Can Africa take the lead on Sustainable Water Infrastructure?

(Final)

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Summary

Well managed water resources and freshwater ecosystems are a prerequisite for sustainable development, and with careful planning water infrastructure investment can yield multiple benefits that deliver *more-for-less*. There are however important caveats. The continued reliance on grey infrastructure alone can fragment and alter freshwater ecosystems, and poorly operated or inadequate infrastructure can lead to water pollution, over-abstraction or disruption of natural water and sediment flows through river systems. In contrast, innovative natural infrastructure options hold the potential to deliver affordable water services alongside multiple additional benefits, such as green space for recreation, biodiversity and carbon storage, but face barriers in comparison to tried and tested conventional engineering approaches. The development of sustainable water infrastructure (that uses natural and conventional infrastructure in combination) therefore presents a significant opportunity but also a challenge. Meeting this challenge will require a whole system, long-term, approach to planning and management that balances the needs of investors, communities and the environment. This is not easy and will become increasingly difficult as the demand for water resources and protection from disasters continues to grow and short-term policy and planning perspectives persist. But momentum for change is growing, and Africa has the geography, human resources and opportunity to take a lead in delivering this change.

Current efforts on the use and incorporation of sustainable water infrastructure across Africa

Over the last few decades, there has been a growing interest in sustainable water infrastructure in Africa and a number of promising research and demonstration initiatives. These focus around four main categories of sustainable water infrastructure (although there are some overlaps between these groups).

- **Constructed wetlands for water (including wastewater) treatment.** The use of constructed wetlands has been explored in several African countries, with centres of expertise now well-established in Egypt, Morocco, Tunisia and Tanzania, and an emerging initiative in Algeria. Constructed wetlands offer great potential as a cost-effective way of removing pollutants and excess nutrients from water before it is discharged to the environment, especially for sites that cannot afford conventional water treatment such as small rural communities, farms and schools, but also for industrial processes and new or existing urban developments. Their true potential however is maximized when they are used as part of a sustainable water management system that integrates water-saving, water treatment, water-re-use, nutrient recycling and energy recovery technologies, using both grey and green infrastructure. For example, treated wastewater can be re-used for irrigation, allowing remaining nutrients in the water to be productively used, while biogas can be recovered from anaerobic digesters and the sludge can be composted and used as a soil improver. They also offer co-benefits for biodiversity and aesthetic value as well as educational opportunities; as seen for example in Témacine in Algeria and Ruaha School in Tanzania (see section 4.2). Their longer-term success however depends on effective operation and maintenance, requiring support for continued funding and training. Natural wetlands can also be used for treating wastewater, but strict control is needed to avoid overloading the system and destroying the wetland.
- **Sustainable drainage systems (SuDS) and urban green infrastructure (GI)**. Although sustainable drainage systems are growing in popularity in developed countries, there are few examples to date in Africa. But this is set to change. There is a centre of expertise in South Africa where various examples are being tested (including green roofs, permeable paving, retention / detention ponds and wetlands) and there are various initiatives exploring the retrofitting of small scale SuDS into informal settlements, working with local communities and Non-

Governmental Organizations (NGOs). SuDS and GI offer tremendous potential to solve drainage problems as well as providing multiple co-benefits for recreation, aesthetic value, carbon storage, air quality, biodiversity and spaces for urban agriculture. Africa is experiencing significant urban growth, and although this provides an opportunity for SuDS and GI to be incorporated, uncontrolled urban development that encroaches on green space is undermining the opportunities for services derived from these spaces. Participatory planning with local communities is the key to successful implementation.

- **Aquifer recharge** can be an effective way of storing large volumes of surplus rainwater, river water or recycled wastewater, especially in arid countries where evaporation rates from reservoirs are very high. There are successful schemes at Atlantis in South Africa, where recharge also helps to provide a barrier against saline intrusion, and at Windhoek in Namibia, which is a world-leading example of successful storage in a highly fractured aquifer system.
- **Land management and restoration** plays a critical role in sustainable water management. For example, forests play a vital role in flood and erosion protection as well as regional rainfall generation, and wetlands can help to regulate water quality. There have been several important initiatives to restore degraded land, working in close collaboration with local communities and stakeholders. If successful, these initiatives provide multiple benefits for biodiversity, flood and erosion protection, water quality, water supply and carbon storage, as well as providing jobs and protecting livelihoods. For example, the Buffelsdraai community reforestation project in South Africa is notable for its contribution to employment and poverty alleviation. It takes considerable time and effort however to build well-functioning relationships with local communities and negotiate solutions that balance trade-offs between different resource users and different environmental, social and economic goals.

What role can Multilateral Development Banks (MDBs) play in promoting the development of sustainable water infrastructure?

The conventional infrastructure narrative presents any biodiversity concern as a conservation issue. To make progress, MDBs have a role in transforming this narrative; and promoting ecosystem services and biodiversity as central considerations in the design of infrastructure solutions that deliver Sustainable Development. This implicitly includes recognizing productive landscape features as integral elements of infrastructure systems.

To enable this transition MDBs have a role in supporting Regional Member Countries, River Basin Authorities and infrastructure promoters in developing plans that:

- **Embed a balanced infrastructure portfolio:** The argument around natural and built infrastructure is often polarized, with vigorous argument given to one at the expense of the other. MDBs have a role in **c**hallenging this false choice (between natural and built infrastructure) and encouraging the use of sustainable infrastructure systems based on a portfolio of natural, hybrid and built infrastructure tailored to the specific context.
- **Ensure visibility is given to local, as well as more regional, impacts and benefits:** Much infrastructure is considered in the context of the large scale impacts it delivers (e.g. contribution to national power generation and water resources). MDBs have a role in demanding (through guidance) that the strong link between natural infrastructure, the services that it provides, and local livelihoods is embedded in the choices made, by ensuring that participation and local impacts are well-reflected in decision-making processes.
- **Ensure that the case for natural infrastructure is heard**: Infrastructure promoters make the case for investment using the rules of the game. MDBs set the rules. MDBs have a role in ensuring these rules give preference to projects that adopt a whole system and long-term view to the

promotion of infrastructure. This will include ensuring (i) natural infrastructure is recognized as an integral component of potential solutions, and opportunities for inclusion are considered early in the planning process (and not simply as a *post hoc* adjunct to conventional built infrastructure), and (ii) appraisal processes enhance the chances for including/selecting natural infrastructure options (and do not prematurely foreclose integrated approaches or systematically bias choices towards built infrastructure). Central to this will be accepting a need for adaptive programmes that avoid an undue bias towards one-off capital investment but recognize the delivery of sustainable water management as a continuous process (and provide the financial structures to enable this).

How can sustainable water infrastructure be integrated into decision-making processes?

Delivering sustainable water infrastructure in Africa will require the misconceptions that surround working with natural infrastructure and natural processes to be overcome. In particular, current planning and decision-making processes tend to isolate water management issues within the context of a narrow engineering or hydrological paradigm. In doing so, little (often insufficient) consideration is given to the opportunities that natural infrastructure offers to enhance ecosystem health and to provide ecosystem services that reduce conventional infrastructure costs (in both the short and longer term). **MDBs have a role in raising the awareness of these opportunities and providing the guidance and tools to promote greater integration of development and ecosystem thinking into planning processes.**

Information is widely available on the engineering performance of built infrastructure (and the expected benefits) but much less is known about the ecosystem services delivered by existing or proposed natural infrastructure. A central barrier to achieving the widespread use of sustainable water infrastructure is the perception that natural infrastructure cannot be relied upon (particularly during extreme events). This simplistic view, in part, reflects the continued reliance upon deterministic standards that underpin engineering design approaches that consider performance in the context of a small number of well-defined design events. To make progress, and avoid potential maladaptation, evidence on the performance of natural and nature-based infrastructure will need to be presented with comparable authority, and in comparable terms, to that of conventional infrastructure. Investment frameworks will also need to be able to accept uncertainty, in both performance and future conditions, and seek an adaptive planning and management approach (based upon a continuous process of r*eview-and-modification*, rather than *build-and-maintain*). These natural services support local livelihoods and provide services to built infrastructure that often go unrecognized (*e.g*. managing the flow of sediments to a reservoir, reducing extreme storm loads). Making this evidence available and adopting an investment framework that rewards the attributes of sustainable water infrastructure are therefore prerequisites to developing business cases that enable the many co-benefits to be identified, valued and factored in, and delivering investment strategies that appropriately combine natural and built infrastructure solutions.

MDBs have a central role in leading Africa to a sustainable water future. This includes informing (through authoritative evidence); influencing (through forums and media and the promotion of good practice frameworks and guidance) and investing (collaboratively and innovatively) to deliver sustainable water infrastructure.

