phosphorus which binds to clay particles and sediments) processes (Enanga et al. 2010).

Vegetation and tree roots also stabilize banks and prevent erosion. During flood events, riparian vegetation slows down runoff by absorbing excess water, reduces peak flow and helps to mitigate potential flood damage downstream (Colgan et al. 2013). Such buffer strips also yield benefits in agricultural areas, both by retaining sediment and nutrients from entering the waterways, thereby preventing water pollution, and maintaining soil productivity on the fields (Schmidt and Batker 2012). Some studies show that riparian buffers can help to reduce the amount of sediment reaching the streams by as much as 80 per cent (Crétaz and Barten 2007).

Trees also provide shade and reduce water temperature fluctuations, which is an important factor for the survival of many aquatic species. Shade provided by riparian vegetation also contributes to maintaining water quality, as high levels of light leads to increases in in-stream primary production, and can change the invertebrate species composition (Parkyn 2004). Increases in summer water temperatures can increase anoxia in stratified lakes, elevate the rate of phosphorus releases from lake and slow moving river sediments and cause algal blooms (Whitehead et al. 2009). Together with changes in actual water flows that affect riparian vegetation and water biota, the combined factors can impact on riparian food webs (Covich et al. 1999). A recent study in Denmark found that relatively short stretches (100–500 m) of riparian forest combat the negative effects of heating of stream water (Kristensen et al. 2013).

Co-benefits

Depending on the extent and the type of vegetation in the riparian buffers, they can provide important biodiversity benefits. Vegetation provides biodiversity habitat for many species, that in some cases can be particularly beneficial for agricultural activities via insects and birds that facilitate pollination of the

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Multiple rows of trees and shrubs, as well as a native grass strip, combine in a riparian buffer to protect Bear Creek in Story County, Iowa, USA.

fields. The cover and shade also provide favourable conditions for birds and other animals that can take refuge in the buffer zones, and which use the riparian buffer zones as corridors for movement. This is important for pastoralist communities that often rest animals in riparian areas for watering, grazing and protection. Riparian vegetation, either designed or natural, is sometimes referred to as "shelterbelts" and offer shade and weather protection (due to cooling effects). They also reduce wind velocities, dust (including air pollutants) and erosion (Bird et al. 1992; Bird 1998; Heath et al. 1999).

In addition, riparian buffers can offer aesthetic and recreation value to nearby communities (Schmidt and Batker 2012). Drought, however, can weaken the resilience of intact riparian vegetation and larger forest ecosystems to pests and disease (Anderson 2008). The falling leaves and debris in turn provide food for aquatic species (Parkyn 2004). Moreover, water systems containing too many dead leaves and stored organic matter can become hypoxic, with decreased pH and fairly high concentrations of tannin and lignin, making the water toxic to fish and other aquatic species (Gehrke et al. 1993; Bond et al. 2008).

Costs

Costs associated with establishment and conservation of riparian buffer strips include land acquisition and any associated foregone economic opportunity, and when necessary, the planting of buffer zones. Where riparian land is on private property, public investment may need to be made for land acquisition or economic incentives for private landowners to establish riparian buffers.

Box 2. Feitsui reservoir in Northern Taiwan

A study was conducted to assess the potential benefits and costs of riparian buffers in the Feitsui watershed in order to protect water quality. The study explored the effectiveness and cost of riparian buffers (and appropriate conservation practices) using four different scenarios, applying simulation models and a statistical relationship between pollution reduction rate and the width and slope of a buffer strip.

A cost-benefit analysis coupled with net present value method was used to estimate the costs of the different planning approaches. Analysis showed that even with same design (5 per cent slope and 30 m width), the costs of the buffers as well as pollutant reduction rate differed remarkably, depending on the placement within the watershed as well as the length of buffer trips. The costs of the four different scenarios assessed ranged from USD 11 million (reducing 46,650 m^3 of silt deposits a year) to USD 142 (annual reduction of silt deposit by 583,120 m^3).

Source: Chang et al. (2010)

The extent and efficiency of benefit delivery of buffer strips greatly depends on the width of the buffers, which may imply minimum land use to achieve anticipated water benefits. For example, a case study in River Njoro Watershed in Kenya shows that the concentration of phosphorus in the soil in riparian buffers narrower than 30m was significantly higher than the reference condition observed in gazetted forest, while there were no significant differences in concentrations among those buffer zones larger than 30m and the reference condition. The efficiency of nutrient removal also depends on the local hydrology, e.g. if the water flows from adjacent lands bypassing riparian buffers on their way to the stream (Enanga et al. 2010). Riparian buffers can therefore be effective in reducing nutrients, but their efficiency increases with width, forest cover and longitudinal connection (Harding et al. 2006; Nilsson and Renöfält 2008).

Where natural riparian buffers and forested areas have been lost due to urbanization and other types of land development, the extent to which such buffers can be restored will be limited, especially in urban areas. Where possible, however, the benefits can be significant. A case study in McKenzie Watershed (Oregon, USA) estimated the value of riparian buffers to be between USD 2,548 and USD 16,588 per hectare (USD 1,031 to USD 6,713 per acre) per year, estimated based on a range of benefits delivered via associated ecosystem services: from water supply and quality to recreation (Schmidt and Batker 2012).

Riparian buffers	
Water management benefits	**Co-benefits**
• Riverine flood control • Water purification and biological control • Water temperature control • Erosion control (bank stabilization)	• Biodiversity benefits (incl. pollination) • Recreational, aesthetic value

3.3 Wetlands restoration/ conservation

Description

Wetlands restoration is the renewal of wetlands that have been drained or lost as a result of human activities. Wetlands that have been drained and converted to other uses often retain the characteristics of soil and hydraulics and therefore can be restored (EPA 2012). In general, the best way to prevent further loss of ecological and economic value due to degradation of wetlands is by eliminating the pressures driving the loss and degradation of wetlands (e.g. designating wetlands as conservation sites).

Benefits

Primary

Wetlands can provide significant support (or even replacement) to traditional infrastructure for water treatment, water supply, drought mitigation and flood control. Often, water quality and quantity regulation services provided by wetlands are cost-competitive (and more sustainable) to those provided by conventional infrastructure solutions, while providing a wide range of socio-economic co-benefits.

Wetlands contribute to water quality through their natural ability to filter effluents and absorb pollutants. Microorganisms in the sediment and vegetation in the soil help to break down many types of waste, eliminating pathogens and reducing the level of nutrients and pollution in the water (TEEB 2011). Thus, wetland restoration can help to provide clean water for ecosystems, energy production, drinking water needs and other uses.

The ability of wetlands to store large amounts of water, and release it slowly, also plays a key role in the natural regulation of water quantity during periods of droughts and floods (Silva et al. 2010). Wetlands can "slow" flood waters, minimizing the potential flood damage downstream and increase resilience to storms, thereby avoiding potential damage to grey infrastructure and human lives. In periods of drought, they can function as "retention basins", providing water through slow release of the stored water. The retention capacity of the different types of wetlands[6] varies and need to be evaluated individually. For instance, some types of high altitude grasslands (also a type of wetland) are known for their capacity to retain humidity and regulate water flows by retaining it in the soils and vegetation. The lower temperatures due to the high altitude also ensure that the evaporation is limited (Echavarria 2002). This may not be the case for all types of wetlands, and the water supply from wetlands can be limited in periods of extreme droughts.

By trapping sediments, wetlands also reduce downstream transport of sediments (Russi et al. 2013), whereas restoring the natural environmental flows can contribute to better biological control (Forslund et al. 2009).

Co-benefits

Beyond the immediate water quantity and quality related benefits wetlands offer recreational value and support livelihoods through e.g. fisheries and tourism. Additionally, they provide habitats for a number of species, delivering some of the highest biodiversity benefits among all GI solutions. They also play an important role in climate change adaptation and mitigation. Peatlands, for instance, are the most important for carbon storage, containing approximately 30 per cent of carbon on land, while covering only 3 per cent of the land area. Restoring and preserving peatlands is therefore a key strategy for climate change mitigation (Russi et al. 2013).

Costs

Wetlands restoration in most cases involves a number of trade-offs, providing improved state of water related ecosystem services and livelihood options for some, while potentially eliminating sources of income for others. One must also consider the potential of creating larger areas of standing water, which can form habitats for the spread of vector borne diseases, especially in the tropics (Forslund et al. 2009). In the long term, benefits are usually enjoyed by the majority of stakeholders; managing the transition period is crucial in successful restoration efforts. Costs of wetlands restoration vary depending on the location and the level of degradation. Russi et al. (2013) found that restoration costs can be high, requiring investment not only in the physical restoration works, but also in long term management, to ensure, often slow, recovery. Nevertheless, cases from around the world show that once restoration of wetlands and associated ecosystem services succeeds, the economic and social benefits can be exceptionally high. Russi et al. (2013) and Alexander and McInnes (2012) provide numerous examples of the economic benefits of wetland restoration.

Wetland restoration/conservation	
Water management benefits	**Co-benefits**
• Water supply regulation (incl. drought mitigation) • Flood mitigation • Water purification and biological control • Water temperature control	• Biodiversity benefits (incl. pollination) • Recreational, aesthetic value • Livelihood income possibilities • Climate change adaptation and mitigation (carbon storage and sequestration)

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[6] The various types of wetlands include freshwater, brackish or saline, inland or coastal, seasonal or permanent, natural or man-made. These include mangroves, (peat) swamps and marshes, rivers, lakes, floodplains and flooded forests, rice paddies, as well as coral reefs (Wetlands.org).

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The Muthurajawela wetlands in Sri Lanka.

Box 3. Restoring coastal wetlands: The Muthurajawela integrated coastal wetland system in Sri Lanka

Muthurajawela covers an area of 3,068 hectares, the largest saline coastal peat bog in Sri Lanka, and together with the Negombo Lagoon, it forms an integrated coastal wetland system of high biodiversity and ecological significance. Its system provides a range of ecological and hydrological services including receiving and retaining high loads of domestic and industrial wastes, and sediment and silt loads, from surrounding and upstream areas. Water quality and fisheries production in downstream Negombo Lagoon are heavily dependent on these wetland services. Negombo Lagoon has a high productivity for fisheries of an estimated 150 kg/hectare/year, involving more than 3,000 families from 26 villages.

Wetland plants facilitate sediment deposition before water enters Negombo Lagoon. They also act as a filter for through-flowing waters and assist in the removal of nutrients and toxic substances. During the rainy season large volumes of water enter the wetland system, from rainfall, through runoff from surrounding higher grounds and via floodwaters from the Dandugam Oya, Kalu Oya and Kalani Ganga which feed the marsh. Muthurajawela buffers these floodwaters and discharges them slowly into the Negombo Lagoon. By maintaining surface, near-surface and possibly groundwater levels, the marsh also plays a major important role in local freshwater supplies. Muthurajawela also acts as a source of freshwater to the tidal delta, and is critical in moderating salinity and pollution levels. Its sheltered waters, flooded vegetation and mangrove areas all constitute important breeding grounds and nurseries for freshwater and marine food species of fish and crustaceans.

Services	Value (USD/year)	Value (USD/ha/year)
Flood attenuation	5,394,556	1,758
Industrial wastewater treatment	1,803,444	588
Agricultural production	336,556	110
Support to downstream fisheries	222,222	72
Firewood	88,444	29
Fishing	69,556	23
Leisure and recreation	58,667	19
Domestic sewage treatment	48,000	16
Freshwater supplies	42,000	14
TOTAL	**8,072,111**	**2,631**

The estimated economic value of sustainable local resource use and recreation on the Muthurajawela Marsh is more than USD 500,000 per year. The provision of localized ecosystem services such as flood attenuation, industrial and domestic wastewater purification and year round surface and sub-surface water supplies have an annual value in excess of USD 7 million a year. The wetland's support to downstream fish productivity in the Negombo Lagoon contributes a value of almost USD 225,000. Combined, these translate into economic benefits of just over USD 2,600/hectare/year for the whole of the Muthurajawela Marsh.

More than 30,000 people, most of them poor slum dwellers and fishing households, gain from these economic goods and services. A valuation study's findings underline the high economic benefits that could accrue from wetland restoration, but also indicate that any reduction in extractive wetland activities would constitute real economic losses to local households.

Source: This case study is adapted from Emerton, L. and Kekulandala, B. (2002).

3.4 Constructing wetlands

Description

While wetlands restoration aims to renew their natural functions, constructed wetlands are created artificially with the aim of simulating the hydrological processes of natural wetlands. They usually take the form of shallow depressions with dense and diverse vegetation cover (CWP 2007). Constructed wetlands function as biological wastewater treatment "technologies", either as a supplement or a substitute to conventional treatment plants. They are often used for nutrient pollution control (and thus reduction of eutrophication risk) of various wastewater streams – domestic wastewater, grey water, urban wastewater from seweage, industrial wastewater, as well as sludge (WECF 2011). Constructed wetlands can also be used to reduce flow velocity, remove nutrients and sediments and mitigate surface runoff from agricultural and livestock fields.

Benefits

Primary

Constructed wetlands are designed to mimic the processes of natural wetlands and their main water management benefits include improved water quality and flood and drought regulation. Wetlands are able to store large amounts of stormwater runoff, and release it slowly, helping to regulate water quantity. It is estimated that constructed wetlands can reduce 5 to 10 per cent of the volume of incoming runoff through seepage and evaporation (CWP 2007). Thus, constructed wetlands also contribute to groundwater recharge.

Just like in natural wetlands, the vegetation and sediments provide a growth media for microbes and filter, and settle pollutants attached to sediments; these attributes are optimized in the design of artificial wetlands (CWP 2007).

Usually, wetlands are constructed to provide secondary and tertiary wastewater treatment and improve local water quality through their natural geochemical and biological processes inherent in a wetland ecosystem. The pollutant removal rates are as high as 85 per cent for suspended solids, 75 per cent for phosphorus, 55 per cent for nitrogen and 45 per cent for organic carbon (CWP 2007).

Co-benefits

Naturally occurring wetlands are important habitats for various bird species, fish populations and other wildlife. Constructing wetlands can establish similar habitats, thereby providing biodiversity preservation, habitat to surrounding species, as well as community and recreational benefits. Depending on the size of the constructed wetlands, additional benefits may include carbon sequestration and storage and new income generating opportunities via e.g. tourism.

The world's largest commercial constructed wetlands are located in Oman. They were built to treat produced water from oil production operations in the Nimr oil fields, as an alternative to disposing water in deep aquifers. The wetlands cover more than 360 hectares and treat more than 95,000 m3 of wastewater each day. Furthermore, they provide habitats to fish and hundreds of species of migratory birds (TNC 2013).

Costs

The costs of constructing wetlands are highly location-specific and depend on the size, land acquisition costs, structure (e.g. damming is cheaper than digging) (BalticDeal 2012), as well as the local costs of building materials, labour and appropriate plants. A very important variable in design is also the purpose of the wetland, i.e. is water being treated for reuse or safe discharge in the environment? Maintenance costs are generally low, but might include costs of pumping where natural slope is not available. Some pre-treatment might also be necessary to avoid build-up of solids in the inflow area, odour nuisances, or clogging of the filter or blockages of the distribution pipes (WECF 2011). Based on these variables, investment costs can vary from just a few dollars to tens of thousands per hectare (BalticDeal 2012).

Cases studies show that constructed wetlands are often the cheaper option for small scale treatment of wastewater, compared to construction of treatment plants, but can be more difficult to use as a substitute for large scale treatment processes due to the larger land requirements and capital costs (Hoffmann 2011). For all uses, assessment should be done individually based on the specifics of the location, treatment needs and strategic priorities.

An artificial wetland was constructed in Washington, D.C. to deal with the regularly occurring Combined Sewer Overflows (CSOs) that were contaminating local waterways. The construction of the artificial wetland to process wastewater cost the city USD 26 million less than a conventional treatment system and saves USD 1.6 million annually in operational costs, while water discharged from the wetlands surpasses the quality of water from the city's wastewater treatment plant (PSNewswire 2013).