Contents

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Figures

1 Introduction

1.1 Context of this assignment

The Stockholm International Water Institute (SIWI), African Development Bank (AfDB), World Water Assessment Programme UNESCO (WWAP), Daegu Metropolitan City, Korea and International Water Management Institute (IWMI) will co-convene a Seminar on *"Sustainable Infrastructure for Inclusive Green Growth"* at the Stockholm World Water Week 2018. This paper supports the preparation of this seminar and develops the agenda for internal dialogue in the Bank regarding a possible future direction towards greater mainstreaming of sustainable water infrastructure in Bank operations; placing non-structural measures and complementary natural infrastructure at the core of water development decision-making.

It is anticipated that the "Sustainable Infrastructure" seminar will draw on successes and lessons learnt to provide a view on:

- the effectiveness of sustainable/green infrastructure across differing temporal and spatial scales;
- financing sustainable/green infrastructure as a feasible investment;
- governance for achieving efficient sustainable/green infrastructure;
- maintenance and operation, expansion, and rehabilitation of sustainable/green infrastructure; and
- opportunities for technical innovation.

The overall objectives are therefore to:

- Identify African examples of sustainable water infrastructure, where a mix of grey and natural (green) infrastructure is used.
- Review these case studies to understand whether sustainable infrastructure is appropriate and feasible in Africa, and if so, what are the conditions or activities required to invest in this approach, whether by the private sector, MDBs, or governments.
- Based on these findings, develop a framework to help ensure key opportunities for sustainable infrastructural approaches are recognized and adequately considered in the decision-making processes of key stakeholders.

These will provide the foundation for building a potential business case for actively promoting the use of sustainable infrastructure in an institution such as the African Development Bank and seeing the protection and enhancement of natural capital as a viable investment.

1.2 Report structure

Following this introductory Chapter, the report responds to the main questions set out in the Project Brief:

Chapter 2: Setting the scene: Africa's unique development context: This chapter focuses on Africa's uniquely diverse climate, geography, ecosystems and decision context and how they act to shape the water development challenge.

Chapter 3: Challenges and opportunities for sustainable water infrastructure: This chapter presents a summary of what is meant by sustainable water infrastructure as well as the challenges and opportunities associated with delivering sustainable water infrastructure.

Chapter 4: Case examples of sustainable water infrastructure: This chapter presents examples of sustainable water infrastructure across Africa and, where relevant, internationally. For each example, we assess the degree to which this a core or supplementary activity to the primary infrastructure decision process.

Chapter 5: Conclusions: This chapter summarizes the key findings from the review.

Chapter 6: The way forward: This chapter sets out the emerging principles of a framework to support a broader take-up of sustainable water infrastructure solutions.

2 Setting the scene: Africa's unique development context

By 2050, Africa will be a very different continent. Its population will have doubled, soaring by another billion. Its towns and cities will house more people than its rural villages. Its economies will have transformed. The question is not where Africa is going: it is whether the continent gets there by following a sustainable and inclusive development path. Fred Kumah, WWF Director for Africa, (WWF, 2017).

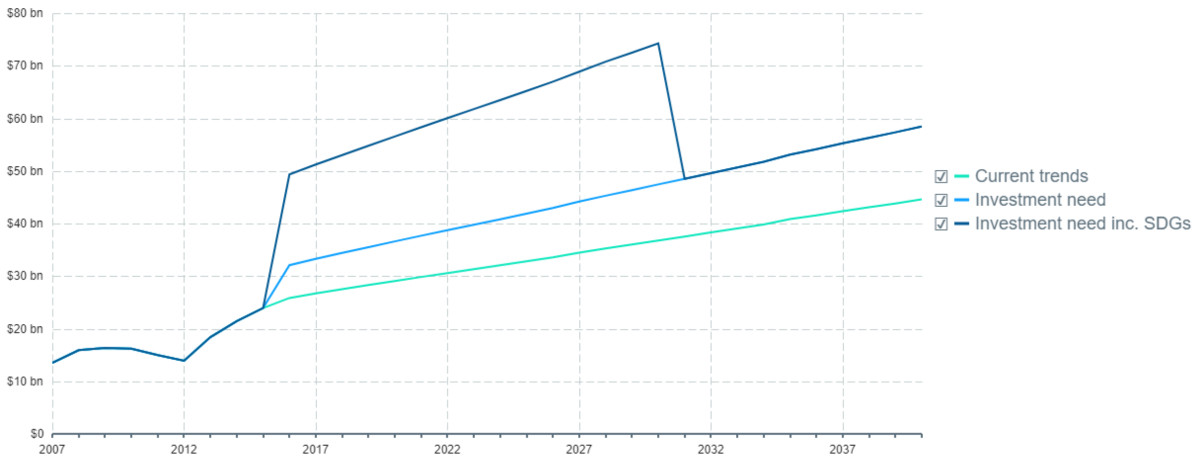
For most African countries economic growth is dependent upon agriculture, mining and manufacturing, and is likely to remain so for at least the next decade (WWF, 2017). Reliable water supply is critical to catalyse growth in these sectors: to generate the energy and grow the crops that will support the development of the continent's cities (the population of which will treble over the next 35 years). The demand for water resources is likely to increase rapidly as Africa's economy grows, people become more affluent, cities expand and the climate changes. In response, pressure on Africa's unique – and, in many places, largely intact – freshwater habitats and biodiversity will continue to grow.

In responding to these demands, inherent conflicts will therefore increasingly arise between water for the environment, agriculture, energy, urban use, mining and manufacturing. Water resources are unevenly distributed across Africa and often out of phase with population centres. For example, the Congo Basin, inhabited by only 10% of the continent's population, is drained by rivers that contain 30% of its water (Jackson, 2009). More sparsely populated rural communities also face water related challenges, including frequent extreme floods and droughts (and associated disease) that add to migration pressures, exacerbating the challenges presented by refugee settlements and informal urban sprawl (WWF, 2017).

Coupled with significant seasonal and inter-annual variability and climate change, the water management challenge in Africa is therefore significant and will demand major investment in water management planning, governance and infrastructure. The Africa Infrastructure Country Diagnostics (AICD) estimates, for example, that to deliver food security Africa will need investments of around US$18 billion for small-scale irrigation systems and $2.7 billion for large-scale systems over the next 50 years (WWDR4, 2012), with expenditure on conventional water infrastructure more generally (i.e. collection, treatment, processing and distribution infrastructure such as dams and levees) projected to more than double by the 2040s (to over $60bn per year, Oxford Economics, 2017). With only $7.9 billion of capital investment in achieving WASH services financed in 2016 there is a significant funding gap[1].

These figures exclude the significant investments that will be required to support the delivery of the UN Sustainable Development Goals (SDGs, United Nations, 2015) – a requirement illustrated in Figure 2-1.

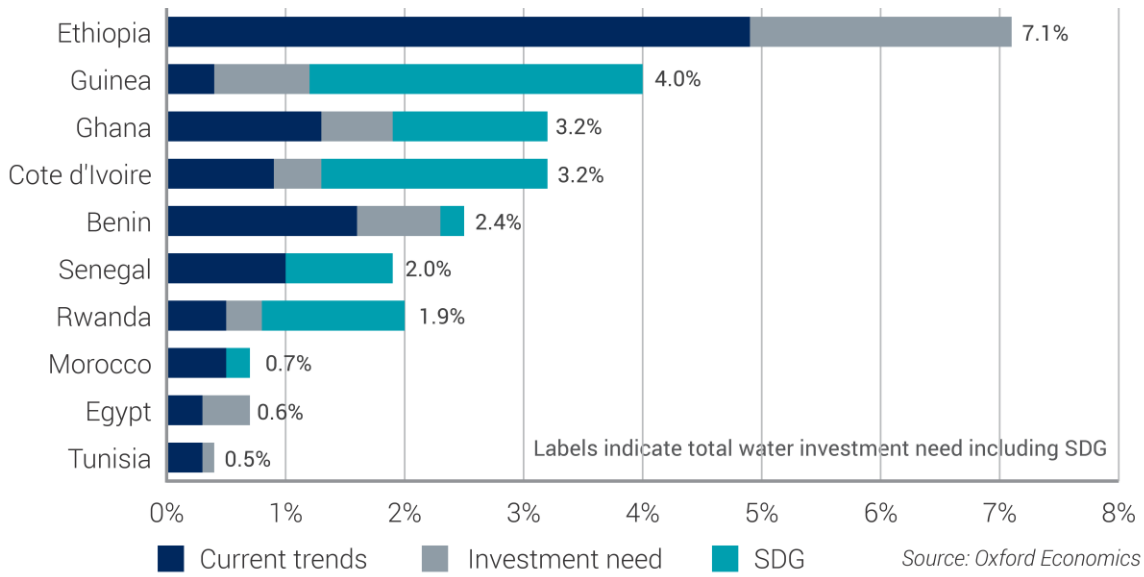
[1] https://reliefweb.int/sites/reliefweb.int/files/resources/The0costs0of0m0itation00and0hygiene.pdf



Source: Global Infrastructure Hub, 2017.

Figure 2-1 Africa's conventional water infrastructure investment: Current trends and projected needs

Significantly greater capital spending is needed in Sub-Saharan Africa, where slow progress to date means capital expenditures of 0.64% of Gross Domestic Product (GDP) through to the 2030s will be needed to close the gap (Hutton and Varguhese, 2016). In some countries the need is much greater than this average (rising to 7% of GDP in Ethiopia) - Figure 2-2.



Source: Oxford Economics, 2018.

Figure 2-2 Country breakdown of water infrastructure investment needs to deliver universal access to clean drinking water and sanitation, 2016-2030 (percent of GDP)

Inherent conflicts will arise in balancing the demands of different stakeholders, and managing environmental, economic, local and national outcomes. How these trade-offs are made will determine the long-term development trajectory of many African countries. There is therefore a critical opportunity for MDBs to influence this trajectory and ensure that investment choices reflect good practice in river basin (e.g. as expressed by Pegram *et al.,* 2014) and water infrastructure planning (based on strategic planning of a complementary combination of natural and built infrastructure). To do so successfully, however, will require difficult and often unique challenges to be recognised. Some of the most important of these are introduced below.

2.1 A dynamic and diverse socio-economic context

Africa faces three compelling socio-economic challenges. These are well-summarised in the recent WWF report *'Africa's watershed moment'* (WWF, 2017) and reflect:

A diversity of economic settings

Africa's economy is as diverse as its people and geography.

Many countries operate highly fragile economies (often dominated by agrarian and/or extractive industries that are highly water dependent) and have limited capacity for long-term planning or investment. Elsewhere rapid urbanisation presents opportunities to diversify and reduce the dependence on water for development, but this presents new problems associated with urban pollution and climate related risks (including urban flash floods).

A billion more people to feed

Agricultural production is up 160% over the past 30 years, but Africa remains a net importer of food and is the only continent where the absolute number of undernourished people has increased over the past 30 years (World Economic Forum, 2016[2]).

Recent years have seen significant improvements in agricultural production across Africa. Eighteen Sub-Saharan African (SSA) countries have reached the Millennium Development Goal (MDG) of halving the proportion of people who are hungry. Country-level programmes (such as the Ethiopian Agricultural Transformation Agency), pan-African groups (like the African Development Bank, the African Union and the New Partnership for Africa's Development) and cross-border initiatives (for example, the Comprehensive Africa Agriculture Development Programme) have all contributed.

Further improvements are needed. By the year 2050, Africa's population is projected to increase by more than 42 million people per year and total population will have doubled to 2.4 billion (UN, 2017). City growth will be a key feature of this trend (. All will need access to water for food, energy and water security, as well as hygiene. Agriculture is already the largest user of water in Sub-Saharan Africa (87% of total water use) (FAO, 2008), and improved water management will be required to respond to this increasing demand (and achieve *'SDG2 – Zero Hunger*').

Water supports not only land-based agriculture but also freshwater aquatic agriculture, and freshwater fish provides a crucial food source to many local communities throughout Africa (Jackson, 2009). Fishing is usually done for subsistence and the fish consumed locally. There are however exceptions including the introduction of alien species for commercial fisheries, such as the Nile Perch in Lake Victoria. The potential expansion of commercial aquaculture presents several water resource challenges, including potential negative impacts for wild fish populations and, ultimately, fisheries' productivity and loss of traditional subsistence activities. Better water management (and more strategic infrastructure development planning) is needed to take advantage

[2] https://www.weforum.org/agenda/2016/01/how-africa-can-feed-the-world/

of the economic opportunities that sustainable agriculture and aquaculture presents (Pegasys, 2017) including intra and inter-continental trade (and the attendant benefits of social cohesion and economic development) whilst avoiding the most negative consequences.

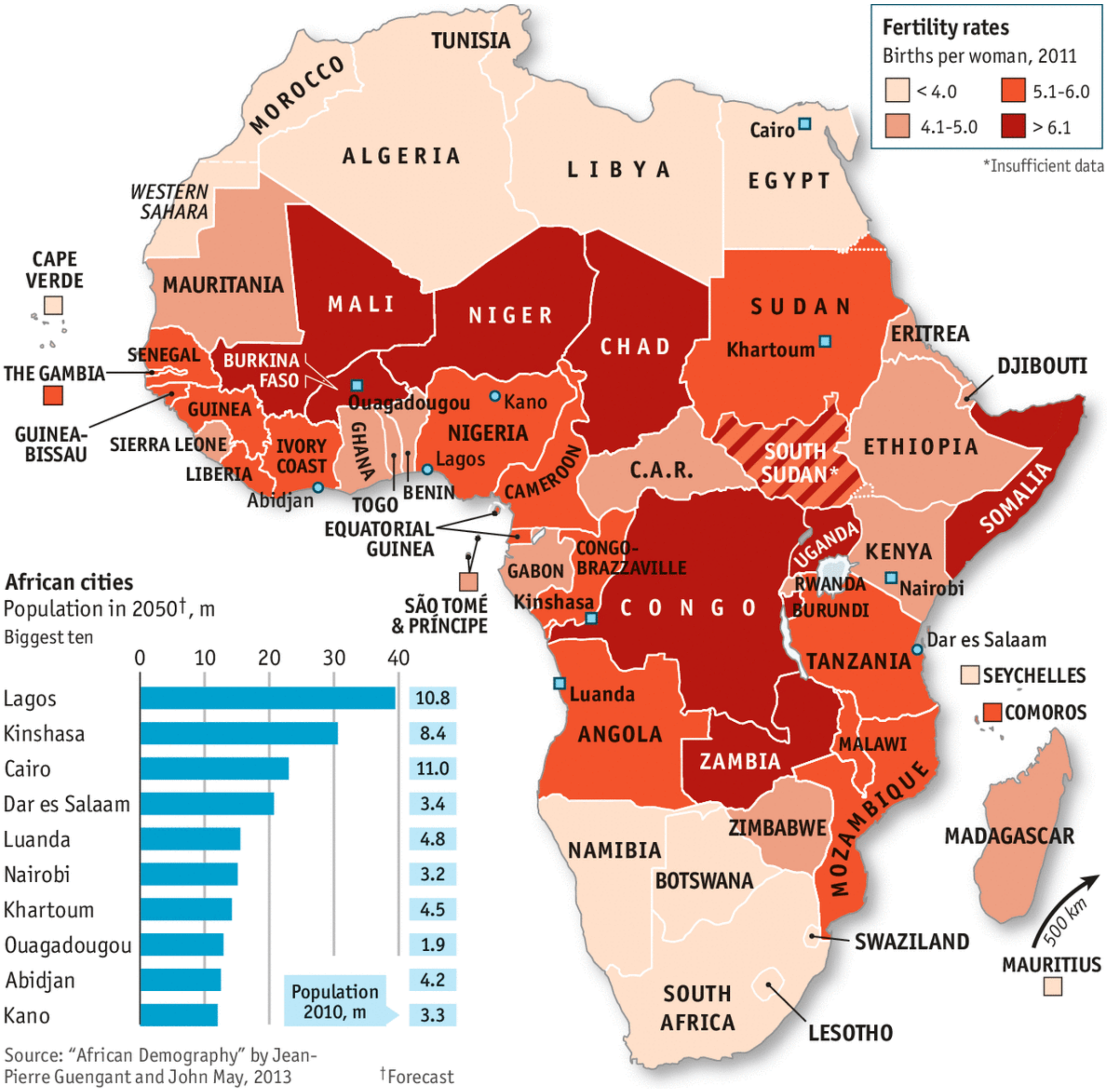


Figure 2-3 Population growth across Africa is projected to be significant by the 2050s

Rural poverty and rapid urbanisation

Rural communities and the informal expansion of urban centres across Africa continue to have limited access to WASH services.

Substantial progress has been made in improving access to WASH (water - for drinking and cooking, sanitation and hygiene) services. Despite these advances, pushed forward by activities in support of the MDGs, many African countries are far from achieving universal access to WASH services – particularly sanitation. This lack of progress is most acute in rural communities (with almost 20 percent of people continuing to rely upon surface water — rivers, lakes, ponds, and irrigation channels — for drinking, cooking and waste disposal).