As is the case in forest restoration, it is also important to consider unintended consequences as part of planning for artificial wetlands (e.g. one concern can be proliferation of invasive species in the nutrient-rich habitats (Tanner et al. 2006)). Another important concern, particularly in the tropics, but also elsewhere in the world, is the creation of new habitats for mosquitos and thereby vector-borne disease risks (Medlock and Vaux 2011).

Constructing Wetlands	
Water management benefits	**Co-benefits**
• Water supply regulation (incl. drought mitigation) • Flood mitigation • Water purification and biological control • Water temperature control	• Biodiversity benefits (incl. pollination) • Recreational, aesthetic value • Reduced water treatment costs • Livelihood income possibilities • Climate change adaptation and mitigation (carbon storage and sequestration)

3.5 Reconnecting rivers to floodplains (levee setbacks or removal)[7]

Description

Along many major rivers, levees have been constructed close to the edge of the river channel, which maximizes the amount of land protected by a levee. By placing levees close to the channel, rivers become more effective conduits for drainage. It can also maximize the use of surrounding lands, even in times of high water levels.

However, levees close to the channel can create a set of problems and challenges. Because they greatly narrow the area available to transport floods, they do work to rapidly flush floodwaters and sediments through the system – but this means that the levees are exposed to high-velocity water along their "wet" side (Figure 1). This can result in erosion and high maintenance costs. In many places, the growing list of sites needing repair has outstripped the maintenance budget, resulting in levees that are more likely to fail during a flood (Leavenworth 2004; American Society of Civil Engineers 2009).

Levees close to a river also dramatically restrict the area of floodplain that benefits from periodic connections with the river and constricts the ability of the river to meander and create new river-floodplain habitats. Because of the vulnerability to erosion mentioned above, these levees often require armouring to prevent erosion and meandering, further diminishing the natural habitat values of the river's edge, which is generally the most biologically valuable habitat. Also, while levees may prevent flooding at one location, they may increase the risk of flooding upstream and/or downstream of the levees. Moving levees back away from the channel - often called "setback levees" - can alleviate these problems.

Benefits

Primary

Setback levees increase channel capacity for carrying floodwaters. By increasing conveyance through a section of river, setback levees can relieve "bottleneck" points on a river where floodwaters would tend to back up and potentially cause flooding.

While levees close to the channel are exposed to deep, high-velocity water during floods, setback levees are less frequently exposed to floodwaters because of the increased channel capacity. Further, because flow over floodplains is generally much shallower and slower than rivers, when setback levees are exposed to floodwaters they are less vulnerable to erosion.

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[7] Adapted from Jeffrey J. Opperman. (2014). "A Flood of Benefits: Using Green Infrastructure to Reduce Flood Risks", The Nature Conservancy, Arlington, Virginia. http://nature.ly/floodofbenefits

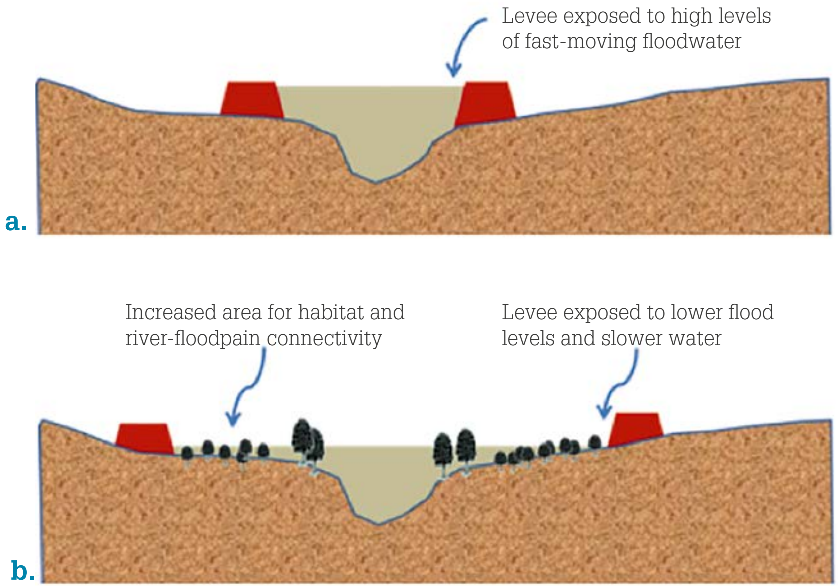

Figure 1. The top image (a) shows levees that are located relatively close to the channel. During a flood (pictured here), the levees are exposed to high levels of fast-moving water, increasing the risk of erosion and the need for maintenance. Further, there is limited area for natural river-floodplain habitats and processes between the levees. The second image (b) shows setback levees. For the same flood, the levees are exposed to lower water levels and velocities, reducing erosion risks and maintenance costs. The area that can support other floodplain benefits is greatly expanded. Source: Opperman (2014).

Co-benefits

In addition to flood-management benefits, setting levees back increases the area of floodplain exposed to periodic inundation from the river, thus increasing the variety of benefits from river-floodplain connectivity. The expanded area on the "wet side" of the levee provides greater room for the channel to meander and create floodplain habitat features, such as wetlands and forests. During overbank flooding, floodwaters spread out on floodplains and, due to slower water velocities on the floodplain, much of the sediment in transport is deposited there. Because nutrients such as phosphorous are largely adsorbed to sediment particles, this deposition can reduce the loads of sediment and some nutrients in rivers and thus improve water quality for downstream water bodies, such as estuaries and near-shore marine habitats (Noe and Hupp 2005). Biogeochemical processes within floodplain wetlands, such as denitrification, can also reduce nitrogen loads in river water (Burt and Pinay 2005; Valett et al. 2005).

During overbank flooding, a portion of floodwaters can percolate into the shallow groundwater. Portions of the reconnected floodplain can continue to be used for agriculture, with crop selection varying by expected inundation frequency.

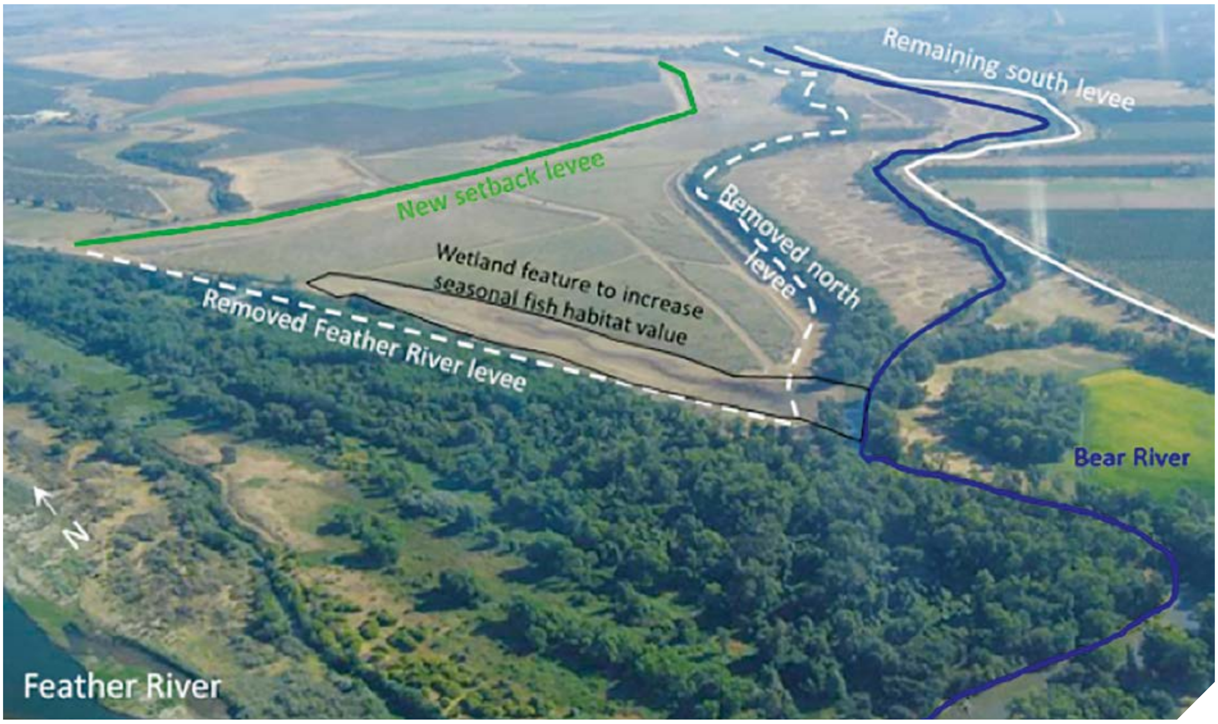

Figure 2. A setback levee project on the Bear River at its confluence with the Feather River (Central Valley, California, USA). To increase conveyance and reduce backwater flooding, the north levee of the Bear River and a section of levee along the Feather River were removed (white dashed line), and a two-mile long setback levee was built (green line). The project lowers flood risk along the Bear River and has restored hundreds of hectares of floodplain habitat. Adapted from Williams et al (2009).

Costs

The primary costs for levee setbacks are the removal and construction of levees and, potentially, the purchase of title or easements on the reconnected floodplain. If a levee needs to be replaced or rebuilt anyhow, then the primary costs are for the difference in land area no longer protected by a levee and now prone to periodic flooding. Because the reconnected floodplain can provide habitat and other benefits, conservation funding can be combined with flood-management funding to implement these projects. For example, funds for river restoration were committed to a proposed levee setback project on the Sacramento River in California, USA (Opperman et al. 2011).

Reconnecting rivers to floodplains	
Water management benefits	**Co-benefits**
• Water supply regulation (incl. drought mitigation) • Flood mitigation • Water purification and biological control • Water temperature control • Erosion control	• Biodiversity benefits (incl. pollination) • Recreational, aesthetic value • Reduced water treatment costs • Livelihood income possibilities • Climate change adaptation and mitigation (carbon storage and sequestration)

Box 4. Reconnecting lakes in the Central Yangtze River Basin in China

The 6,300 km long Yangtze River drains a 1,800,000 km^2 basin and is home to more than 400 million people. Extensive lakes and floodplains of great environmental importance, as well as retention areas that attenuate the large summer floods, are found along the central Yangtze. In the last 50 years in Hubei Province, 1,066 lakes, 757 covering 2,150 km^2, have been converted to polders, reducing wetlands areas by 80 per cent and flood retention capacity by 2.8 Bm3 or 75 per cent. Damage from four major floods between 1991 and 1998 resulted in up to thousands of deaths and billion of dollars in damages. Lakes were also polluted, including by application of fertilizer to aquaculture pens. The loss of connection to the Yangtze River prevented diluting flows and migration of fish. Recently, drought has increased water pollution, and higher temperatures with climate change are expected to exacerbate eutrophication.

In 2002, the World Wide Fund for Nature (WWF) initiated a programme to reconnect lakes in Hubei Province to the Yangtze River through opening the sluice gates and facilitating sustainable lake management. The programme focused on three lakes: Zhangdu (40 km^2), Hong (348 km² and Tian'e Zhou (20 km^2). Alternative and more sustainable livelihoods for local residents was a priority, in an area where the average income is just USD 1.34 per day. In conjunction with this work, WWF formed partnerships with government agencies and others to explore options for more sustainable river basin management.

Since 2004-2005 in Hubei Province, the sluice gates at lakes Zhengdu, Hong and Tien'e Zhou have been seasonally re-opened and illegal and uneconomic aquaculture facilities and other infrastructure removed or modified. The success of these adaptations was replicated by the Anhui Government at Baidang Lake (40 km^2) since 2006. Now these 448 km^2 wetlands can store up to 285 Mm^3 of floodwaters, reducing vulnerability to flooding in the central Yangtze region, although this has not yet been tested in practice. Cessation of unsustainable aquaculture, better agricultural practices and reconnection to the Yangtze River have reduced pollution levels. In Lake Hong, pollution fell from national pollution level IV (fit for agricultural use only) to II (drinkable) on China's five-point scale. Subsequently, the Anhui Government has reconnected a further eight lakes at Anqing covering 350 km^2.

Of immediate benefit for the Yangtze River Basin was the increase in wild fisheries species diversity and populations. Within six months of reconnection of Zhangdu Lake, the catch increased by 17.33 per cent and nine fish species returned to the lake. Similarly the catch increased by 15 per cent in Baidang Lake. Development of certified eco-fish farming by 412 households increased income of fishers by 20 to 30 per cent on average. Similarly, the income from fisheries at the Yangcai Hu area of Hong Lake increased by 25 per cent after restoration. Bamboo farming has commenced, especially to stabilize steeper lands near the lakes. Access to cleaner water supplies is another benefit.

Twelve migratory fish species have now returned to the lakes. At Zhangdu Lake, 60 km^2 of lake and marshland were designated as a nature reserve by the Wuhan Municipal Government. To strengthen the effectiveness of wetland conservation efforts in the Yangtze River basin, a Nature Reserve Network was established to link 17 nature reserves (12 later designated) covering 4,500 km^2. As a result of these benefits, in 2006 the Hubei Provincial Government adopted a wetlands conservation master plan and allocated resources to protect 4,500 km^2 by 2010.

Sources:

Adaptationlearning.net (2010).
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Pittock, J. and Xu, M. (2011).

3.6 Flood bypasses[8]

Description

A common grey infrastructure solution to control riverine flooding is the building of levees and thus the disconnection of rivers from their floodplains. However, as described previously, levees may create new problems (upstream/downstream flooding) and they are prone to failures. Levee setback (Section 3.5) is one GI solution to this; another is establishing flood bypasses.

Flood bypasses are often portions of the historic floodplain that, during major flood events, are reconnected to the river and become inundated. For example, portions of the Yangtze River's historic floodplain, known as Flood Detention Areas, can be reconnected during floods. Along the Rhine River in the Netherlands, Germany and France, governments are pursuing a programme called "Room for the River" that will include features that allow the floodwaters to move into portions of the historic floodplains (Vis et al. 2003; Forster et al. 2005). These connected portions of the floodplain are very large (hereafter referred to broadly as "flood bypasses"). For example, the Yolo Bypass in the Sacramento Valley, USA, encompasses 24,000 hectares, while the Birds Point-New Madrid floodway, located on the west bank of the Mississippi River in southeast Missouri, is around 52,000 hectares.

Benefits

Primary

Flood bypasses act as flood relief valves in two ways: by providing conveyance and storage.

Conveyance. They increase the cross-sectional area available to move floodwaters safely through a particular stretch of river. This is analogous to opening up more lanes at a bridge toll crossing during rush hour to manage intense traffic. For example, the Yolo Bypass conveys approximately 80 per cent of the volume of major floods safely around the city of Sacramento. By increasing conveyance, strategically placed floodways can also reduce "backwater flooding," which is caused by the "piling up" of floodwaters at and behind a bottleneck, such as where bluffs constrict the river. Similar to levee setbacks, the vegetation within a bypass can influence its hydraulic roughness and affect the ability to convey floodwaters. Thus, some bypasses are managed for vegetation with low roughness.

Storage. Flood bypasses can detain and store water, functioning similarly to a flood-control reservoir. While conveyance is analogous to adding lanes, a bypass providing storage can be viewed as a parking lot alongside a major freeway. During a particularly heavy period of traffic, a large number of cars exit the highway and park in the lot, staying there until traffic ebbs. The highway "downstream" of the parking lot will experience lower peak traffic because of the cars parked in the lot. The effect is known as "peak shaving"- reducing the height of the flood peak experienced at some downstream point. The Jianjiang Flood Detention Area along the Yangtze River is intended to function in this manner with floodgates that can be opened as the flood is rising. It has the capacity to hold five billion cubic meters of water, reducing the height of the peak against the levees that protect cities with millions of inhabitants.

Flood bypasses can provide a mix of conveyance and storage benefits that vary with the size of the feature, its location in the river system and the characteristics of the flood. Bypasses also vary in the frequency with which they are used. The Yolo Bypass is inundated relatively frequently - almost every year - while some of the floodways on the Mississippi have been used only a few times in 80 years.

Co-benefits

Because the floodways are only inundated during floods they can be used for a variety of economic activities, with landuse varying with the frequency of inundation. For example, the New Madrid Floodway has been used rarely (twice since the 1930s). It is almost entirely farmed and includes 200 homes whereas the Bonnet Carre Spillway has been used 10 times in that period. Due to the frequent inundation, the Bonnet Carrre spillway is uninhabited with land managed for fishing, hunting and recreation. Because in California the flood season (winter to early spring) and the growing season (spring to fall) have little overlap, much of the Yolo Bypass is in productive agriculture, despite the fact that it is flooded nearly every year. The agriculture in the bypass is in annual crops that are not jeopardized by up to months of inundation.

Bypasses can provide significant environmental benefits. Approximately one third of the Yolo Bypass

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[8] Adapted from Jeffrey J. Opperman. (2014). "A Flood of Benefits: Using Green Infrastructure to Reduce Flood Risks", The Nature Conservancy, Arlington, Virginia. http://nature.ly/floodofbenefits

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Yolo Bypass Wildlife Area in California, USA.

is in wildlife refuges, including managed wetlands. Much of the land within the three Mississippi River floodways that are in Louisiana are in natural vegetation and support abundant fish and wildlife. Even floodways that are in agricultural land use can provide environmental benefits, particularly during periods of inundation. When bypasses are frequently inundated for long periods of time, the floodwaters are able to percolate into the soil and recharge the groundwater. This recharge can serve as a valuable "groundwater bank" during a drought (Jercich 1997).

Costs

Costs of establishing a flood bypass at any location consists of the investment needed in construction works (including weir or gate to direct water into bypass, and levees to delineate the floodway), as well as any costs associated with easements or title for land to ensure access to the floodplains.

The costs of the above-mentioned variables are highly location-dependent, as appropriate management practices, land costs and construction costs come into play. The maintenance costs-benefits are also dependent on the characteristics of the floods – e.g. some floodplains, such as the Yolo Bypass, are inundated frequently, while others only once in several decades, or even less (Opperman 2014). In general, projects of such magnitude can involve very high investment, though the costs can often be counterbalanced by avoided grey infrastructure investments (Opperman et al. 2011), reduced flood damage (particularly in economically active urban areas) and the wide range of co-benefits that are brought about to people and wildlife.

Establishing flood bypasses	
Water management benefits	**Co-benefits**
• Riverine flood control • Groundwater recharge	• Biodiversity benefits • Recreational, aesthetic value • Income from hunting, fishing, farming, etc.

3.7 Green roofs

Description

Green roofs (also referred to as eco-roofs) are building roofs that are fully or partially covered with vegetation. The choice of vegetation is usually plants or trees well suited for the local weather conditions, which are grown in a growing medium (soil, sand or gravel), planted over a waterproof membrane. Constructing additional layers in the form of root barriers, drainage nets and irrigation systems, can also be part of establishing green roofs (Foster et al. 2011).

Depending on the main purpose, green roofs can be either intensive or extensive. Extensive roofs use a soil (or other growing media) depth of around 5-15 cm, while intensive green roofs have a soil depth of 15 cm or more (CNT & American Rivers 2010). Intensive green roofs contain more resilient vegetation with deeper roots, while extensive roofs serve more of an aesthetic purpose.

Benefits

Primary

Green roofs can function as an integral part of regulating water quantity in cities by reducing storm runoff and thereby preventing floods from overburdening sewers. As roof vegetation grows, it can store large amounts of water. This is released later during the process of evaporation from the soil or the transpiration process of the plants themselves. In this way, green roofs alleviate the burden of public sewage systems and help to avoid overflow during storms with high precipitation (CNT & American Rivers 2010). Green roofs can reduce the annual roof stormwater runoff by up to 50 to 60 per cent through retention of up to 90 per cent of runoff from smaller storms (up to 25mm), and at least 30 per cent for large storms (Foster et al. 2011). For example, a green roof demonstration project on the roof of Chicago City Hall in the USA demonstrates that its green roof

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Green roof in Lancaster, Pennsylvania, USA.

has been able to retain 75 per cent of runoff from a 25 mm storm (Dunn 2007) (See Box 11).

Co-benefits

Additional benefits from green roofs include their aesthetic value, improved air quality, reduced noise pollution, water nutrient pollutant control and carbon sequestration. Vegetation on green roofs can remove a number of air pollutants, including particulate matter (PM), NO_X, SO_2, CO and O_3, as well as store carbon (Foster et al. 2011). This could be of particular importance in urban centres that are exposed to smog formation. The cooling effect of vegetation counteracts smog formation through slowing the reaction rate of nitrogen oxides and volatile organic compounds (CNT & American Rivers 2010).

Green roofs also provide significant cost savings through energy savings. The vegetation cover on the roof can provide both additional insulation and cooling benefits. The cover of plants prevents the roof surface from overheating, and therefore reduces building cooling needs. Buildings can also benefit from the evaporative cooling that occurs with release of water stored in the growing media (CNT & American Rivers 2010).

Green roofs also support local biodiversity. For example, an urban regeneration project in Malmö, Sweden, increased the local biodiversity by 50 per cent through (among other measures), green roofs, which attracted birds and insects (Naumann et al. 2011). Green roof initiatives can also support local businesses and income generation activities through employment creation, increased demand for building materials and urban agriculture opportunities.

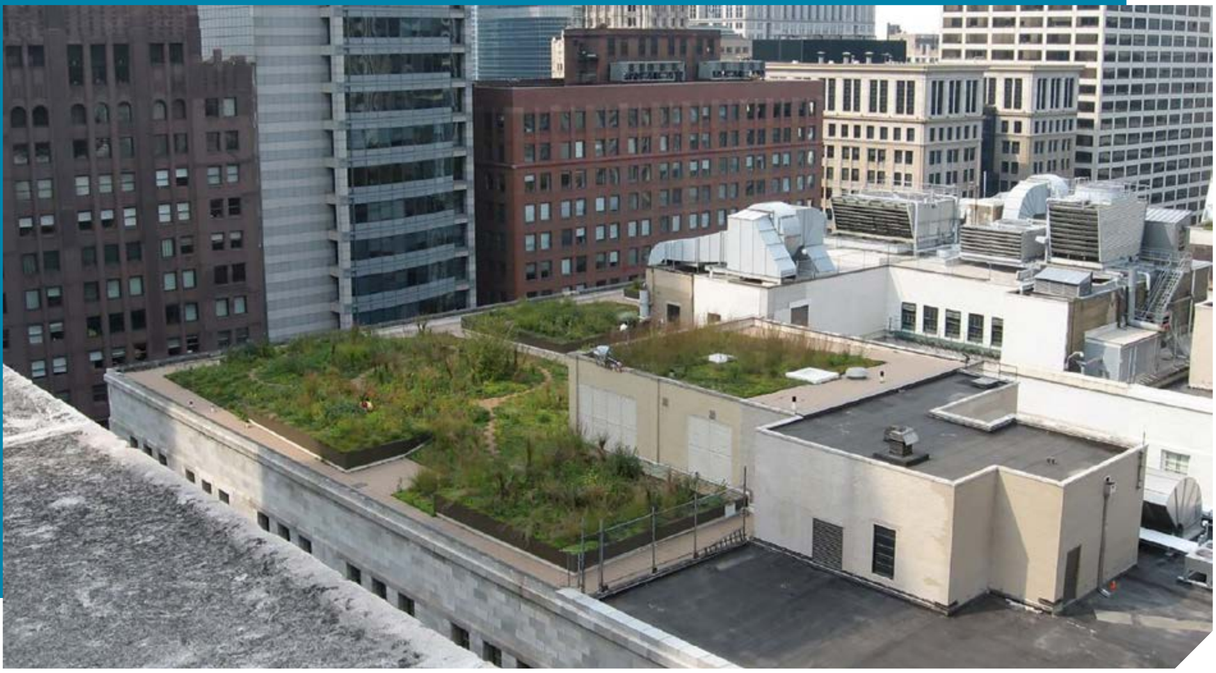
In the view of climate change, green roofs can help build the adaptive capacity of cities. They are particularly suited to address two climate change related issues: temperature and extreme precipitation. Green roofs can help to counteract urban heat island effect. Several studies show that converting to green roofs can help to reduce surface temperature of the roofs by up to 30-60°C and ambient temperature by up to 5°C, depending on the type of conventional roofs used. The vegetation cover also protects the underlying roof cover from the impacts of wind, UV and temperature impacts, thereby increasing the life span of the roof up to three times (Foster et al. 2011).

Costs

Costs of establishing green roofs differ remarkably depending on the geographic location, the type of roof, local labour and material costs. For example, a study based in the US, estimated costs to be between USD 65 to USD 450 m^2 for constructing extensive roofs and USD 200 to USD 900 m^2 for intensive roofs (Foster et al. 2011). Additional costs may need to be factored in if there is a need to structurally reinforce or retrofit buildings to be able to carry the extra weight created from the soil and vegetation. Costs of maintenance vary depending on the type of vegetation, staff costs and weather conditions. One case study shows that the approximate costs of that equal 2 to 3 per cent of the initial investment costs annually (Foster et al. 2011).

Despite the additional investments required in the initial phase of establishing a green roof, the net present value of green roofs has been estimated to be as much as 40 per cent higher than conventional roofs. The cost savings accrue from reduced costs in stormwater management, lower energy consumption and improved air quality. Studies show energy savings from green roofs in the range of 15 to 45 per cent (for cool and white roofs up to 65 per cent) in energy savings, mainly through lower cooling needs (Foster et al. 2011). In Basel, Switzerland, green roof regulations have spurred installation of green roofs. As of 2007, 23 per cent of the flat roof area in Basel was green roofs, supporting endangered species and providing energy savings of 4GWh (Naumann et al. 2011). The exact cost saving depends on local rainfall conditions, energy costs, etc.

Green roofs	
Water management benefits	**Co-benefits**
• Flood mitigation (urban stormwater control)	• Biodiversity benefits • Aesthetic value • Improved air quality • Reduced noise pollution • Carbon sequestration • Energy savings (reduced cooling and heating needs) • Reduced urban heat island effect



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City of Chicago green roof.

Box 5. Green roofs in Chicago, USA

In an effort to address and plan for the future impacts of climate change, including increased flood risks and public health stresses, Chicago adopted and is implementing its Chicago Climate Action Plan. The plan emphasizes green infrastructure (including green roofs, tree planting and rainwater harvesting) as a strategy for climate change adaptation and reduction of risks of the combined sewer overflow problems in the region. To date, Chicago has over 400 green roof projects in various stages of development.

Green roofs, along with bioretention and infiltration practices and tree plantings also yield co-benefits for reduced building energy use, direct carbon sequestration and public health. The 20,000 square foot (1,900 m^2) roof on Chicago City Hall has helped decrease stormwater runoff and improve urban air quality by reducing the urban heat island effect around the site. Since its completion in 2001, the green roof has saved the city USD 5,000 a year in energy costs (Chicago Green Roofs 2006). Monitoring of local temperatures found that the "cooling effects during the garden's first summer showed a roof surface temperature reduction of 21°C and an air temperature reduction of 15°C" (ASLA 2003).

Clark, Adriaens and Talbot (2008) looked at an economic model to determine the length of time required for a return on investment (ROI) in a green roof compared to a conventional roof system. The green roof was more expensive than the conventional roof at installation (USD 464,000 versus USD 335,000). Over the 40-year lifetime of the roof, the Net Present Value (NPV) of the green roof system was between 25 per cent (low air pollution benefit estimate) and 29 per cent (high air pollution benefit estimate) less than the NPV for a conventional system (USD 602,000).

The analysis also evaluates the green roof assuming a low air pollution benefit versus high air pollution benefit. Under the low estimate for health benefit valuation, the greatest potential economic contribution is due to energy savings. Annual benefits for the green roof system in this scenario were USD 2,740 (2006$) per year. Energy savings account for nearly USD 1,670 or 61 per cent of the benefits. In this scenario, benefits due to mitigation of nitrogen oxides accounted for 33 per cent of the annual benefits. Stormwater fee savings only account for 7 per cent of the annual benefits.

When a high estimate for valuation of public health benefits was used, air pollution mitigation was the main economic benefit. With total annual benefits of USD 5,240, 65 per cent of the benefits (USD 3,390) are attributable to air pollution mitigation. Energy savings remained the same but accounted only for 32 per cent of the total annual benefit. The stormwater benefit is further reduced to only 3 per cent of the total. While the monetary value of the health benefits is uncertain, in both the high and low estimates, public health benefits contribute significantly to the total annual benefit of green roofs.

Sources:
ASLA (2003).
Chicago Green Roofs (2006).
City of Chicago (2008).
CNT & American Rivers (2010).

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Rain garden in a parking lot.

3.8 Green spaces

Description

Green spaces refer to areas of land that are partly or completely covered with grass, trees or other types of vegetation, creating basis for bioretention and infiltration-related practices. Most of these are relevant to an urban context, as they help to deal with stormwater runoff in the presence of large areas of impervious surfaces. This section will look at examples of rain gardens and bioswales.[9] Although delivering similar benefits, the two GI solutions have slightly different functions.

Rain gardens are landscaped depressions designed to infiltrate and filter stormwater runoff, containing vegetation and sometimes an underdrain. Rain gardens are designed specifically to withstand high amounts of rainfall, stormwater runoff, as well as high concentrations of nutrients typically found in stormwater runoff – particularly nitrogen and phosphorus (Lowimpactdevelopment.org 2007), minimizing the amount of rainwater that enters storm drains. Design therefore includes careful consideration with regards to choice of appropriate soils and plants. Rain gardens can be dug at the bottom of slopes to collect rain water (CNT & American Rivers 2010) and usually take form of shallow, vegetated basins, gathering rain water from e.g. disconnected downspouts or other impervious surfaces.

Bioswales are a landscaping technique used to redirect and filter pollution from stormwater. The main difference between rain gardens and bioswales is that the primary purpose of bioswales is to transport water from one area to another (often ending in a rain garden), maximizing the amount of time that rainwater spends in the swale to increase removal of silt and pollutants. Bioswales consist of vegetated, mulched or xeriscaped[10] channels often designed to manage larger amounts of runoff from a specified impervious area e.g. a road) (Soil Science Society of America 2014). Bioswales consist of a drainage course, with sloped sides, and vegetation or compost in the centre (EC 2012). Similar to rain gardens, vegetation chosen for bioswales is typically with high tolerance to wet conditions, e.g. native grasses. Bioswales can be installed next to paved areas – parking lots, pavements, roads, etc. (CNT & American Rivers 2010), but might not be as well suited for high density urban areas, due to the relatively large space requirements for the pervious surface. Their often linear nature however, makes them well suited for residential roads and highways.

Benefits

Primary benefits

The primary benefits of establishing bioretention and infiltration areas (also referred to as bioretention cells) relate to controlled runoff and pollutant filtering. Both rain gardens and bioswales provide retention and treatment of runoff, and facilitate water infiltration (CNT & American Rivers 2010). The reduced stormwater runoff helps to mitigate flooding and sewer overflows by slowing down the runoff flow, and improves groundwater recharge through the enhanced water infiltration. Case studies show runoff reduction of up to 86 per cent from grass bioswales (CVC & TRCA 2010). They also help to trap silt and other pollutants that are carried by the runoff – as the water percolates through, it is treated by a number of physical, chemical and biological processes, removing loads of heavy metals and sediments, and thereby improving water quality and protecting local waterways from pollution (Forest Research 2010). Studies have found that well-designed bioretention cells are efficient in removing heavy metals - copper (Cu), zinc (Zn), and lead (Pb) typically by more than 90 per cent (and as high as 98 per cent), phosphorus removal as high as 80 per cent, and about 60 per cent removal in nitrogen (lid-stormwater.net. 2007).

Co-benefits

Rain gardens and bioswales contain vegetation, which facilitate carbon sequestration and contributes to improved air quality by removing some of the air pollutants (CNT & American Rivers 2010). As with most GI solutions, the reduced amount of stormwater runoff in the system minimizes the amount of water requiring treatment, thereby reducing energy consumption and delivering costs, while increasing air quality benefits.

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[9] This section will have a closer look at the examples of rain gardens and bioswales only, though most vegetated areas bring about benefits of bioretention and infiltration – e.g. urban forests, wetlands, etc.