The inequality between rural and urban centres is also striking; in Angola, for instance, there is a difference of close to 40% between access to basic water services between urban dwellers and rural residents (JMP, 2017). This discrepancy further disadvantages rural areas, particularly girls and women who often shoulder the daily burden of collecting potable water, often from sources far from homes. When water supply and sanitation improve in rural areas, health and quality of life improve, and other major goals such as poverty alleviation, socio-economic development, improvement in education (especially for girls) and gender equality are addressed as well. Rural communities also often rely directly upon healthy freshwater ecosystems for their livelihoods and food. Investment in sound water management is therefore a necessary (although not a sufficient) pre-requisite to reducing rural poverty and achieving *SDG 10 – Reduced Inequalities*.

These rural water issues increasingly combine with the allure of economic opportunities to encourage about 17 million people each year to migrate from rural communities to expanding urban centres (UNHCR, 2011). Coupled with non-migratory population growth, the urban population in African cities is expected to treble by 2050 (Jackson, 2009), with the urban population exceeding the rural population of Sub-Saharan Africa by about 2040 (an urbanization trend reflected globally, with the proportion of the world's population living in urban areas projected to increase from 54 to 66 percent by 2050s, with much of the expected urban growth taking place in Africa (UN, 2014)). In response, African cities will be drivers of economic growth, diversity and trade, driving a rapid increase in Africa's middle classes, expected to grow from 355 million (34% of Africa's population) in 2010 to 1.1 billion (42% of the population) in 2060 (WWF, 2015). Growing demand for water in cities will require a significant improvement in water management, particularly urban water quality, to achieve *SDG 11 – Sustainable Cities and Communities*; a challenge that presents multiple opportunities for the development of Sustainable Water Infrastructure (urban wetlands, green roofs, and sustainable drainage approaches) alongside more conventional infrastructure.

2.2 A diverse biophysical setting

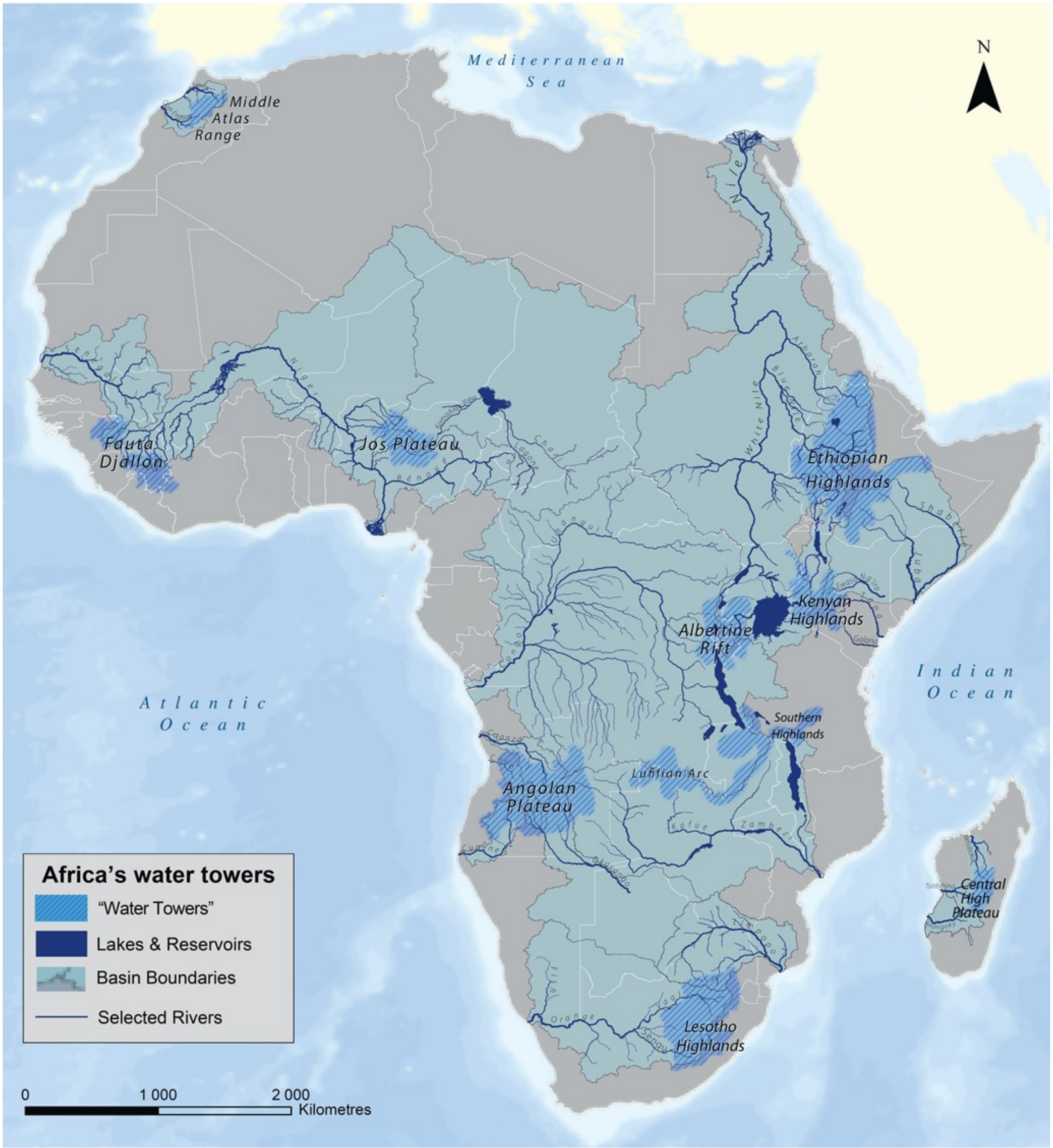
Interconnected physical geography

Africa, the second largest continent (after Asia), represents about one-fifth of the total land surface of Earth and can be divided into eight major physical regions: the Sahara, the Sahel, the Ethiopian Highlands, the savanna, the Swahili Coast, the rain forest, the African Great Lakes, and Southern Africa. Lying almost entirely within the tropics, and equally to north and south of the equator, Africa exhibits little temperature variation; rather the most important climatic differences are due to variations in rainfall (a variation primarily driven by a combination of topography and ocean interactions).

The most important physical features in the context of water are the mountainous and elevated *'water tower'* topographies. These provide the source waters for the major African rivers such as the Nile, the Niger, the Senegal and the Orange that carry water to areas that would otherwise be too arid to support much life (Figure 2-4). A network of important wetlands are associated with these rivers (for example the inland delta around the Niger, Sudd Marshes and many others) and they

SAYERS AND PARTNERS

support a wide range of important local and regional ecosystem services[3]. These rivers are often transboundary (crossing multi-national watersheds) and, in most cases, River Basin Authorities (RBAs) exist to develop cooperative management plans. Despite these efforts, many geo-political tensions remain (such as those between Egypt, Sudan and Ethiopia associated with the development of the Ethiopian Great Renaissance Dam). In some instances, the difficulties are a function of limited evidence or capacity to deliver the innovative, multi-scale, solutions needed.



Source: : Africa Water Atlas: Water Towers and main rivers

Figure 2-4 Africa's topography and important 'water towers'

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[3] See for example https://www.wetlands.org/publications/water-shocks-wetlands-human-migration-sahel/

Complex and diverse ecosystems

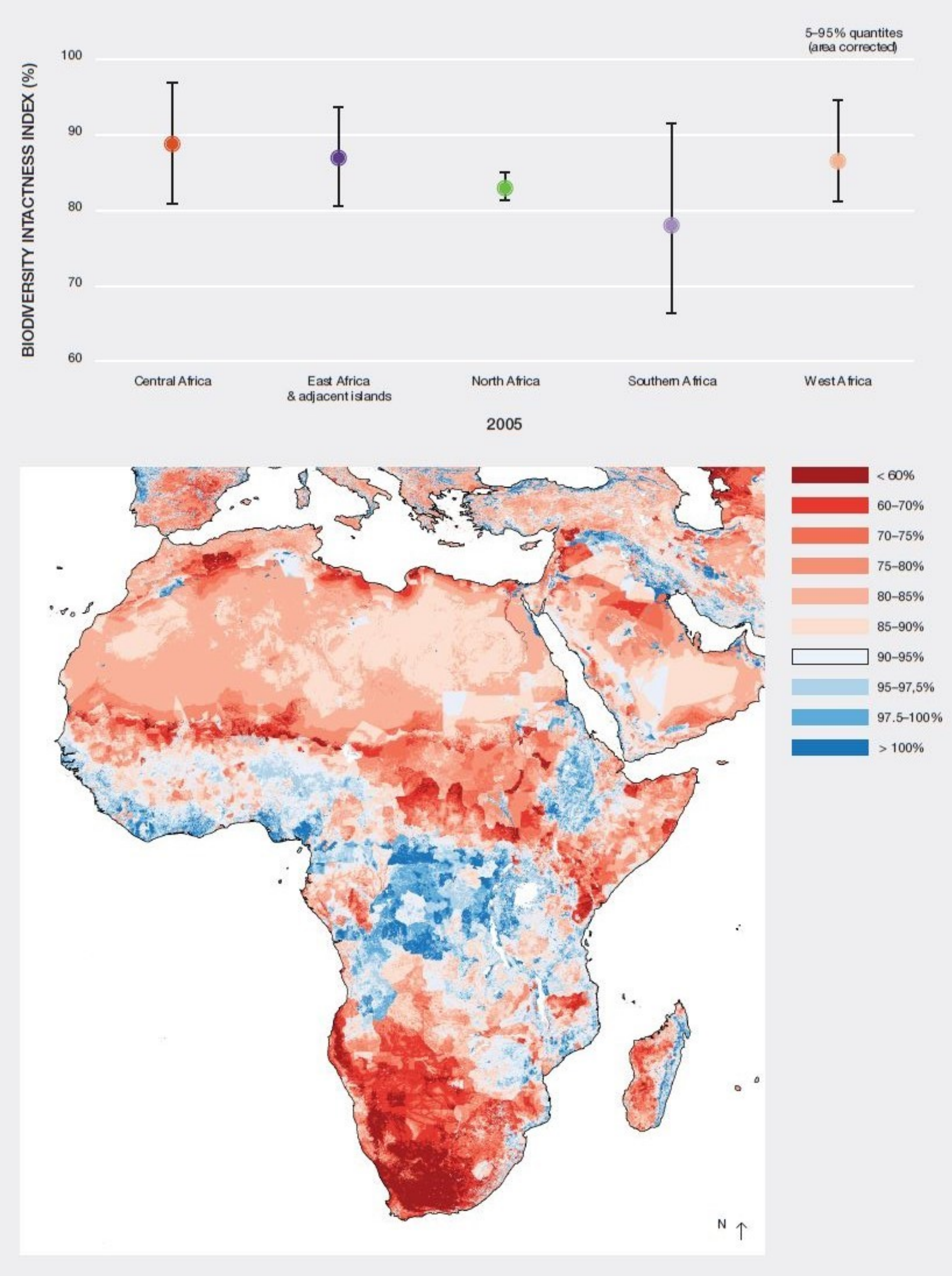
Africa is home to a rich and unique flora and fauna containing over a quarter of the world's biodiversity, with the greatest concentrations occurring in the African equatorial ecosystems, South Africa and Madagascar (UNEP-WCMC, 2016 *apud* Cromier-Salem *et al.,* 2018; Figure 2-5).

Africa's highly diverse **terrestrial ecosystems**, ranging from forests to arid/semi-arid ecosystems are being threatened by the increasing change in land-use, for example, conversion to agriculture and deforestation, leading to habitat fragmentation and destruction. In response, most, if not all, terrestrial ecosystems in Africa have already experienced major biodiversity losses in the past 30 years, which has negative impacts nature's contribution to people; a trend that will be exacerbated by climate change (Cromier-Salem *et al.,* 2018).

The inland waters of Africa support a diverse aquatic life, with the highest levels of **freshwater biodiversity** found in the Rift Valley Great Lakes (Lake Malawi, Lake Tanganyika, and Lake Victoria) and in the rivers of the Congo. Along much of the Mediterranean and Atlantic coasts of Morocco, Algeria and Tunisia, in Upper and Lower Guinea, southern and eastern South Africa and in the Great Lakes in eastern Africa, high levels of development and associated demands on water resources are degrading freshwater ecosystems. As a result, many species are currently under severe threat with knock-on impacts on livelihoods (as 45% of fish and 58% of plant species are regularly harvested). Climate change is projected to degrade freshwater ecosystems further, resulting in an estimated 10% decline in freshwater biodiversity by the 2050s (Cromier-Salem *et al.,* 2018).

The wide continental shelf along the northwest coast of Africa, the mangrove forests of West and East Africa and the adjacent islands provide diverse habitats that support high levels of **marine and coastal biodiversity**. The Red Sea is home to many, often unique, flora and fauna including seagrasses, coral and mangroves. With overexploitation, habitat degradation and loss, acidification, pollution from land-based sources (a particularly important consideration in the content of this report), invasive alien species and sea level rise, highly valuable ecosystem services are being threatened. For example, approximately 20–30% of African mangrove has been lost in the past 25 years (Cromier-Salem *et al.,* 2018).

Africa maintains an almost intact assemblage of large-bodied vertebrates (**megafauna**; Gill, 2015; Ripple *et al.,* 2016 *apud* Cromier-Salem *et al.,* 2018). The health of Africa's megafauna is inextricably linked to maintaining intact freshwater and terrestrial ecosystems and is highly vulnerable to habitat fragmentation.



Blue areas: Within safe limits for the maintenance of ecosystem health
Red areas: Beyond the safe limit for the maintenance of ecosystem health

Source: Newbold et al. (2016), and chart from GEO BON-PREDICTS (https://geobon.org/) *apud* Cromier-Salem *et al.,* 2018.

Figure 2-5 Africa biodiversity: Biodiversity Intactness Index

2.3 Complex and emerging water governance arrangements

The strong mega-trend of rapid urbanization will continue to sharpen water competition across Africa. This will add to the complexity of the water governance needed to ensure water is allocated according to multi-scale priorities (local, city, country and basin) and to be capable of delivering multiple outcomes at those scales, including inclusive economic growth, poverty reduction and ecosystem health. Africa faces unique challenges in achieving this goal; not simply the misalignment of water resource and urban growth and the diversity of geographies and economies, but also the variation in governance capacity and the interaction between informal and formal decision making.

Moving towards sound water governance in Africa faces several interconnected challenges. These are briefly introduced below.

Inclusion and participation

There are difficulties in mobilising participatory (inclusive) decision-making, at local, city and river basin scales, due to the lack of appropriate platforms for negotiations to take place between stakeholders. This undermines the legitimacy of the decision process and restricts innovation in the solutions provided. An ecosystem services lens, therefore, is central to sustainable water infrastructure, supporting the identification (and engagement) of all stakeholders affected by the potential investment choices and its impacts on the flow of a range of ecosystem services and their dependents (and not simply those with a vested interest in the project or those immediately impacted).

Diversity of policy and regulatory environments

Different types of water management activities take place at different spatial scales; from regional scale restoration of environmental flows that might involve changes to basin-level water allocation (via a basin water allocation plan) to localised water management issues such as the correct siting, maintenance and operation of a constructed wetland for water treatment. Likewise, management of pollutant loads might involve whole-of-basin regulatory measures or, alternatively, local action to address specific discharges by a user. Multiple, and often distinct, policy and regulatory environments (formal and informal – see below) and the context of rapid growth make collective action across scales difficult in Africa. It is particularly difficult to reconcile the increasing focus on regulatory frameworks based on localisation and local content, a positive development in many respects, with the requirements for multi-scale management of water resources and freshwater ecosystems that is a pre-requisite of delivering sustainable water infrastructure (see below).

Integrating informal and formal arrangements

Successful implementation of sustainable water infrastructure often demands a fully participatory approach, which in turn requires dealing with both formal and informal governance systems, such as national and local government alongside community groups. It is challenging to overcome the complexities introduced through these parallel formal and informal governance systems, but this can enable informal modes of governance to be effective contributors to formal decision-making and implementation, without losing the social and economic benefits that the informal system produces. For example, participatory planning of small scale sustainable drainage options in informal settlements can harness the local knowledge and innovation of residents (e.g. Fitchett, 2017).

Integrating local and regional planning

From communities (including nomadic), to towns, cities and trans-national River Basins, growing water demands and use in the context of urbanization puts an added emphasis on waste water treatment and the need for viewing water in an integrated landscape perspective, beyond the city borders. Integrated planning is needed to prevent regional scale plans having adverse local impacts, such as through over-abstraction of water for large scale irrigation schemes (Reid and Orindi, 2018), and vice versa, such as local reclamation of wetlands for agriculture affecting regional biodiversity and ecosystem services (Turpie *et al.,* 2016a).