[10] The term "xeriscaped" is used to define green spaces designed in such a way that they do not require additional water for maintenance.


© Aaron Volkening

Bioretention / bioswale in median of Grange Avenue in Greendale, Wisconsin, USA.

Like forest cover, vegetated areas reduce the urban heat island effect,[11] as evaporation provides a cooling effect, and the vegetated surfaces are less heat absorbing than paved areas. Larger vegetated areas can also reduce surrounding noise levels. Additional benefits include the aesthetic and recreational value of the green spaces for the local communities (CNT & American Rivers 2010). Larger rain gardens can also provide species habitats. Establishing green spaces in the form of community gardens can also prove to be valuable in urban food production and provide educational opportunities for children and adults alike.

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[11] Urban heat island effect occurs when urban areas are considerably warmer than the surrounding rural areas. It occurs due to high human activity (e.g. cars, buses, appliances, etc.), as well as the high concentration of built environment that absorbs heat and replaces vegetation (hence, drier surroundings due to lack of evaporation).

Costs

Costs of rain garden and bioswale construction are relatively low and largely depend on land, vegetation and labour costs. Foster et al. (2010) estimated that the costs of installing bioswales in an alley (in the US) would cost approximately USD 24 to USD 100 per meter of established bio-swale. Costs of rain gardens are estimated at USD 32 to USD 65 m^2. A study from the Center for Watershed Protection in the US estimated and compared the construction costs of grass bioswales, and found the average construction costs to be USD 4.5 m^2, with costs ranging from USD 3 to USD 9 m^2 (CNT & American Rivers 2010).

The maintenance costs of rain gardens and bioswales are low, once vegetation has been established. They do require regular inspections in order to ensure that dense vegetation cover is maintained and that soil maintains its ability to infiltrate water. Depending on the concentration levels of the various water contaminants, additional costs may occur as a result of the need to replace some plants as they reach the limit of pollutant uptake, or even die. Attention must also be given to ensuring that plants grown in green spaces receiving larger streams of pollutants (e.g. heavy metals that are absorbed, but not dissolved) are not posing a threat to human and/or animal health via further consumption in the food chain.

When designing green spaces it is important to ensure that the increased water infiltration does not result in negative downstream impacts. For example, increased water infiltration could elevate groundwater levels to such an extent that basements become flooded. Careful planning and knowledge of the local hydrology is therefore necessary.

Green spaces	
Water management benefits	**Co-benefits**
• Flood mitigation (stormwater runoff control) • Water purification • Water supply regulation (improved groundwater recharge) • Temperature control (shading of water ways)	• Biodiversity benefits • Aesthetic value • Improved air quality • Energy savings for water treatment • Carbon sequestration • Reduced urban heat island effect • Reduced noise pollution

3.9 Permeable pavements

Description

Conventional pavement alternatives such as asphalt and concrete are impervious surfaces, preventing any runoff infiltration. Permeable pavement is made of materials that allow for the water to infiltrate, be filtered and recharge groundwater. Types of permeable pavement materials include pervious concrete and asphalt, permeable interlocking concrete pavers (PICPs), concrete grid pavers, and plastic reinforced grass pavement (Hunt and Szpir 2006). Materials used for permeable pavements usually contain coarse particles resulting in a high permeability (pore-space for water to pass through). Permeable pavements usually have two underlying layers: one of finer sediment that work as a filter, and one of gravel that conveys and stores water and gives structural support. Though permeable pavements are constructed of conventional grey materials, they strive to mimic and support water ecosystem services provided by soils and thus are included in this guide as part of the array of GI solutions.

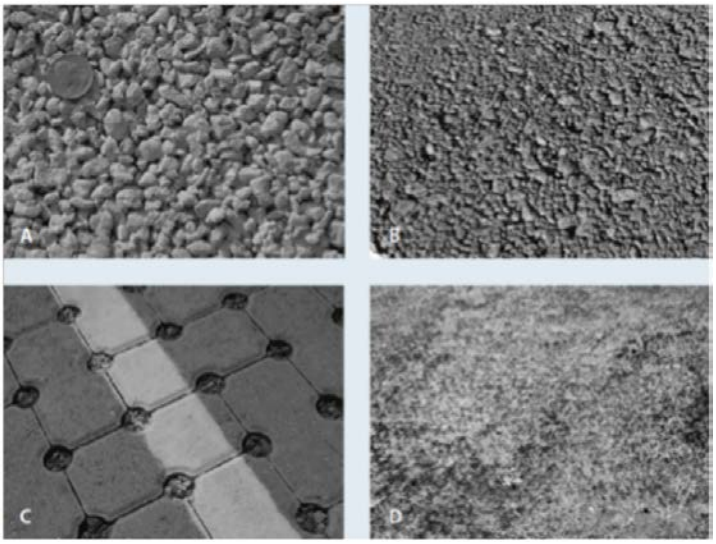


Figure 3. Types of permeable pavements: (A) pervious concrete, (B) pervious asphalt, (C) permeable interlocking concrete pavers (PiCPs), (D) plastic grid reinforced grass pavement (Hunt and Szpir 2006).

In application of permeable pavements, care must be taken to avoid potential groundwater and soil contamination due to the high permeability. For example, there is a risk that salts used in de-icing of roads can reach groundwater, as well as increase mobility of some heavy metals in the soil (such as lead, copper and cadmium). For these reasons, permeable pavements are usually advised for areas with low traffic volumes and low exposure to potential contaminants (CVC & TRCA 2010), such as residential roads, parking lots, walkways, driveways, patios, etc. Excluded areas unsuitable for permeable pavements include fuel stations and zones where hazardous materials are handled.

Benefits

Primary benefits

Permeable pavements can provide important alternatives to conventional runoff control infrastructure in urban environments.

Installing permeable pavement can reduce storm runoff by 70 to 90 per cent (Foster et al. 2011), reducing risk of flooding and overflow of sewage systems. Excess runoff in an urban setting also poses sanitation risks through accumulation of contaminants, such as oil, grease, toxins and pathogens, which can reach the local waterways (EC 2012). In addition, the permeable structure and upper underlying soil layers (often gravel and sand), help to improve water quality. Pollutants in the runoff water are captured in the layers of the pavement. Studies showed that the amount of removed pollutants equals 85 to 95 per cent for suspended solids, 65 to 85 per cent for phosphorus, 80 to 85 per cent for nitrogen, 30 per cent for nitrate and up to 98 per cent for metals (CRWA 2008).

Co-benefits

Auxiliary benefits include reduced noise levels, due to the higher porosity of the surface, and mitigating the urban heat island effect. Permeable pavements absorb less heat and help reduce heat through evaporation (Foster et al. 2011). This in turn has a positive impact on the surrounding environments, also reducing energy needs for cooling. The reduced urban heat island effect also decreases ground level ozone formation, improving local air quality (CNT & American Rivers 2010). By alleviating the sewer system load, they can also contribute to reduced energy needs for wastewater treatment.

For colder climatic conditions there are also cost savings in a reduced need for road salt in winter (by up to 75 per cent). The decrease in salt use also reduces pollution in local waterways (CNT & American Rivers 2010).

Costs

The estimated costs of installing a permeable pavement are USD 30 to USD 150 per m^2 (in the USA) with a lifetime between seven and 35 years, depending on the type of pavement and required maintenance (Foster et al. 2011). Permeable pavements require maintenance and clogging is the main concern for such pavement systems. These pavements usually need to be vacuum swept three to four times a year to prevent pores from becoming clogged (CRWA 2008). Permeable pavements are also rarely used in locations that are subject to heavy loads, although some types have been developed and are used in e.g. commercial ports.

Long term application of permeable pavements would also need proper monitoring to ensure that the pollutants captured by the pavements do not migrate to the underlying soils.

Furthermore, when using permeable pavements it is important to ensure that the increased water infiltration does not result in negative downstream impacts. For example, increased water infiltration could elevate groundwater levels to such an extent that basements become flooded.

Permeable pavements	
Water management benefits	**Co-benefits**
• Flood mitigation (stormwater runoff control) • Water purification • Water supply regulation (improved groundwater recharge)	• Improved air quality • Reduced urban heat island effect • Reduced noise pollution

3.10 Water harvesting

Description

Water harvesting refers to redirection of rainwater and stormwater runoff, and storage for productive use (agriculture, drinking water and more). Rainwater harvesting has a long history and has been used by many ancient civilizations to support agriculture and cope with seasonal water availability. There is a wide variety of rainwater harvesting techniques, and the choice of the specific solution greatly depends on the area available for catchment, as well as intended end use. Water harvesting techniques can be divided in two main types: *in situ* and *ex situ*.

In situ rainwater harvesting aims to increase the amount of rainfall stored in the soil by trapping and storing it in the desired location (primarily to ensure water for crops and other vegetation). In essence, this method ensures that rainwater remains where it falls with little distance between capture and usage areas. In *in situ* water harvesting, soil serves as the storage medium, with landscape serving as the collection and storage area. Examples of *in situ* water harvesting include terracing, pitting and conservation tillage practices; often, these are identical to measures used for soil conservation (UNEP and SEI 2009).

Ex situ water harvesting uses systems where rainwater is captured in areas external to the final water storage. Capture areas in this case include natural soil surfaces or rooftops, roads and pavements in urban areas. Water is stored in natural or artificial reservoirs, with little or no infiltration capacity. Examples include capturing and storing water in dams, wells, ponds, cisterns, etc. (UNEP and SEI 2009). Storage in artificial reservoirs can be considered to be a form of grey water infrastructure, according to the definition of this guide. This approach is included here, as it can deliver a number of relevant water management co-benefits.

Benefits

Primary

For *in situ* water harvesting methods, the primary benefits are increased water infiltration and water holding capacity in the soil, which results in higher soil fertility. Improved infiltration also reduces runoff from slopes and facilitates groundwater recharge (Agriwaterpedia 2014).

For *ex situ* water harvesting, primary benefits relate to reduced stormwater runoff and increased availability of water for productive use (e.g. drinking water or water for cattle). In urban areas, the reduced stormwater runoff volumes also contribute to minimizing the amount of pollutant loads entering stormwater collection systems, mitigating potential negative water quality effects (EPA 2013). The reduced volume of stormwater entering sewage systems relieves the load of water treatment plants and reduces risk of combined sewer overflows during storm events. This translates to reduced costs and energy use for water treatment and conveyance. In addition, it contributes to water conservation, reducing the pressure on surface water sources and groundwater. When used for irrigation purposes in households, the harvested water also enhances groundwater recharge.

Co-benefits

In situ water harvesting practices usually contribute to soil conservation through preventing soil erosion and soil loss, thus providing better conditions for crops and other vegetation in the area. For rural areas this means increased food security and resilience to droughts as well as reduced need for irrigation water and energy use for water transport.

In urban areas, reduced energy requirements for water treatment and transport can contribute to better air quality, and reduced CO_2 emissions from local power plants. Even if treated for potable use, rainwater, in most cases, requires less energy than conventional water treatment and distribution.

In many regions of the world, water harvesting techniques are part of cultural heritage, and have historically been part of community development. Re-establishing some of the traditional rainwater harvesting structures can therefore also contribute to preservation of traditional knowledge. Examples of such structures include the vast variety of traditionally used rainwater harvesting structures in India – e.g. kundis, khatris, and more (rainwaterharvesting.org 2013).

Costs

The costs of water harvesting vary depending on the design of structures chosen, but the technologies applied are generally low-cost. For the more traditional in situ solutions, especially in rural areas, the costs might only relate to the labour costs needed for construction. For urban solutions costs will be comprised of the expenses related to storage tanks, cisterns, pumps, as well as distribution pipes, where applicable. Some costs might occur in connection with energy for pumping, protection to deter mosquitos and water pre-treatment, where needed.

For outdoor use, the needed pre-treatment is usually minimal e.g. gravity filtration or first-flush diversion (CVC & TRCA 2010), whereas indoor and potable use might require more complex solutions such as ultraviolet light disinfection, ozone treatment, chlorination and reverse osmosis (EPA 2013). For passive systems, maintenance costs are minimal, mostly relating to removing debris and avoiding clogging and vector breeding by regular maintenance of screens. For more complex active systems, the time and cost requirements for maintenance would be correspondingly higher.

The UK Rainwater Harvesting Association cites USD 2,400 to USD 3,300 as an average cost for a household rainwater harvesting system (UKHRA 2013), while the Centre for Science and Environment in India estimates a cost for one building's rainwater harvesting system to be between approximately USD 50 and USD 550 (rainwaterharvesting.org 2013).

A study examining lifecycle costs of rainwater harvesting in four developing countries found that capital expenditure for storage rainwater harvesting systems ranged from USD 40 to USD 200 per m^3, while for sand dams (*in situ* measures) it was as low as USD 10 to USD 30 per m^3 (Batchelor et al. 2011).

It is important to note that large scale rainwater harvesting can significantly affect the natural hydrological regime of a river by reducing surface runoff and increasing groundwater recharge and evaporation losses. This may negatively impact downstream water users, including ecosystems. Therefore, planning for rainwater harvesting of a larger magnitude needs to be done with care, and proper knowledge of the local hydrology is essential.

Water harvesting	
Water management benefits	**Co-benefits**
• Water supply regulation (water storage and improved groundwater recharge) • Flood mitigation (reduced stormwater runoff) • Water purification (increased infiltration)	• Reduced costs of water conveyance and treatment, energy savings • Climate change adaptation, increased resilience • Maintained crop productivity, soil conservation • Cultural value, preservation of traditional knowledge

Box 6. Water harvesting ponds in the Tana River Basin, Kenya

The Tana River Basin covers an area of 126,028 km². The upper basin comprises the slopes of the Aberdare and Mount Kenya mountain ranges in the eastern part of the catchment, from where the watershed's gradient gradually declines till it reaches the Indian Ocean towards the southeast. The Tana River drainage network, the longest river in Kenya, stretching about 1,014 km, drains excess water.

Water harvesting ponds are currently being used in the upper, middle and lower parts of the Tana Basin as part of a wider ecosystem rehabilitation scheme to promote improved water and ecosystem management. There are many different designs with varying shapes, materials and dimensions. The water concentrated in the ponds originates from the surrounding naturally sloping surfaces, or is conveyed from paved surfaces (roads, paths) and channels (cut-off drains). Circular and trapezoidal ponds are the most common design. It is suitable in most agro-ecological zones that provide enough rains to fill the reservoir (>400 mm/yr).

The benefits of harvesting water in these ponds include an increase in water flow regulation, erosion control and water supply. The construction of ponds makes water available during dry spells in the rainy season, and for a few months after the rains. The water is used to irrigate high value cash crops and fruit trees, to water the livestock, and for domestic use. They are often established near homesteads were they can be easily reached.

Table below outlines the low costs for building the harvesting ponds, providing Ethiopia and Pakistan as comparative locations.

Location	Investment costs	Cost per m³ (USD)	Maintenance costs
Kenya	USD 132 100m^3	1.3	USD 0.27 m^3
Ethiopia	USD 154 for 1 plastic lined pond of 100m^3	1.5	USD 0.47 m^3
Pakistan	Not available	0.4-1.2 (excavation costs for a pond of 3500 - 4500m^3)	Not available

Source: Knoop, L., Sambalino; F. and van Steenbergen, F. (2012).