Operationalising (regional) plans: Translating plans to actions

Contemporary approaches to water management reflect a paradigm of integration; and concepts such as Integrated Water Resource Management (IWRM) recognise the economic and ecosystem service benefits of managing water and related resources in an integrated manner. In principle, most river basin authorities (RBAs) recognize the need to adopt such an approach and acknowledge that rivers and wetlands provide important ecological services such as waste assimilation, floodwater storage, and erosion control as well as additional social and economic benefits, including local livelihoods and alleviating poverty within river basins. While the rationale for such an approach is conceptually clear, most transboundary watershed managers focus on an IWRM framework that looks at traditional water infrastructure to manage water quantity, flood defence, navigation, and hydropower *etc.* For example, in the Congo River Basin (CRB) the development focus is on hydropower and navigation. This development path takes little account of the impacts of navigation and dams on ecosystem services nor of deforestation on water losses that affect navigation (Dimple *et al.,* 2011). Links among ecosystem services (the forest's capacity to generate rainfall and the regional linkage to the integrity of forested 'water towers'), the serious problem of deforestation in the Congo, and the significant decline in river discharges and consequent reduction in days of navigation are now being recognized through the IWRM lens but are not yet evident in water management policies or plans. Significant human resources and innovative financing will be needed to bridge the implementation gap and deliver sustainable water futures in highly conflicted basins such as the Congo and elsewhere in Africa.

Transparency

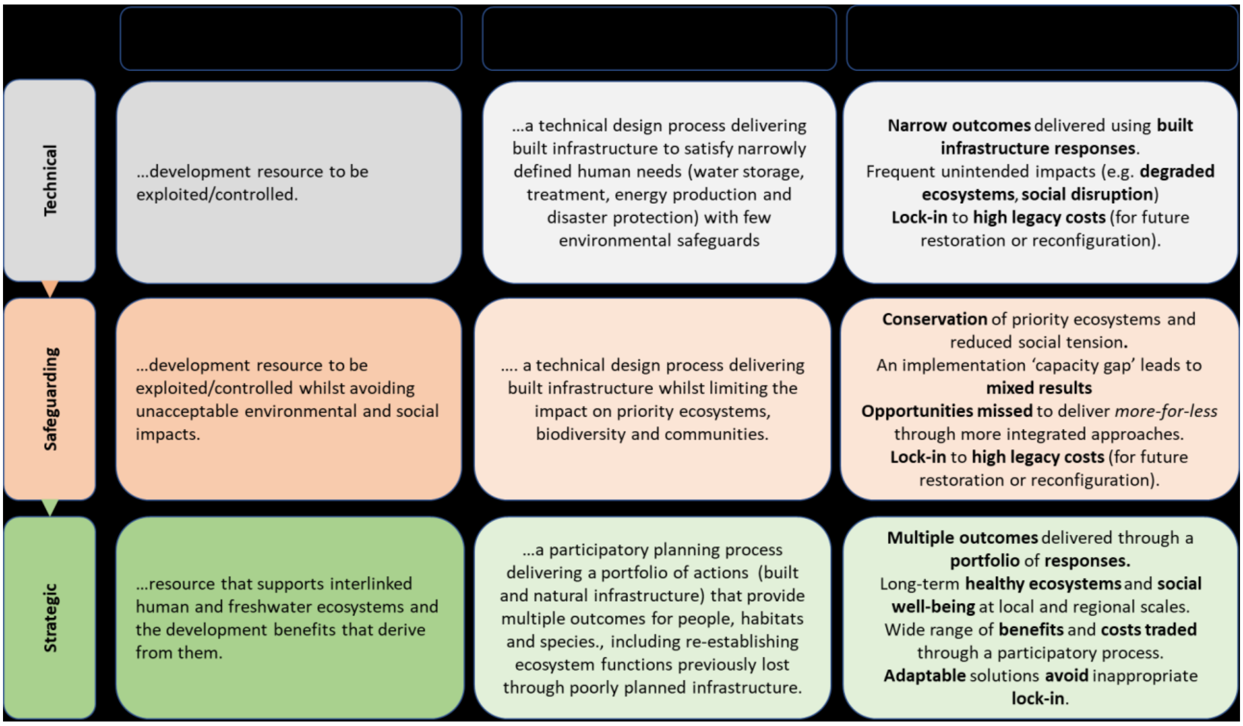
The lack of transparency, accountability and participation in decision making processes and associated opportunities for corruption presents a further challenge for sustainable water infrastructure. In one sense, the typically small scale and decentralised nature of many sustainable water projects helps to reduce the potential for corruption and fraud, but conversely this can also act as a disincentive for those that are able to influence the decision if they are looking for opportunities to 'siphon off' money from large investments in conventional built infrastructure.

3 Challenges and opportunities for Sustainable Water Infrastructure

3.1 Evolution of water infrastructure planning

Water management has often evolved in response to extreme events and development pressures. This heuristic approach has yielded some important incremental shifts in both policy and planning (such as the concepts of catchment management, integrated approaches and ecosystem-based adaptation) but it has been slow to influence the planning and design of the supporting water infrastructure (Sayers *et al.,* in press). In part this reflects the diversity of water infrastructure (both in type and scale), and the varying geographies and socio-economic contexts within which they are promoted. This is not to say no progress has been made; it has, and central to this progression is the changing perception of the role of water in society. A WWF/GIWP collaboration has explored this progression (Source: Green Water Infrastructure: A Strategic approach to the planning and management natural and built water infrastructure (Sayers *et al.,* in press). Next in the series on Strategic Water Management in the 21st Century, WWF and GIWP

Figure 3-1) and this is briefly discussed below.



Source: Green Water Infrastructure: A Strategic approach to the planning and management natural and built water infrastructure (Sayers *et al.,* in press). Next in the series on Strategic Water Management in the 21st Century, WWF and GIWP[4]

Figure 3-1 Evolution of water infrastructure planning

Phase 1: Technical

Water is seen as a development resource to be exploited/controlled

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[4] https://www.wwf.org.uk/strategic-water-management

Water planning is seen as 'technical' exercise that tailors infrastructure designs towards delivering single, well-described, benefits (i.e. reflecting a '*predict and provide' or 'flood control, predict and protect'* paradigm, Sayers *et al.,* 2014, 2017) with few (if any) environmental safeguards. Governance and planning arrangements are such that the objectives are delivered through project-based built infrastructure with a single promoter and limited consideration of, or collaboration with, other activities in the basin. In this regard the water infrastructure planning mirrors the approach adopted by many other infrastructure sectors (from energy planning to transport).

The potential for negative impacts (present and future, local and regional) are largely ignored, or at best narrowly considered as part of standalone post-design assessments that offer little opportunity to influence the design concept. As a result, ecosystems may degrade (for example, due to unforeseen disruption of flow and connectivity) and future generations may be locked-in to potentially maladapted (and high cost) development pathways (reflecting limited consideration of future change and the long-lived nature of the infrastructure choices made). This does not imply that all built infrastructure, planned and designed in this way, leads to degraded ecosystems or disadvantaged communities. Although many schemes have, others with smaller footprints have not, and continue to serve their original purpose well with few negative impacts.

Phase 2: Safeguarding

Water is seen as a development resource to be exploited/controlled whilst avoiding unacceptable environmental impacts

During this phase the twin-track approach to water resource planning emerges (focusing actions towards both supply and demand management, structure and non-structural solutions) alongside efforts directed towards limiting the impact on priority species and habitats (including the allocation and maintenance of environmental flows). Effort is also directed towards restoring degraded ecosystems (through the reoperation or even removal of built infrastructure, e.g. Penobscot and Edwards Dams in US, Opperman *et al.,* 2018). The underpinning concept sees water planning, and associated built water infrastructure, as an intrinsic companion of development and any associated biodiversity concern as a conservation issue. The safeguarding planning context is often based on the (unwritten) assumption that the present system state is as good as it will be, and a succesful outcome retains existing ecosystem functions (e.g. a forest remnant above a town is safeguarded and preserved). Whilst there may be some minor enhancement activities to satisfy particular needs, the focus is primarily on maintaining existing priority ecosystem processes.

Phase 3: Strategic

Water is seen as a resource that supports interlinked human and freshwater ecosystems.

Well-functioning water infrastructure is seen as a pre-requisite for Sustainable Development by ensuring adequate long-term supply of a suitable quality of water and sanitation services, protection against unwanted flooding, safeguarding the natural environment (avoiding water pollution, over-abstraction and limiting greenhouse gas emissions) and maximizing co-benefits (such as provision of energy and fertilizers, biodiversity, carbon storage, recreation and aesthetic value). In this context Sustainable Water Infrastructure (*the focus here*) supports a 'strategic' approach that recognizes the ability of natural landscape features to complement built infrastructure in managing water related issues at multiple scales (local to whole basin, short to long term) and across multiple demands (from pollution, flood management, water storage and supply, water treatment, navigation, etc.). The conventional infrastructure narrative (presented in Phase 2) is transformed to a participatory (and fair) process that places social well-being, ecosystem health and biodiversity as central considerations in Sustainable Development (Sayers *et al.,* 2017); a narrative that implicitly includes recognizing productive landscape features as integral elements of infrastructure systems. Such an approach provides opportunities to deliver win-win outcomes (lower cost and healthier ecosystems, e.g. Opperman *et al.,* 2018) and recognizes the importance of system-scale behaviour in maintaining environmental flows and connectivity (Brisbane Declaration, 2017).

This strategic lens enables an ambitous vision to be set and innovative plans that challenge the status quo to be developed; plans that recongise the synergies between natural and built infrastructure (e.g. expanding forest ares to complement conventional responses in meeting the demand for services; a process that goes beyond restoration). In this context a strategic approach parallels the recognised need to "operationalize" the more conceptual framing of IWRM and recognises that sustainable water infrastructure is well founded in the principles of integrated water management approaches.

To aid this transition, a series of 'golden rules' that underpin a more strategic approach to water management have been developed through an on-going international collaboration led by WWF. To date, guidance has been developed on strategic approaches to River Basin Planning (Pegram *et al.,* 2013); Flood Risk Management (Sayers *et al.,* 2013); Water Allocation (Speed *et al.,* 2013); Drought Risk Management (Sayers *et al.,* 2016) and River Restoration (Speed *et al.,* 2016). The current focus of this collaboration focuses on water infrastructure and associated 'golden rules' are emerging that support the transition reflected here (Sayers *et al.,* in press).

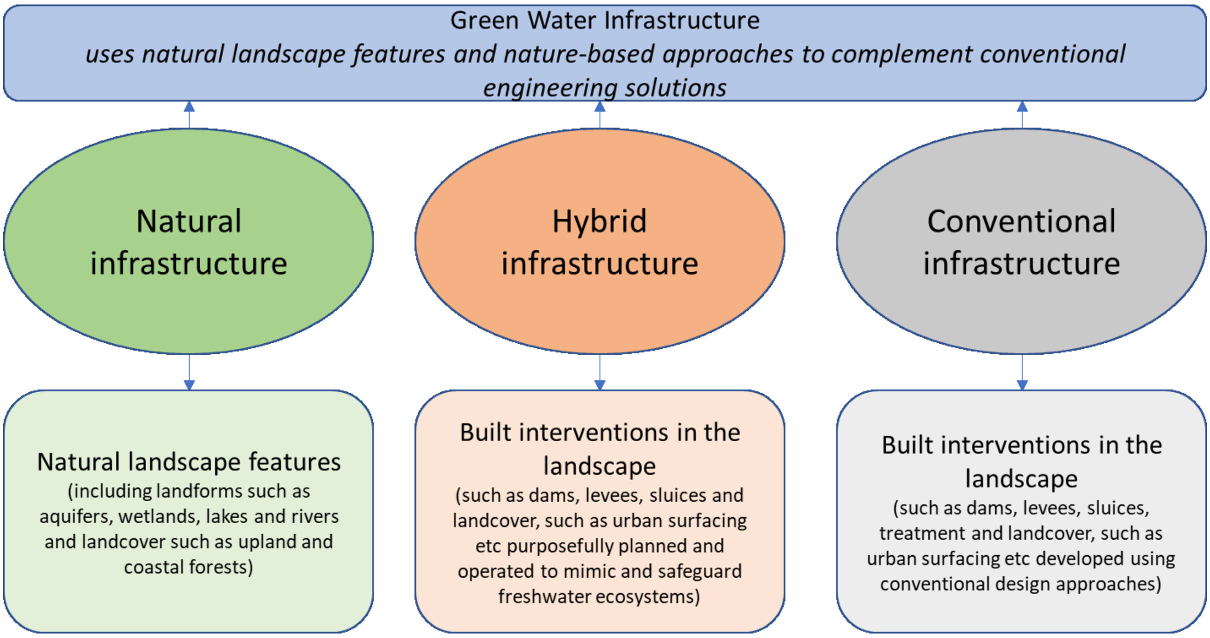
What is sustainable water infrastructure?

The recent release of the *2018 World Water Development Report (WWDR2018) Nature-Based Solutions for Water* call for a better assessment of the value of nature-based solutions in addressing water resource issues, and how these may be used to complement conventional, or grey, infrastructure solutions. Such approaches include activities to protect or restore the ecosystem functions of a watershed that provides water resources to downstream communities, species and habitats. The WWDR 2018 goes on to note that the increased interest in sustainable infrastructure reflects a shift in perspective that mirrors broad changes from a protection paradigm to one of resilience (recognizing that no single solution provides a complete solution). In essence, the WWDR 2018 advocates an approach in which the choice is not between 'grey' or 'green' infrastructure development but how best to provide a 'blended' approach that safeguards or enhances ecosystems services, reduces the long-term costs of conventional infrastructure and delivers the water resource requirements; an approach consistent with the strategic approach in the preceding section.

In this context, Sustainable Water Infrastructure (SWI) is used in this paper as shorthand for an appropriate mix of natural and built infrastructure (and reinforces the concept of Green Water Infrastructure being developed in support of strategic framing promoted by WWF, see Source: Sayers *et al.,* in press

Figure 3-2). It includes (i) conventional 'grey' water infrastructure (such as water treatment works, storm water conveyance structures, sewage pipe systems, waste water treatment plant etc.); (ii) natural infrastructure (natural and semi-natural landscape features such as rural and urban forests, wetlands etc.), and (iii) hybrid infrastructure (such constructed wetlands, artificial infiltration/recharge basins, urban parks and river corridors, community gardens, green roofs and bio-filtration facilities).

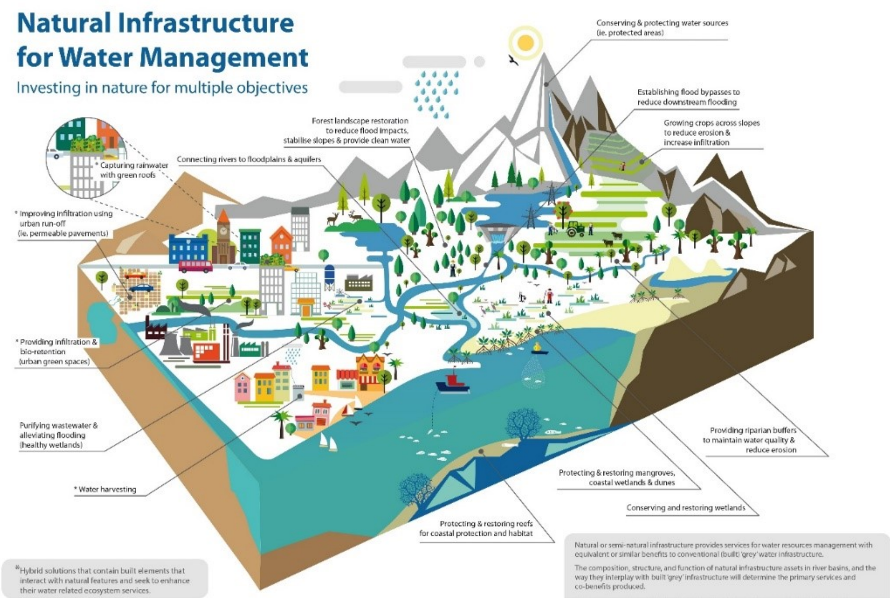
SAYERS AND PARTNERS



Source: Sayers *et al.,* in press

Figure 3-2 Green water Infrastructure is based on a porfolio of natural, hybrid and built infrastructure

SWI encompasses all of these types of infrastructure and explicitly recognises the need to use the advantages of one to compensate for the disadvantages across multiple scales (from local to river basin scales, from short to long term) of another. The preferred 'blend' of infrastructure will, of course, reflect the context. Opportunities for natural infrastructure to offer a productive contribution to the management of water however will unquestionably exist throughout rural and urban/ peri-urban settings (Figure 3-3).



Source: IUCN infographic: https://www.iucn.org/theme/water/resources/infographics

Figure 3-3 Example opportunities for natural and hybrid water infrastructure across a river basin

Why focus on urban and peri-urban opportunities?

The successful take-up of SWI will be central to the delivery of many Sustainable Development Goals (SDGs), and more broadly to achieving Nationally Determined Contributions (NDCs) to climate mitigation and the Aichi Biodiversity Targets, amongst other goals. This does not imply that all situations will require complex blends of natural and built infrastructure, and the balance of contributions will vary according to context, but purposefully pursuing options that are predicated on the basis of a SWI approach will be important in all settings.

This assignment is predominantly concerned with SWI designed to improve water supply, stormwater management and sanitation efforts in urban and peri-urban areas. This focus recognises the urgency and opportunity presented by the Africa's rapid and on-going process of urbanisation (see Chapter 2) as well as opportunities to rehabilitate or replace ageing, inappropriate, or insufficient conventional infrastructure with SWI approaches. There are of course interactions between water management in urban areas and the wider catchment in support of community WASH services (*e.g.* the lack of adequate WASH services at a community level may be a direct result of, or exacerbated by, poor catchment practices, and good catchment management practices may improve the opportunity for urban WASH services). The Uganda Watershed Partnership programme[5], for example, aims to improve WASH Services through building the capacity of Civil Society Organisations (CSOs) in lobbying and advocacy to improve governance and management of water resources.