3.11 Protecting/restoring mangroves, marshes and dunes

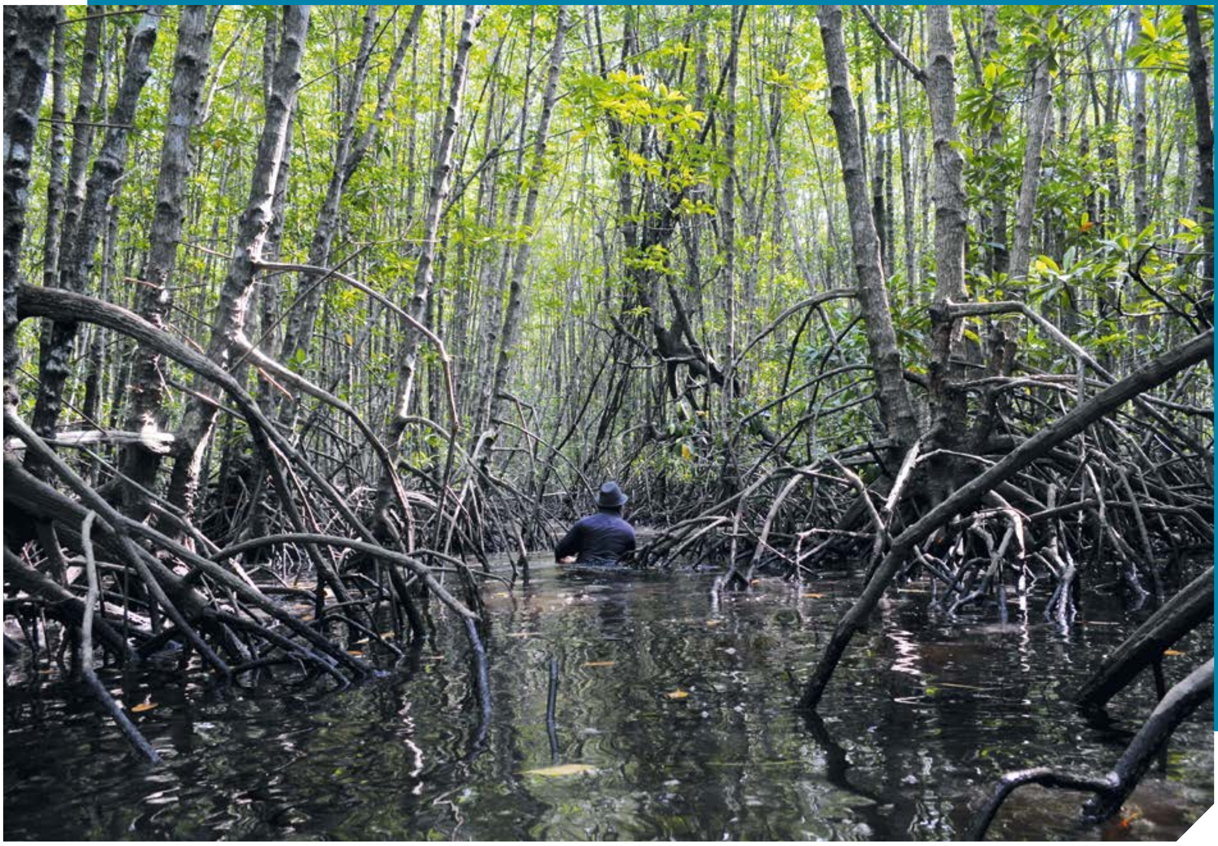
Description

Coastal wetlands such as marshes, dunes and mangroves are instrumental in reducing vulnerability to hazards of often densely populated coastal areas and are also source of income and support to livelihoods of millions of people. Today, these coastal habitats are under dire pressure from climate change, sea level rise and destruction resulting from human activities (World Risk Report 2012).

Salt marshes are saline wetlands that are flooded and drained by salt water brought in by the tides. They often border freshwater or brackish environments and are home to saltwater tolerant grasses, shrubs and other vegetation, and mostly occur in temperate coastlines (Healy 2005). Soils of salt marshes consist of deep mud and peat, containing large amounts of decomposed plant material. Salt marshes, like other coastal wetlands, are rich and important habitats for people and biodiversity (NOAA 2014).

Coastal sand dunes are naturally occurring wind-formed sand deposits representing a store of sediment in the zone just landward of normal high tides, functioning as a natural defence barrier between the sea and the land. Coastal sand dunes are highly dynamic in their natural state, changing in response to varying wind and water levels (Linham and Nicholls 2010).

Mangroves are trees and shrubs that are found in intertidal ecosystems where fine sediments accumulate and freezing is rare. They inhabit extreme environments, including those with high salinity, high temperature, and extreme tides and muddy organic sediments devoid of oxygen (Alongi 2009). Mangroves have specialized prop roots and



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Mangrove roots, Kubu Raya, West Kalimantan, Indonesia.

pneumatophores[12] that take up atmospheric oxygen above the sediment surface and their root systems create a dense tangle that traps more sediment suitable for more mangrove growth. Just like salt marshes, mangroves are found in the intertidal zone of coastlines and estuaries, but are mostly common to tropical and sub-tropical coastal areas. They are, therefore, particularly important for resource-dependent communities in many developing countries.

Coastal ecosystem impact by agriculture, land and water development, shrimp farming and other sources has increased rapidly in recent decades. Mangrove ecosystems could all but disappear within 100 years at current rates of loss (Duke et al. 2007). The most efficient way to maintain water-related ecosystem services of these coastal wetlands is elimination of existing pressures, e.g. limiting coastal deforestation, land development and potential pollution sources. Where a certain stage of degradation has been reached, restoration efforts can be carried out.

Planting nurse species, such as native cord grasses, for example, may be an effective way to help stabilize bare sediment and mitigate erosion in preparation for either natural or planted colonization by mangroves (Lewis 2005). Mangrove colonization success and survival are sensitive to tidal flooding depth, frequency and duration (Lewis 2005), which need to be restored to conditions meeting species requirements for successful recovery and survival of mangrove communities. Restored sites can then be planted with native species where no natural seed source exists and no other impediments stand in the way of success.

For coastal dunes, interventions may include dune rehabilitation or construction of artificial dunes (with the aim to replicate the functions of natural dunes). Salt marshes can be re-established and rehabilitated

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[12] Pneumatophores are lateral roots that grow upward (negative geotropism) for varying distances and function as specialized respiratory root structure in certain aquatic plants.

via managed re-alignment schemes (which may involve retreating existing line of defense), or through vegetation transplants from other locations (Linham and Nicholls 2010).

Benefits

Primary

These coastal ecosystems provide significant coastal protection benefits in attenuating storm surge and floods, reducing damage to infrastructure and human health (World Risk Report 2012).

Vegetation and sediment present in the wetlands help to reduce incoming wave and tidal energy by enhancing energy dissipation in the intertidal zones. This can significantly reduce risk of storm damage and coastal flooding by lowering the height of storm surges. In essence, these coastal wetlands function as natural barriers between the sea and the land. Every mile of continuous wetlands is believed to reduce storm surge by 8 to 20 cm (CBD 2013). The effects of these barriers were clearly seen during the tsunami off the Indonesian island of Java in July 2006, where areas with dense coastal vegetation were much less impacted than areas without (CBD 2013).

Coastal wetlands also stabilize shorelines by trapping sediments and reducing erosive wind and wave energy, and helping to build land seawards. For example, coastal sand dunes are able to supply sediment to the coastline in times of erosion, and store it in reserve for times when it is needed (Linham and Nicholls 2010).

Co-benefits

Coastal wetlands provide a number of essential co-benefits. Mangroves and saltmarshes play an important role in mitigating climate change by storing carbon. Degradation of coastal wetlands, on the other hand, releases high amounts of carbon, in the order of 2,000 $tCO_2/km^2/yr$ (an average of 50 years) (Russi et al. 2013).

They are also important biodiversity hotspots, particularly in the tropics. For mangroves, for instance, the diversity of a mangrove forest at any single location is relatively low. However, they host up to about 90 per cent of marine species at some point in their life cycle (Sandilyan and Kathiresan 2012). They also prevent saltwater intrusion, provide habitat in support of fisheries and wildlife use (by providing vital breeding and nursery grounds for a vast variety of birds, fish, shellfish and mammals), and produce raw materials for fuelwood, construction, industry and medicine (Lewis 2005; UNEP-WCMC 2006).

Mangroves also export large amounts of organic matter to offshore ecosystems (Dittmar et al. 2006), thereby supporting offshore fisheries. Sandilyan and Kathiresan (2012) estimate that 80 per cent of the world's fish catch depends on mangrove production to some extent. They also contribute to climate regulation through carbon uptake and to recreation and tourism value.

Costs

Maintenance of coastal wetland ecosystem services in general requires restoration of the tidal hydrology, the proper mix of freshwater with saltwater, nutrients, and sediments to tolerable concentrations of toxic materials. The costs borne by the actual restoration efforts may also need to be evaluated in connection with foregone investment in land use and development, as coastal areas are often highly desirable locations for economic activity.

For mangroves, change in policy, planning and management is usually required to mitigate the persistent impediments to mangrove colonization and survival. Preferred restoration methods take advantage of the ability of mangroves to recover by removing or otherwise treating the impediments to natural restoration at the source. Although restoration efforts are important, studies show that most failed projects went directly to seedling planting without removing impediments to mangrove colonization and survival (Lewis 2005). Therefore, focussing on stressors that present threats to mangrove populations should be a priority.

Areas that have been cleared and dyked for mariculture, salt production, or other purposes require dyke breaching at the minimum and total removal optimally. In some instances, the sediment may need to be treated to the extent possible to reduce acidity or contaminant concentrations. Where roads or other structures are built on fill that blocks tidal flux, it is usually necessary to construct breaks in the structure large enough to allow sufficient restoration of the tidal flux. Restoring sources of freshwater often is more challenging because of the expense. There may be some latitude for reducing water surface area and evaporation in large reservoirs and irrigation diversion that can be explored. Irrigation water may also require purchase of water rights. The condition of watersheds providing freshwater is also important, especially in dry areas where freshwater evaporation is increased by large impoundments or water is diverted for consumptive use. Coastal dykes and other structures, for instance, can trap water and expose it to evaporation that concentrates salts to intolerable levels (Lewis 2005). Increased nutrient concentrations in municipal wastewater, agricultural runoff or mariculture can increase the susceptibility of mangroves to salinity-related stress and mortality (Lovelock et al. 2009).

The exact costs of restoration or protection efforts are highly variable and will depend both on local labour costs, investments needed in altered management practices, and any additional costs based on potential causes of mangrove degradation described above. In Viet Nam, for example, around 20,000 hectares of mangrove plantations protect coastal communities from storm surges. The maintenance of mangroves costs around USD 1 million annually, but in turn is estimated to save USD 7 million in annual dyke maintenance (Monsma 2012).

For sand dunes, costs may involve construction associated with artificial dune construction or rehabilitation, such as building fences to trap sand and help stabilize sand surfaces, or vegetation planting to stabilize the dunes and facilitate accumulation of sand for dune growth (Linham and Nicholls 2010). These alone are not likely to be high; however, land costs, foregone investment and land development limitations may add to the technical costs.

For restoration and re-establishment of salt marshes, additional costs can involve vegetation transplants and elevation of the site (Linham and Nicholls 2010).

The cost benefit analysis of interventions should always be evaluated taking into consideration the wide range of benefits delivered by these ecosystems. For instance, in Thailand the costs of mangrove restoration were estimated at USD 9,318 per hectare, while the benefits in fisheries, coastal protection and wood and non-timber forest products amounted to USD 12,392 per hectare (Russi et al. 2013). In view of predicted sea level rise, restoration and conservation efforts of these coastal ecosystems can create significant savings for adaptation. On the condition that the sea level rise will not be too rapid, most of these coastal ecosystems will undergo adaptation to changing conditions without external intervention. This is not the case for grey infrastructure that requires continuous investment in maintenance and adjustment (Linham and Nicholls 2010).

Protecting/restoring mangroves, marshes or dunes	
Water management benefits	**Co-benefits**
• Coastal flood/ storm protection • Shoreline stabilization, erosion and sediment control • Reduced saltwater intrusion	• Biodiversity benefits (habitats preservation, breeding and nursery for birds, fish, shellfish and mammals) • Climate change mitigation and adaptation (carbon storage, storm protection) • Income opportunities (fisheries, raw materials, tourism) • Recreational, aesthetic value

Box 7. Coastal protection in Lami Town, Fiji

A cost-benefit assessment analysis was undertaken for Lami Town in Fiji, to compare the various options for reducing the town's vulnerability to storms. A comparison of engineered options and ecosystem-based GI alternatives showed that the unit costs of GI alternatives (such as replanting mangroves, reducing upland logging and replanting stream buffers) were several times cheaper than engineered solutions. It was, however, also acknowledged that in most cases engineered storm protection was more efficient in reducing damages than green infrastructure.

Evaluated on the basis of cost-to-benefit and assumed level of avoided damage (benefit for every dollar spent and taking into consideration the amount of avoided damage), ecosystems-based protection scenario proved to be the most cost-efficient. The best plan for storm protection was deemed to be a combination of engineered and GI protection measures, and using the more efficient, engineered measures in targeted areas of commercial importance.

Source: Rao et al. (2012).

3.12 Protecting/restoring reefs (coral/oyster)

Description

Coral and oyster reefs are considered to be types of coastal wetlands. Coral reefs are shallow-water marine ecosystems characterized by massive calcium carbonate formations secreted by colonies of coral polyps and algae living in their tissues (Sheppard et al. 2005). Reefs build up as each coral species secretes uniquely shaped carbonate skeletons over older skeletal remains. The foundations of older reef structures are riddled with tunnels and channels created by physical and chemical erosion and the effects of reef inhabitants. Coral reefs are home to high fish and invertebrate biodiversity, all uniquely adapted to reef life, yet fundamentally dependent on coral survival. They tolerate little environmental variation and are particularly vulnerable to small changes in water quality, but they can recover once adverse events end, as long as local sources of colonizing organisms and suitable substrates are available (UNEP-WCMC 2006).

In their natural setting, oyster reefs are often found seaward of salt marshes (Scyphers et al. 2011) and are a source of valuable services both to ecosystems and humans. It is estimated that up to 80 per cent of the world's oyster reefs have been lost, a rate unprecedented for any other marine habitat (TNC 2012). This loss also represents an enormous reduction in the ecosystem services provided by these reefs including food, habitat for bird and marine species and a buffer for coastlines against waves.

The sustainability of both coral and oyster reefs is also threatened by rapid environmental change, which overwhelms reef-species adaptation and resilience following destructive events. The pressures on reefs include human activities (such as sedimentation, water pollution, resources extraction and commercial fishing) (Waddell 2005; Burke et al. 2011), as well as the effects of climate change. Among the latter is the increasing atmospheric concentrations of carbon dioxide and excessive heat, which cause intolerable acidity and water temperatures (Hoegh-Guldberg et al. 2007; De'ath et al. 2009).

Where possible, conservation measures can be put in place and actions taken to deal with the pressures and causes of degradation of coral and oyster reefs. In addition to eliminating or mitigating the source of reef impact, methods of oyster reef restoration and coral transplantation are often used to increase the rate of coral and oyster colonization at damaged sites (Epstein et al. 2001).

For coral reefs, transplantation ideally starts with collecting fragments of living coral rock as soon as possible and storing them in a suitable location until they can be moved to the restoration site (Japp 2000; Epstein et al. 2001). Fragments can then be attached to suitable substrate. In difficult locations, artificial structures can be installed to provide a stable foundation for coral transplants (Japp 2000). Transplantation success depends on the species, transplant shape and type, status of substrate attachment and environmental conditions (Japp 2000). Where that is not possible, coral may be transplanted from nearby reef locations or from coral nurseries prepared in advance for restoration needs.

Similarly, oyster reefs can be constructed artificially to replicate their natural functions. Case studies show that creating large-scale man-made coral reefs is possible, and they are able to replicate many of the functions provided by naturally occurring coral reefs (TNC 2012).

Benefits

Primary

For a long time, grey solutions have been dominant in coping with coastal hazards. Approaches include artificially hardening the shoreline or creating artificial barriers by dumping gabions made of cement and rock into the water (World Risk Report 2012). This is not only damaging to marine ecosystems, but can also shift the impacts of storms to communities down shore, increasing the need for additional defence structures.

There has been growing awareness and evidence of coral and oyster reefs playing a major role in coastal stabilization and coastal defence (World Risk Report 2012). Coral reefs provide natural breakwaters that can mitigate flooding and the erosive effects of storms along low-lying shores (Japp 2000; UNEP-WCMC 2006). They have shown to reduce the wave energy and height that impacts coastlines (Sheppard et al. 2005) attenuating and reducing more than 85 per cent of incoming wave energy (World Risk Report 2012). By forming a natural barrier, the reefs are the first line of coastal defence from the damaging impacts of waves, erosion and flooding.

Like coral reefs, oyster reefs protect from coastal erosion and wave erosion (TNC 2012). Evidence shows that oyster reefs also prevent coastal marsh retreat (Scyphers et al. 2011). Due to their complex structure, these natural barriers reduce water velocities, increase sedimentation rates and provide improved conditions for settlement and retention of propagules, thereby improving the chances of species survival (Scyphers et al. 2011).

Co-benefits

Coral reefs and oyster reefs have enormous significance in the lives of millions people. Tropic coastal populations in particular depend heavily on the resources provided by these ecosystems (World Risk Report 2012), where many reef species support fisheries and other livelihood sources (Burke et al. 2011). The reefs also play an important role in sustaining traditional lifestyles and carry cultural significance to local communities. In addition, they are home to rare species with relevance to e.g. production of medicinal products. Coral reefs are also popular tourist attractions (Burke et al. 2011) creating basis for significant income from the tourism sector, such as recreational scuba diving and snorkelling.

Oyster reefs are shown to provide food and shelter for crabs and fish species, which in turn increases the catch for fisheries. They also have shown to remove nitrogen from coastal waters, preventing algal blooms and dead zones (TNC 2012).

Costs

Restoring coral reefs is usually a very expensive and technologically complex exercise. The critical features making coral reefs such effective protection barriers, are the size, height, hardness and structural complexity of the reefs (i.e. friction) (World Risk Report 2012). Once lost, such features are very difficult and expensive to replicate. The best approach, therefore, is to protect reefs from external stressors before they are degraded, focusing on the sources of human impact. The creation of no-fishing zones at reefs, for example, appears to restore reef resilience and may make them somewhat less susceptible to increases in global temperature and carbon dioxide (Mumby and Harborne 2010; Selig and Bruno 2010).

A study on oyster reef restoration projects in the Gulf of Mexico, for instance, has shown that investments in restoration activities could yield a several-fold return on investment through gains in fisheries and avoided damage for properties and public infrastructure. The case study assessed a USD 150 million investment over ten years in restoring 160 km of oyster reefs in the Northern Gulf of Mexico. The assessment showed that the initial investment would be returned twofold in the period via new jobs and goods and services delivered to the local communities (TNC 2012).

The accelerated rate of global climate change requires particular consideration in relation to the long-term fate of restored reefs. The risks of eventual coral reef loss at the warmest edges of coral reef ranges, for example, can occur regardless of the success of the restoration efforts and need to be considered in connection with investment decisions. A troublesome concern is also elevated ocean acidity from increasing carbon dioxide (Hoegh-Guldberg et al. 2007). However, many studies have shown that in most cases investments in coral and oyster reef protection yield manifold benefits, once the socio-economic co-benefits are considered.

Protecting/restoring reefs (coral/oyster)	
Water management benefits	**Co-benefits**
• Coastal flood/ storm protection • Shoreline stabilization	• Biodiversity benefits (habitat preservation) • Climate change mitigation and adaptation (carbon storage, storm protection) • Income opportunities (fisheries, raw materials, tourism) • Recreational, cultural, aesthetic value

Box 8. Protecting coral reefs in Solomon Islands

The Coral Triangle (Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands and Timor Leste) is an area of global significance as it is the epicentre for marine biodiversity and supports abundant coral reefs and fish. Totaling more than 5,750 km², Solomon Islands coral reef areas occur where large lagoon complexes are protected by volcanic islands, raised islands, sand cays, and fringing and barrier reefs.

The majority (>95 per cent) of the collection of corals in Solomon Islands is based on wild-harvest i.e. from non-farmed populations. The wild harvest of coral for the aquarium, curio and lime trades results in the removal of specific coral types which, if over harvested, can cause degradation and destruction of reef habitat, further reducing ecosystem resilience. Negative socio-economic effects can be expected for communities dependent on affected reef ecosystems for food and/or cash. In rural communities of Solomon Islands there is often limited awareness of the long-term consequences of coral extraction activities. This lack also contributes to increased vulnerability of coastal communities and reduces the future benefits of coral reefs.

Furthermore, climatic factors are also affecting the stability in the region with climate change predictions indicating more intense and longer floods and droughts, increased variability of monsoon rainfall, sea level rise and more intense cyclones and typhoons. Changes in ocean conditions may also have direct or indirect implications for ecosystem services from coral reefs. Warming of the global ocean may result in symbiotic algae in corals dying or being expelled, thus producing coral bleaching. This is predicted to have devastating effects on coral reef-associated fish species. With climate change, it is highly likely that the volume of water in the sea may increase to such an extent that many of the world's corals will not be able to adapt quickly enough to the increase in depth, again with potentially serious consequences on coral reef associated species. The benefits from protecting this ecosystem are clear: better protection from storm surges and coastal flooding and the survival of the biodiversity and freshwater resources in the region, on which people's livelihoods depend.

Organizations like WWF and TNC are working together and among local communities, businesses and the scientific world within the Coral Triangle to ensure that the coral reefs are protected. With the backing of economic valuation studies, there is also a strong economic argument for support of these coral reefs.

The total economic value of the reefs in Solomon Islands in the research carried out by Albert et al (2012) was estimated at SBD $1.2 to $4.3 million (USD 100,000 to USD 420,000) per km² reef per year in direct, indirect (through coastal protection) and non-use value. Indirect use value of coral reefs, using replacement value of shoreline protection as a proxy has an estimated value of SBD $936 (USD 129) per km shoreline, resulting in a total value of SBD $140,000 to USD 2.1 million per km² (USD 20,000 to USD 290,000) reef per year across the case study communities. Taking into consideration all the coral-destructive activities (that are contributing up to 12 per cent of the total economic value at one of the coral trade sites), as well as other pressures on coral reefs in Solomon Islands (e.g. terrestrial runoff, climate change impacts, over-fishing herbivores and increasing population pressure), there is a move towards considering policy that addresses the impacts of coral harvesting and promotes alternative sustainable techniques.

Sources: Albert, J.A., Trinidad, A., Cabral, R. and Boso, D. (2010). Economic value of coral reefs in Solomon Islands: Case-study findings from coral trade and non-coral trade communities, The WorldFish Center, Solomon Islands & the Asian Development Bank Knowledge Management Project. http://sites3.iwlearn3.webfactional.com/cti/knowledge-hub/document-library/payment-for-ecosystem-services-pes/economic-value-of-coral-reefs-in-solomon-islands http://wwf.panda.org/what_we_do/where_we_work/coraltriangle/solutions/climate_change/

4

METHODOLOGY FOR WATER MANAGEMENT OPTIONS ASSESSMENT

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Green Infrastructure benefits and co-benefits (e.g. carbon sequestration, health benefits, improvements in biodiversity, etc.) are frequently neglected in investment decisions due to a lack of awareness of these benefits and perceived difficulties in valuing them (particularly the co-benefits) in financial and economic analyses. As understanding of the full role and value of GI expands, so will its uptake in water management decision making and engineering processes. Economic valuation can help to place GI on a more equal footing with grey infrastructure for water management, allowing decision-makers to adequately weigh economic tradeoffs alongside other considerations and enhancing transparency in decision-making. Valuation can also be used to optimize the allocation of resources across green and grey infrastructure options (either individually or together). Additionally, the quantitative case for GI investments can provide powerful support to decision-makers.

This chapter provides the reader with a general six step economic methodology, Green-Grey Analysis (GGA), geared specifically for water management decision-making based on Talberth et al. (2013a and 2013b). Green-Grey Analysis builds on existing case studies of green and grey infrastructure analysis and is rooted in classic decision and public investment theory already employed by water managers, planners and practitioners. It couches valuation of GI within a broader analysis of portfolios of green and grey options to meet a *specific water management investment objective*. The methodology includes six general steps: 1) define an investment objective; 2) specify investment portfolios using green and/or grey infrastructure components; 3) model outcome efficiencies; 4) calculate present value costs and benefits of infrastructure portfolios; 5) conduct benefit-cost or cost-effectiveness analysis to compare portfolios; and 6) conduct risk and uncertainty analysis (See Figure 4 below).

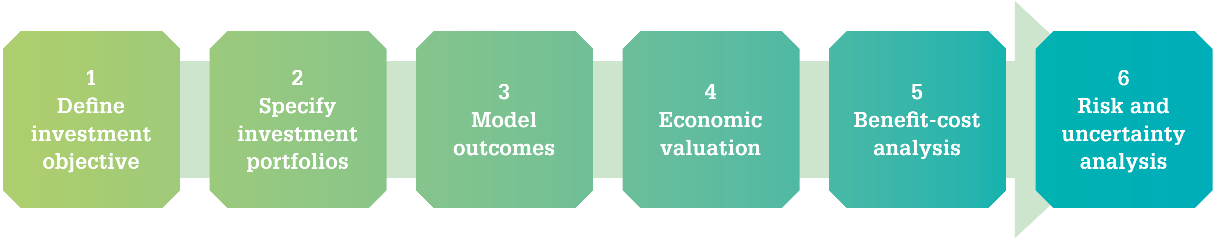

Figure 4. Six Steps of Green-Grey Analysis (GGA)

The goal of this chapter is to provide the reader with important challenges and activities to consider under each of these six steps and guide the reader through the methodology using an example case study on water quality regulation from Sebago Lake in Maine, USA.[13] Finally, this chapter concludes by detailing several cases of GI valuation.

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[13] See: Talberth et al. (2013b).

Case Study: Introduction

Sebago Lake is the primary drinking water source for the 200,000 people living in the city of Portland, Maine and has some of the best water quality in the Northeastern United States. It is no coincidence that nearly 80 per cent of the watershed providing water to Sebago Lake is also forested. This forest cover naturally filters contaminants from the water and provides a variety of co-benefits including provision of salmon habitat, recreational value and carbon sequestration. As such, the water utility, the Portland Water District (PWD), was able to obtain a filtration avoidance waiver under the United States Environmental Protection Agency (EPA) 1989 Surface Water Treatment Rule, which waives requirements for PWD to construct an expensive filtration facility as long as the utility maintains standards for turbidity and either fecal or total coliform.

Recently, a study by the United States Forest Service (Gregory et al. 2008) found that areas in the watershed are at a high risk of forest conversion due to trends in upstream development, deforestation, and population growth. These trends could jeopardize PWD's filtration avoidance waiver, forcing the utility to construct a filtration facility which could range in cost from USD 97 to USD 155 million over 20 years. As a result, PWD, with the World Resources Institute and input from local stakeholders, conducted an analysis to determine if using green infrastructure options could minimize their chance of losing their waiver and meet water quality goals.

4.1 Defining an investment objective

Green-Grey Analysis provides water resource managers with a tool to weigh the trade-offs of using green as well as built or grey infrastructure components to meet a specific water management investment objective to supply ecosystem services. These include water quality, water supply, drought mitigation, flood control and shoreline protection. The first step in the economic valuation is to define an investment objective. The choice of investment objective will influence the type(s) of economic valuation and decision-support tools (i.e. benefit-cost or cost-effectiveness analysis) that should be used to weigh trade-offs. Water resource managers and other infrastructure investment decision-makers will generally try to meet at least one of three types of investment objectives:

- Minimize the cost of mitigation for natural or human disasters (e.g. climate change or flooding) and the cost of expected losses
- Minimize the cost of meeting a regulatory, planning or reliability objective
- Maximize net benefits of infrastructure required to meet growing resource needs based on population or consumption growth projections

Objective 1: Minimizing the cost of disaster risk mitigation

This objective applies to the case where water resource managers seek to install or upgrade infrastructure to mitigate risks associated with human or natural disturbances such as climate change, shoreline flooding, catastrophic wildfire or droughts, and where both green and grey infrastructure options are available to reduce risks. In the case of shoreline flooding, for example, water resource managers might consider constructing sea walls or levees, restoring degraded mangroves and coral reefs, or a combination of the two. Water resource managers will also likely consider not only minimizing infrastructure investment costs, but also minimizing the expected value of economic losses associated with a disaster.

Objective 2: Minimize the cost of meeting regulatory, planning or reliability objectives

This objective applies to the case where water resource managers must install or upgrade infrastructure to meet regulatory requirements or planning and reliability objectives. Regulatory requirements might include, for example, standards for water quality and sanitation, or specific regulations for sewage and stormwater management. In this case, water resource managers must consider how they can meet these objectives at the lowest cost.

Objective 3: Maximize net benefits for target populations

This third objective applies to the case where water resource managers must install or upgrade infrastructure to meet the needs of a growing population or resource demands. For example, population growth in a municipality might necessitate expansion of drinking water provision or sanitation services. In this case, water resource managers will consider how to generate the greatest economic benefits at the lowest cost for municipality residents.

Case Study. Step 1: Defining Investment Objective

For the Sebago Lake example, the objective for PWD was to minimize the chance of losing their filtration avoidance waiver and hence, minimize the costs of having to construct a new filtration facility, which falls most directly under Objective 1.

4.2 Developing infrastructure investment portfolios

After determining the investment objective, the second step in the economic analysis is to specify portfolios of available investment options for meeting the determined objective. A portfolio might include a single infrastructure component or multiple components - including only green or only grey infrastructure, or some combination of the two (hybrid solutions).

There are several factors to consider when choosing investment portfolios. For example, GI options might be less well understood than grey infrastructure options. As a result, it is important to include stakeholders such as local resource users and GI experts (e.g. environmental engineers or hydrologists) to determine infrastructure component options. Additionally, water resource managers should consider that GI components include not only investments in restoration activities or conservation of environmental assets like forests and wetlands (e.g. conservation easements), but also investments in land management practices and awareness among landowners (e.g. sustainable timber harvest practices).

In weighing infrastructure options, water resource managers should also consider the level of substitutability between green and grey infrastructure, what level of infrastructure investment is feasible for a given area, how landowners and users will behave and respond to new infrastructure requirements that assume private sector involvement, and how to sequence infrastructure components (e.g. are incentives needed to encourage landowner participation in restoration or conservation components?).

Finally, an important consideration is that in some areas, either as a result of regulatory requirements, or a desire to ensure multi-barrier protection, it may be important to include redundancy and an adaptive management[14] plan in the design and implementation of GI options in order to address risks and uncertainties associated with achieving desired outcomes with GI. Given these uncertainties, discussed in greater detail below, it is advisable to bring stakeholders and experts to the table early if water resource managers are unfamiliar with GI options.

Case Study. Step 2: Developing Infrastructure Investment Portfolios

For Sebago Lake, two portfolios were created, a "Grey" portfolio and a "Green" portfolio. The Grey portfolio was straightforward in that it only considered the construction of a filtration facility to support PWD's current primary disinfection measures. The Green portfolio was constructed based on inputs from local stakeholders, who helped identify a suite of five forest-based green infrastructure elements over the next 20 years that would help to mutually maintain water quality in the watershed (also in addition to current primary disinfection measures). These included riparian buffers, upgrades to culverts that were at a high risk of failure in severe storm events, third-party sustainability certification of future timber harvests and forest management, reforestation of riparian zones and conservation easements. A variety of watershed-specific studies and data sources were consulted to determine the extent to which each GI option would be available and feasible. For example, VanDoren et al. (2011) created a GIS-based Conservation Priority Index tool that identified area available for new riparian buffers and reforestation area with high, medium and low potential.

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[14] Adaptive management refers to a structured process whereby lessons learned from investment decisions and outcomes are iteratively built into decision-making.

4.3 Modelling environmental outcomes

After identifying infrastructure portfolios, the relationship between a given level of investment in green or grey infrastructure and the environmental outcome sought must be quantified. For grey infrastructure, the relationship between investment and environmental outcome is generally easily demonstrated. For example, water filtration technologies are able to produce predictable results and water filtration facilities generally have multiple testing mechanisms to verify water quality.

Estimating a change in environmental outcome resulting from investments in GI is more complicated and requires determining and quantifying biophysical or dose-response relationships (Emerton and Bos 2004). For example, if an investment portfolio includes establishing conservation easements on forested land and engaging farmers to employ best management practices for the purpose of improving water quantity provision, the effect of these GI components on water quantity will not be immediately understood and would change over time, depending on both environmental factors (e.g. climate conditions and fire risk) and landowner/user behaviour. Biophysical modelling, probabilistic modeling, econometric modelling and other modelling approaches are able to examine how changes in ecosystem function relate to changes in GI services provided (Emerton and Bos 2004). These models can greatly improve our ability to make quantitative predictions about the impact of GI on water resources in a particular ecological context. For example, Cerucci and Conrad (2003) used the Soil and Water Assessment Tool (SWAT) and the Riparian Ecosystem Management Model (REMM) to determine optimal riparian buffer configurations to minimize pollution in south central New York's 37 km^2 Town Brook watershed. They determined the added utility of buffer widths as well as the most affordable parcels in which to establish riparian buffers. Other examples include the InFOREST model developed by the Virginia Department of Forestry (Gartner et al. 2013), which is a GIS-based tool designed to provide natural resource managers with information on forestlands ecosystem services, and the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) tool, described in Chapter 5.

For cases where modelling is too complex or too expensive, environmental outcomes can be estimated using expert opinion and local stakeholder guidance to construct scenarios of likely outcomes (for more information, see the risk and uncertainty analysis described in section 4.6). Ultimately, any economic analysis is limited to the accuracy of the underlying science and assumptions, though the same is true of engineered grey infrastructure. The science connecting a wide range of GI components to water resource outcomes generally is extensive and robust. However, even with the latest models, predicting additional or "marginal" benefits with precision is still a challenge, often leaving economists to make conservative assumptions. Even with this conservative approach, however, analyses to date have demonstrated in many cases the clear potential for cost-effectiveness of GI options relative to grey infrastructure alternatives. Meanwhile, the science underpinning the water-related benefits of GI investments is advancing rapidly (Schmidt and Mulligan 2013).

Case Study. Step 3: Modeling Environmental Outcomes

For the Sebago Lake example, no modeling has yet been conducted to estimate how GI options will impact local water quality or reduce the risk of losing the filtration avoidance waiver. Consequently, the analysis used conservative assumptions when estimating the extent to which each infrastructure component would be applied and its likely costs. Additionally, the analysis assumed that implementing the full suite of GI options would effectively reduce the waiver loss. As part of the risk and uncertainty analysis, impacts of those assumptions were then tested by running scenarios with different natural infrastructure cost and effectiveness estimates (more details provided in section 4.6).

4.4 Economic valuation

After modelling environmental outcomes, the costs and benefits of each portfolio should be identified and valued. These costs and benefits must be put in present value terms to allow easy comparability of costs and benefits. Generally, the timeframe of analysis to estimate cost and benefits should be pinned to the lifetime of grey infrastructure components or to the payback term on bonds or other financing instruments (Talberth et al. 2013b).

Costs

Costs of infrastructure, either green or grey, include installation and capital costs, annual operation and maintenance (O&M) costs, opportunity costs and transaction costs. We also consider negative externalities in this section, which can pose unintended costs for water resource managers. Considered and unintended costs are examined below:

- *Installation and capital costs* include the initial labour as well as all capital or equipment costs.
- *Operation and Maintenance (O&M) costs* are incurred over an infrastructure component's lifetime and include annual labour, energy, and other input costs, as well as scheduled maintenance and monitoring costs. These costs are straightforward for grey infrastructure, but GI requires additional considerations. Like grey infrastructure, GI often requires basic O&M expenditures on an ongoing basis. For example, protected areas secured as GI require ongoing funds for robust enforcement to ensure ecosystem function is not degraded by human activity. Furthermore, some GI investments might require adaptive management and monitoring expenditures (e.g. iterative data collection and reporting) to ensure desired results are achieved from GI components. Green Infrastructure might require additional expenditures due to climate-related and other risks like changing species composition and increasing incidence of disturbances such as wildfires, insects and disease which can affect the water-related functions of GI and require additional investments to maintain water services (Gartner et al. 2014).
- *Opportunity costs* are associated with foregone alternatives in land use or activity. For example, if a GI strategy includes afforestation on marginal cropland, then the opportunity cost would be the foregone income from agricultural production on that marginal cropland. Grey infrastructure might also incur opportunity costs if the construction of a facility, for example, displaces productive land use. These costs are often, but not always, included in infrastructure installation and maintenance costs. For example, in the case where a farmer is paid for afforestation on his or her marginal cropland, the negotiated payment should cover the forgone income to that farmer from agricultural production on that land, plus a profit margin.
- *Transaction costs* are costs incurred to make economic exchanges, such as communicating with landowners on an infrastructure decision and organizing meetings and information dissemination. These costs are typically included in installation, capital, and O&M costs, but GI might require additional transaction costs if a change in landowner or user behaviour is required.
- *Negative externalities* are costs that result from unintended consequences of infrastructure installation.[15] Negative externalities are possible with both green and grey infrastructure but are more commonly associated with grey infrastructure. For example, traditional grey infrastructure for stormwater control in developed countries, including engineered storm drains, was developed to transport stormwater away from urban centres. However, grey stormwater infrastructure can also cause flooding downstream, contribute to nutrient pollution of water bodies and lead to overflow events that can contaminate drinking water.

Benefits

On the benefits side of the equation, green and grey infrastructure can provide direct benefits as well as several ancillary or co-benefits (i.e. positive externalities).

- *Direct benefits* are the services for which infrastructure is primarily designed (e.g. water filtration or flood control). These services can be valued using market and non-market methodologies. In many cases, investment portfolios are calibrated to provide a given level of services, for example, to meet a regulatory requirement or other specific need, and then compared on the basis of cost. In other cases, direct benefits are explicitly valued and factored into the analysis. In either case, it should be noted that the "benefits" of GI often come in the form of avoided or reduced costs associated with grey infrastructure. For example, mangrove plantations in Viet Nam have been found to avoid costs in the form of damage to dykes by providing a "first line of defence" for shoreline protection (IFRC 2012).

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[15] Externalities can be both positive and negative, and refer to costs or benefits that are unintended consequences of a decision or investment. They are not always incorporated into economic and financial analyses.

- *Ancillary benefits* are the "positive externalities" of infrastructure. For example, an investment portfolio designed to provide clean water might include investments in reforestation. The economic benefits from forests include not only clean water, but also carbon sequestration, habitat improvement, recreation opportunities, sustainable timber products, and enhanced property values. A water filtration plant, in contrast, only supplies clean water. Given the value of these co-benefits for human welfare, it is important to consider them in an economic valuation. These benefits should be accounted for in a way that is decision-relevant, being careful to present analysis results in a way that will resonate with the interests of key decision-makers and stakeholders. In India, for example, investments in grey and green infrastructure to rehabilitate degraded drylands for agricultural production have also generated several ancillary benefits, including reduced travel time for fetching drinking water and fuel wood, improved childhood nutrition and education, improved biodiversity and income diversification (Gray and Srinidhi 2013).

There are multiple valuation methodologies available to capture both market and non-market benefits from GI - for example, market prices and stated or revealed preference (for more information on market and non-market valuation methodologies, see Pagiola et al. 2004; Pascual and Muradian 2010; Schumann 2012). In many cases, past economic studies can be used to approximate non-market values (i.e. benefits transfer). Carbon sequestration, for example, can be valued as a public good drawing on several existing studies approximating its non-market economic value. Alternatively, if GI investors intend to commoditize this benefit into carbon credits and sell those credits in carbon markets, this source of revenue can be valued based on market prices and subtracted from the total GI project costs.

Another important consideration for GI is that, unlike grey infrastructure, GI has the potential to appreciate over time, which can result in potential cost savings. Take for example, an investment in wetland rehabilitation for shoreline protection services. If the area is well managed and protected, a wetland will literally grow and expand its ecosystem services, providing, for example, increased shoreline protection services, whereas seawalls and levees will depreciate in value.

Case Study. Step 4:
Economic Valuation

For the Sebago Lake example, the analysis period was tied to the lifetime of the filtration facility of 20 years. Costs and benefits were identified based on consultations with local stakeholders and experts. For example, to determine the likely filtration costs, Talberth et al. (2013a and 2013b), consulted engineers with the PWD to first determine the most suitable filtration facility for the area and the likely costs. Costs of green infrastructure were also based on consultations with local stakeholders. Under the analysis, the benefit was assumed to be the same for both scenarios: meet EPA water quality standards. However, the analysis also identified co-benefits that the GI portfolio would generate over and above what the grey infrastructure would generate including carbon sequestration, provision of salmon habitat and recreational value.

4.5 Benefit-cost, cost-effectiveness, or multi-criteria analysis

Several decision support tools are available to compare costs and benefits of infrastructure options. Two of the most common include benefit-cost analysis (BCA) and cost-effectiveness analysis (CEA). Benefit-cost analysis aggregates all present value benefits and costs and compares them, while CEA identifies the least-cost option for obtaining an environmental outcome objective. The primary difference is that CEA does not consider benefits. As the benefits of GI often come in the form of avoided costs and are (relatively) easily monetized, BCA is widely used, but CEA is also applicable. The third investment objective (maximize net benefits for target populations) focuses on maximizing benefits so BCA is the more applicable tool.

There are several metrics to report results for BCA and CEA analyses. These include, for example, present value, net present value and benefit-cost ratio. Present value presents the discounted value stream to the present year. Net present value compares the present value stream of benefits with the present value stream of costs by subtracting total discounted costs from total discounted benefits. Both present value and net present value speak directly to the balance sheets of water beneficiaries like water utilities and private businesses; results tell a decision maker what each option means for their bottom line while achieving needed objectives. Benefit-cost ratio, on the other hand, is the ratio of net present value benefits to net present value costs and is another useful indicator of whether a project is a worthwhile investment. For all indicators, the investment portfolio with the highest value is the superior option.

An alternative approach for comparing infrastructure options is multi-criteria analysis (MCA). Unlike BCA or CEA, where all costs and benefits must be monetized for comparison in a single unit (USD dollars), MCA allows assessment of options along several criteria that have different units (both quantitative and qualitative). These criteria are weighted according to their relative importance and used to "score" infrastructure options. With MCA, decision-makers can rank infrastructure options not just by economic efficiency, but also by their ability to deliver any other desired outcomes like equity, biodiversity, public acceptance and quality of life.

When using either CBA or CEA, future costs and benefits must be brought into present value terms so they are easily comparable (Waite et al. 2014). This can be accomplished through discounting, whereby values are adjusted to account for the time value of money using a discount rate. There is no single discount rate that is appropriate; rather, the discount rate should be relevant to the infrastructure context and the geographic region. For example, the discount rate can be tied to the consumption rate of interest or rate of return on private investment (EPA 1999). It is important to note that the lifetime of some ancillary benefits associated with GI will extend well beyond the analysis period. The U.S. Environmental Protection Agency (EPA) provides a good rule of thumb whereby benefits realized in the future should only be counted in the analysis if they relate to actions taken during the period of analysis. Thus, if an analysis period is 20 years, then GI benefits should only be counted if they accrue during that 20-year period (EPA 1999). Conversely, if an analysis is retrospective (e.g. costs and benefits occurred in the past), past values should be adjusted for inflation based on national inflation rates.

Case Study. Step 5: Benefit-cost, Cost-effectiveness or Multi-criteria Analysis

Under investment objective 1 for the Sebago Lake example, the most applicable decision support tool was CEA, which would allow PWD to determine the least-cost option to reduce its risk of losing the filtration avoidance waiver. As a result, benefits were not quantified.

4.6 Risk and uncertainty analysis

Like grey infrastructure, GI presents several sources of risk and uncertainty. Sources of risk include the possibility that floods, fires, insect outbreaks, and extreme drought affect the function of GI over the long run. Sources of uncertainty include poor existing data on implementation costs, lack of understanding about relationships between GI components and desired environmental outcomes, and lack of understanding about important land use trends, market trends, landowner behavior, or policy or regulatory changes that have bearing on the investment decision (Talberth et al. 2013b).

Risk and uncertainty can be handled through project design and project analysis. In terms of project design, infrastructure portfolios can be developed that provide redundancy or multi-barrier protection - i.e. that has two or more elements designed to achieve the same outcome. For example, a drinking water utility might treat a source water body through ozone or ultraviolet treatment, but might also purchase conservation easements for forested property surrounding the water body to ensure contamination risks are reduced. Additionally, infrastructure plans should include systematic GI monitoring, evaluation and adaptive management to ensure desired outcomes.

In terms of project analysis, standard approaches for estimating uncertainty and risk include sensitivity analysis, scenario development and probability analysis (Waite et al. 2014). Sensitivity analysis is an approach that alters the values of variables that carry some degree of uncertainty (e.g. costs and benefits estimates and discount rate) to see how analysis results change. This effectively tests how important each variable is to the final result.

Scenario development generally involves working with stakeholders and available biophysical, economic, and other data to define a set number of realistic scenarios of outcomes. Scenario development is useful where biophysical and statistical modelling is time or resource intensive for an economic valuation practitioner.

Case Study. Step 6: Risk and Uncertainty Analysis

In the Sebago Lake example, a Green-Grey Analysis of infrastructure options for source water protection in Portland, Maine, constructed six scenarios by varying assumptions associated with the efficacy of GI measures, costs and discount rate (Talberth et al. 2013a). By developing scenarios, analysts are able to provide water resource managers with a range of potential outcomes in terms of costs and benefits, and if possible conduct further analysis to approximate the likelihood of each scenario.

Finally, probability analysis provides a more quantitative way to address uncertainty and allows variation of more than one variable at a time. Waite et al. (2014) state, "This approach is beneficial where there are multiple uncertain parameters and for ecosystem valuations that involve complex system dynamics (e.g. climate change). Monte Carlo analysis is a popular approach that requires assigning a probability distribution to each of the uncertain variables. Monte Carlo analysis conducts statistical manipulations of the probabilities and then models results on the probability distribution of the economic valuation outcome".

4.7 Making the quantitative case for Green Infrastructure: Case studies

Green-Grey Analysis and other methods to make the *quantitative case* for GI are increasingly accessible to water management decision-makers. There are several examples of economic analysis to support GI decision making for source water, stormwater, wastewater and storm surge protection. While these analyses are not *always* favorable for GI, they provide a critical foundation for smart decision-making.

It should be noted that the bulk of these examples come from the United States and other developed countries; while there are many examples of GI investment in the developing country context, this type of supporting economic analysis is less common. In places like the Uluguru Mountains of Tanzania, where substantial agriculture-related deforestation has led to massive sedimentation in the headwaters that provides the nation's capital with hydropower and drinking water (Lopa et al. 2012), the *qualitative case* is clear for investments to halt deforestation, initiate reafforestation efforts, and promote sustainable agricultural practices to prevent sedimentation. Limited resources in these cases can preclude investment in detailed economic analysis to support decision-making.

Still, as GI options are considered on a broad scale, and particularly if private businesses are to invest in GI, the *quantitative case* is likely to be an important factor in decision-making in developed and developing countries alike.

Table 4: Examples of Economic Analysis Comparing Green and Grey Infrastructure (Schmidt & Mulligan 2013)

Clean Water Services, Tualatin River, Oregon, USA (2006)	Niemi et al. (2007) compared the costs of reducing thermal pollution of the Tualatin River in Oregon for GI and grey infrastructure options. The study found that the grey option, installing two mechanical chillers to cool water before it is discharged to a stream, would cost USD 60 to USD 150 million. The GI option, establishing riparian forests to shade water and augmenting stream flows with releases from upstream reservoirs, was estimated to cost USD 6 million but came in at USD 4.6 million, realizing a savings of USD 50.4 to USD 145.4 million, relative to the built alternative.
New York City Department of Environmental Protection, New York, USA (2006)	In the late 1990s, in the face of growing development pressures in its largely privately-owned Catskill-Delaware watershed, New York City initiated a plan to protect its source water and avoid the cost of a filtration plant by investing in its 2,000 square mile watershed. A filtration plant would have cost the city USD 8 to USD 10 billion in current dollars - roughly USD 6 billion to build and USD 250 million annually to maintain. In contrast, the cost of securing GI in the watershed was estimated at USD 1.5 billion. The watershed programme has staved off the need to build a filtration plant and provided an annual USD 100 million injection to the rural economy in the upper reaches of the watershed by providing supplemental income to farmers and forestland owners, paying local contractors to install septic systems and set up stormwater protection measures, and by promoting ecotourism (Kenny 2006).
Portland Water District, Portland, Maine, USA (2013)	In the Crooked River Watershed, the World Resources Institute estimates the Portland Water District would save an expected USD 12 million - and possibly as much as USD 110 million - over the next 20 years by investing in GI alternatives to a membrane filtration plant, including conservation easements, reafforestation, culvert upgrades, riparian buffers and forest certification (Talberth et al. 2013b).
Northern Vietnam (2012)	The International Federation of Red Cross and Red Crescent Societies conducted a benefit-cost analysis of a 17-year community-based disaster risk reduction effort by the Viet Nam Red Cross that planted mangroves for shoreline protection. The actual costs of project implementation totaled USD 8.88 million. Estimated benefits of the project include avoided risks to communities (USD 15 million), direct economic benefits through enhanced aqua production and honeybee farming (USD 0.344 to 6.7 million), and avoided CO_2 emissions (USD 218 million) (IFRC 2012).
City of Philadelphia, Pennsylvania, USA (2009)	The City of Philadelphia conducted a benefit-cost analysis comparing several green and grey infrastructure options for controlling combined sewer overflow events in four watersheds (Stratus Consulting 2009). Green options such as tree planting, permeable pavement and green roofs were compared with conventional grey options such as storage tunnels within a benefit-cost framework that considered a wide range of non-market benefits. The net present value (NPV) of GI ranged from USD 1.94 billion to USD 4.45 billion, compared to net grey infrastructure benefits of USD 0.06 billion to USD 0.14 billion over a 40 year period.
Northeast England, UK (2007)	Turner et al. (2007) conducted a benefit-cost analysis to evaluate the economic efficiency of green and grey options for reducing coastal flood risk within the Humber estuary in Northeast England. Many of the flood defense structures along the English coastline are reaching the end of their design lives, and given concerns about sea level rise and increasing severity and frequency of storms on these structures, planners are considering alternative options, namely, managed realignment. Managed realignment involves the repositioning of an existing hard sea defense to a more landward location, thereby allowing more space for the creation of intertidal habitat. The “extended deep green” scenarios that emphasized managed realignment had positive NPVs over a longer timeframe, indicating that managed realignment can be more economically efficient than holding the line through repair and maintenance of sea walls over a period of 25 years.

While the cases in the table above illustrate a variety of analyses geared primarily to assess whether GI investments are worthwhile, GI valuation has also been used in efforts to determine the most cost-effective approaches for investing in GI. In India, for example, economic analyses have been used to assess the relative cost-efficiency of top-down versus bottom-up approaches to Watershed Development (WSD) - a national strategy to restore rainfed regions across the country to reduce poverty and improve land productivity (Gray and Srinidhi 2013). Recent meta-analysis of WSD projects in India are highlighting the importance of capacity building of watershed communities in sustainable land management practices and promoting GI interventions (e.g. afforestation, reafforestation, bans on livestock grazing for newly planted areas, biodiversity registers) alongside technical interventions to improve benefit-cost ratios (Kerr 2002; Joshi et al. 2005).

5

PRACTICAL TOOLS FOR QUANTIFICATION AND VALUATION OF BENEFITS

Planning for a GI project requires work on both quantification and valuation of benefits and co-benefits. For planners and communities new to GI approaches, this can be an overwhelming task. There are, however, a growing number of available tools and initiatives developed to support wider application of GI and assist the planning and decision-making processes.

The following section gives an overview of a number of practical tools and studies that can assist in the evaluation of feasibility and benefits of GI projects. Most tools do require a minimum level of locally appropriate data inputs in order to make meaningful calculations. This might be a challenge in countries where local water data sets and monitoring systems are not well developed or easily accessible. In this case, the tools can help to guide the process, advise on data needs, inform of the benefits and co-benefits associated with the type of GI, and offer options for calculations that can be used to quantify these. International proxy data (e.g. from similar climate zones or international standard tables) can also be used as indicative values, where information is unavailable. The tools presented here can therefore be adapted for use both in developed and developing country contexts. It is important to note that the use of proxy data and benefit transfer methods[16] must be done with caution. Unless the transfer is well justified (e.g. the two contexts are comparable) or appropriately adjusted (using context specific data) benefit transfer may have large transfer errors and give poor results.

Green Value Calculator

The Center for Neighbourhood Technology (CNT) (USA) has developed the Green Value Calculator to compare performance, costs and benefits of Green Infrastructure (GI), and Low Impact Development (LID) solutions for stormwater management. By entering a row of relevant indicators and data, the Green Value Calculator can be used to compare benefits of a number of GI solutions, including green roofs, tree cover and bioswales.

Link to Green Value Calculator:
http://greenvalues.cnt.org/calculator/calculator.php

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[16] Benefit transfer methods use available information from studies already completed in another location and/or context, to estimate economic values for ecosystem services for locations where such assessment is not available or possible (See http://www.ecosystemvaluation.org/benefit_transfer.htm)

Green Infrastructure Valuation Toolkit

The Natural Economy Northwest programme (UK), in collaboration with a number of local organizations and regional development agencies, has developed a valuation framework for assessing the potential economic and wider returns from investment in green infrastructure and environmental improvements. A prototype Green Infrastructure Valuation Toolkit was made available to the public in 2011. The Toolkit includes a comprehensive user's guide and a set of individual spreadsheet-based tools that can be used for assessment of the value of green assets for various benefits or projects. The Toolkit also includes three case studies and presents results from applying the toolkit.

Link to the resources under Green Infrastructure Valuation Toolkit: http://www.greeninfrastructurenw.co.uk/html/index.php?page=projects&GreenInfrastructureValuationToolkit=true

City Biodiversity Index (CBI)

The City Biodiversity Index (also known as Singapore Index) was developed in partnership between Singapore National Parks, the Convention on Biological Diversity (CBD) and the Global Partnership on Local and Sub-national Action for Biodiversity. It aims to assist cities in self-assessment and benchmarking of conservation efforts and evaluation of progress in reducing the rate of biodiversity loss in urban ecosystems. Although primarily targeted at measuring progress related to implementation of CBD and biodiversity targets, the index can be used to track progress in relation to achieving biodiversity-related co-benefits, in connection with green infrastructure projects.

Link to the User's manual for CBI: http://www.cbd.int/authorities/gettinginvolved/cbi.shtml

In-VEST: Integrated Valuation of Environmental Services and Tradeoffs

In-VEST is a set of free open-source software models under the Natural Capital Project and is designed to map, assess and value a wide range of ecosystem services to support decision-making processes and assessment of tradeoffs. The tool can be used with ArcGis software or with stand-alone software and includes 16 distinct InVEST models suited to terrestrial, freshwater, and marine ecosystems. In-VEST can be used to assess a number of ecosystem services relevant to GI co-benefits (e.g. carbon storage, water purification and more).

InVEST
integrated valuation of
environmental services
and tradeoffs

Link to tool: http://www.naturalcapitalproject.org/InVEST.html

Resource Investment Optimization System (RIOS)

The Resource Investment Optimization System was also developed under the Natural Capital Project. It is free open source software tool designed specifically for watersheds, which helps to assess cost-efficiency of watershed investments. The system was developed in collaboration with partners in Latin America and is currently being tested in a number of sites in Latin America. It can help to inform the decision-making processes by assessing which watershed investments will yield best economic returns, what change in ecosystem services delivery will take place and how these relate to alternative investment strategies (e.g. investing in green v grey solutions within a watershed). This could be used as an important tool to make better choices for GI financing.

Link to the tool: http://naturalcapitalproject.org/RIOS.html

i-Tree Vue

The i-tree Vue software offers a number of tools to analyse available land cover data and estimate land cover, including tree canopy and some of the ecosystem services provided by urban trees. The effects of planting scenarios on future benefits can also be modelled using the software. The tool can be relevant in assessing impacts of proposed GI on delivery of related ecosystem services and co-benefits (basic scenarios can be modelled for carbon storage and sequestration, pollution removal). A beta version of i-Tree Hydro is also available, designed for use in watersheds to simulate the effects of changes in tree and impervious cover characteristics on stream flow and water quality.

I-Tree Vue link: http://www.itreetools.org/hydro/index.php

Health economic assessment tool (HEAT) for cycling and walking

The HEAT tool was designed by the World Health Organization (WHO) Regional Office for Europe and helps to estimate the economic savings resulting from reductions in mortality as a consequence of regular cycling and/or walking. It can be used to assess economic value of potential GI co-benefits (e.g. green spaces). The tool is designed with default parameters relevant for Europe, but these can be adapted to fit different context by using data appropriate for other locations.

HEAT
Health economic
assessment tool

Link to the tool, methodology and user guide: http://www.heatwalkingcycling.org/

Liverpool Green Infrastructure Strategy

Liverpool Green Infrastructure strategy (UK) provides valuable information on mapping green infrastructure in a citywide context, and application of spatial tools in the evaluation process. While many elements of the strategy are focused on the local policy context specific to Liverpool, important lessons can be learned from the mapping exercises. These include identifying existing green infrastructure, potential benefits, as well as needs of the residents. The strategy includes an audit of existing green infrastructure assets, and their functions, as well as spatial data on identified public benefits and needs.

Link to Liverpool Green Infrastructure strategy resources:
http://www.greeninfrastructurenw.co.uk/liverpool/

The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits

The Center for Neighborhood Technology in the US has developed a guide for quantification and valuation of benefits from GI. The guide offers a simple overview of GI solutions along with easily understandable steps necessary to calculate a variety of performance benefits. It also includes a set of illustrative case studies that estimate the quantity and value of selected benefits.

Link to the pdf document:
www.cnt.org/repository/gi-values-guide.pdf

Woodland Carbon Code

The Woodland Carbon Code voluntary code was designed to ensure transparency in woodland carbon projects. The code guidelines were developed by the UK Forestry Commission and are intended to help assess the carbon sequestration of forest projects (and to guide through the certification process). The Carbon Sequestration section 3 of the guidance provides directions for calculating carbon removals based on types of established tree cover and other parameters. Although additional data inputs might be required for tree species non-native to central and Northern Europe, the overall calculation guidelines can be useful in assessing the extent and consequently value of co-benefits of e.g. establishment of an urban forest.

Guidance manual can be found here: http://www.forestry.gov.uk/forestry/infd-8hut6v

Case Studies Analysing the Economic Benefits of Low Impact Development and Green Infrastructure Programmes

The EPA published a comprehensive Green Infrastructure case overview in 2013, with focus on improved stormwater management using GI and LID approaches. The publication includes 13 case studies from North America, presenting different approaches to valuation of economic benefits from implementation of GI/LID programs. Although focused on case studies from the United States, the publication offers a good overview of various approaches to economic valuation of GI benefits on a municipality level.

Link to publication: http://water.epa.gov/polwaste/green/upload/lid-gi-programs_report_8-6-13_combined.pdf

6

BENEFITS, BARRIERS AND THE POSSIBLE WAY AHEAD

This guide emphasizes that one of the main benefits of GI in water management is that GI typically involves a deliberate and conscious effort to utilize the provision of ecosystem services to provide primary water management benefits, as well as a wide range of secondary co-benefits using a more holistic approach. These co-benefits, such as provision of food, recreation and erosion control, can be multiple and extend far beyond those that a specific water management intervention may initially seek to address.

In addition, GI can generate significant cost savings in operation and help to alleviate pressures on existing water infrastructure, potentially avoiding large investments in new or expanded grey water infrastructure. Examples include generating water treatment cost savings as a result of watershed protection or wetlands conservation, and relieving pressures on urban sewage systems through improved stormwater runoff management.

An additional benefit of many GI solutions is that their value and function can increase over time, not only for the delivery of primary water management benefits, but also for co-benefits. This is in contrast to the majority of grey water infrastructure, which tends to depreciate in time.

On a policy level, GI can play an important role in the wider strategies for climate change adaptation, as well as mitigation. National level water planning and adaptation often hinder public participation and lack both vertical and horizontal coordination. The sustainable management of ecosystems also serves as GI and provides services that help people adapt to climate change. These can be applied at multiple scales, allows for a coordinated approach to adaptation at the basin level, and promotes ownership of adaptation strategies, particularly for rural and local communities who are highly dependent on natural resources, and where environmental pressures are high (Sanchez and Roberts 2014). Climate change benefits of these individual solutions have been described in previous sections and include, among others, carbon sequestration, reduced urban heat island effect, as well as coastal and riverine flood mitigation.

Importantly, GI contributes to biodiversity conservation and helps to protect numerous species, common and rare, through conservation of existing and creation of new habitats. In this respect, valuation of ecosystem services across a river basin provides us with powerful arguments to integrate biodiversity values in GI decisions. River sediments and nutrients may support the health of beaches and marine parks that are found far downstream but are critical contributors to the national economy. There are however other criteria and considerations that play an important role in the decision-making process, including the cultural or intrinsic value of an ecosystem (Emerton and Bos 2004).

Despite the numerous benefits, ensuring inclusion of GI solutions in options assessments for water infrastructure remains a challenging task, for a number of reasons:

- GI is a relatively new concept in targeted delivery of water services, and there is lack of awareness of the full range of benefits of GI among water managers, utilities and the wider public.
- The ability of GI solutions to deliver the anticipated water ecosystem services is governed by complex natural processes that can be affected by a number of variables (e.g. climate change, extreme weather events, disease). Thus, predictions of GI efficiency over longer periods of time are subject to an inherent variability.
- The economic analysis of GI is relatively new with a lack of historical cost and benefit data to draw from. On the other hand, there is a wealth of historical cost and benefit data for grey infrastructure. This increases the perceived risk (i.e. uncertainty) associated with GI; such projects may have to pass a higher threshold in order to be considered. As a result of this uncertainty, GI valuation studies often employ conservative assumptions and produce

wide ranges of estimated benefits. Conservative assumptions and the omission of ancillary benefits can lead to the underestimation of the value of a GI investment.

- The full assessment of costs and benefits are often rooted in several disciplines involving differing methods for calculation, and many of the benefits relate to delivery of ecosystem services that are challenging to value in the first place, e.g. improved air quality or improved recreational opportunities. These disciplines might include social science to investigate the future causal link with conflicts or degradation stemming from an infrastructure development project, and relevant social issues, especially governance. Actions to address them need be planned and costed as well. This can increase resource needs for cost-benefit assessments of GI.
- Initial investments in GI can be expensive, despite relatively low maintenance costs. Additionally, it may take several years until GI solutions are able to deliver a full range of benefits. Business risk categories range from land ownership to ecosystem disturbance affecting delivery of services such as carbon sequestration and water storage. However, there are tools to protect the interests of financial investors in such projects, as well those of landowners. Financial best practices must be expressed clearly, with transparency and accountability in honouring obligations. Since it is equally important to protect the interests of local partners, social safeguards, such as equitable distribution of revenues, also need to be included in best practices.

This guide addresses the lack of awareness of the variety of water management benefits that can accrue from implementation of GI. It also promotes inclusion of GI in the portfolios of options assessments for water management infrastructure. To this end, further development of tools in economic valuation of ecosystem services will be instrumental. This requires further research in quantifying and valuing benefits (and co-benefits) of GI, as well as developing appropriate methods for monitoring and evaluation. In time, efforts by economists in this area of research and the benefit of hindsight will lend additional clarity to the real returns provided by GI (Schmidt and Mulligan 2013) and the value changes over time.

Building on the work done in preparation of this guide, possible next steps and priority areas for research may also include:

- Further development and elaboration on cost-benefits assessment methodologies for water infrastructure options assessments, particularly combining it with learnings from Life Cycle Assessment studies on the quantification of environmental and social impacts
- Tools needed for development of combined portfolios of green and grey infrastructure
- Identification of the main challenges for wider GI adoption on a policy level, and communication of benefits to target audiences
- A critical and comparative evaluation of the practical tools for the quantification and valuation of benefits
- Pilot testing of selected methodologies and tools for the quantification and valuation of benefits in a variety of specific geographies and situations
- Consolidation and dissemination of experiences and lessons learned from the above, as well as other parallel efforts to make progress in this area.

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