Note: Although this paper focuses primarily on SWI in the urban / peri-urban setting, catchment and rural examples are included to highlight the spatial connectivity within freshwater ecosystems and the importance of upstream catchment management in protecting urban water resources (for example through the upstream management of sediment flows, water quality and quantity).

3.2 Sustainable water infrastructure: Benefits

Sustainable water infrastructure seeks to deliver multi-benefits for economic, social well-being and ecosystem health. These co-benefits are briefly introduced below.

Inherently multiple benefits; local and regional

Well-functioning SWI yields multiple benefits: food production, materials production (including timber or fuelwood), erosion protection, climate regulation, pollination, cultural services (recreation, aesthetic value, 'sense of place') – and delivers these to the benefit of local people, regional economies and ecosystems.

The concept of SWI (as promoted here) is similar and compatible with other tools and concepts being promoted internationally, primarily the promotion of Strategic Water Management (promoted by WWF) that builds upon an Ecosystem-Based Approach as advanced through the Convention on Biological Diversity, the Wise Use of Wetlands outlined in the Ramsar Convention on Wetlands, concepts of Green Infrastructure (such as the Flood Green Guide, WWF), Ecosystem-based disaster risk reduction (DRR) and Climate Adaptation Ecosystem Services as well as the *WWDR Nature-Based Solutions for Water report.* All these approaches highlight the potential role that natural and nature-

[5] https://watershed.nl/blog/how-good-water-resource-management-leads-to-improved-wash-services/

based infrastructure can play in supporting healthy ecosystems and providing associated services of benefit to local communities and economic development. Where these approaches differ is the degree to which the ecosystem services can be used to complement built infrastructure to deliver outcomes for both freshwater and human systems. The promotion and use of SWI differs slightly from other approaches in that its starting point is to purposefully seek solutions that use a blend of built and natural infrastructure as its core mission (an approach that aligns with Strategic Water Management approaches advocated earlier, as set out by WWF).

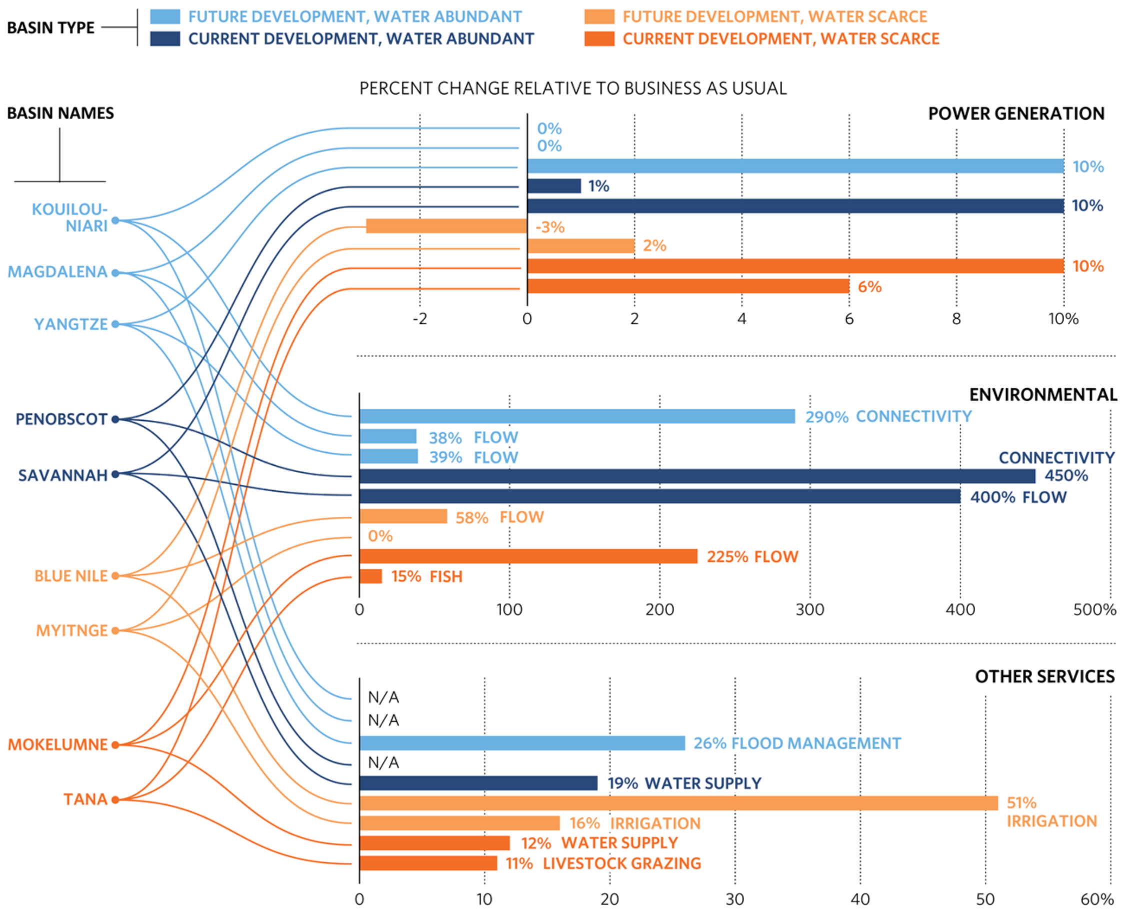
Built infrastructure generally addresses a specific issue and is designed to accommodate a narrow set of specified conditions and deliver an equally narrow set of prescribed outcomes (e.g. to satisfy a relatively predictable demand through the consideration of relatively predictable supply options; a so-called predict and provide approach). It rarely provides co-benefits and usually has a high carbon and material footprint. In contrast, natural infrastructure is inherently multi-benefit, including the potential to improve the performance or reduce the associated cost (capital or revenue) of built infrastructure. For example, upstream catchment restoration may act to attenuate flood flows and reduce downstream extremes or reduce sediment losses from the upstream catchment and prolong the life of a downstream reservoir. In promoting a blended response, SWI has the capacity to deliver multiple services of value; to both the local population (through the range of ecosystem services provided by the natural infrastructure component) and to the regional economy (primarily through well-functioning built infrastructure).

Lower costs; short and long-term

SWI, involving a blend of natural and built responses, may be more cost-effective and affordable and/or require less maintenance than conventional solutions.

Natural infrastructure can support the delivery of water related goals and reduce the requirement for conventional infrastructure. In some instance, the need for built interventions may be removed altogether, but in most cases the purposeful use of natural infrastructure will reduce the design burden and hence the cost of built infrastructure. Consider for example the case of water supply. A conventional design process would involve the identification of the demand, and design, build and operation of conventional infrastructure to supply, store, treat, and distribute the water. Working with natural infrastructure to support this process provides opportunities to reduce costs, from upstream actions to enhance the quality and security of supply (such as afforestation and shelter belts, to reduce the sediment load and thus the need for filtration and reservoir dredging) to downstream wetlands providing an additional layer of water treatment. Similar synergies are well described in the case of catchment and urban flood management and the attenuation of coastal storms.

There is an increasing body of evidence supportive of the assertion that SWI type approaches are often less costly than built infrastructure alone, both in the short and longer term. The Hydropower by Design (HbD) initiative led by The Nature Conservancy (TNC), for example, explores the opportunities for sustainable hydropower (as defined as energy development that is consistent with maintaining a broad spectrum of values from river systems) through system-scale planning, development and management. The TNC reports (Hartmann *et al.,* 2013; Opperman *et al.,* 2017) illustrated how system-scale solutions enable free-flowing rivers to be maintained (compared to what would occur through a conventional built infrastructure focus), all also allowing energy generation. ‘System’ in this context is used to refer to any level beyond individual projects and, through model-based case study illustrations (in the US, China and Latin America) demonstrate the benefits of such an approach (Figure 3-4). These include (i) the ability to identify potential conflicts earlier on than can project-based approaches alone, allowing greater flexibility to find alternatives; (ii) operational efficiencies, such as for cascade operations, sediment passage, environmental flows, and safety (dam design/flood management); (iii) for a given level of energy development, produce a configuration of projects that allows maintenance of more of other values, including other water-management benefits and also environmental and social values. Some specific examples of how natural infrastructure (constructed wetlands) can reduce total costs across the whole project lifecycle are presented in section 4.1.



Economic and environmental improvement possible through application of Hydropower by Design in case studies compared to a conventional built infrastructure case (of comparable cost).
Source: Opperman *et al.,* 2017

Figure 3-4 Economic and environmental improvement opportunities provided by system scale approaches to hydropower

Equality and cohesion

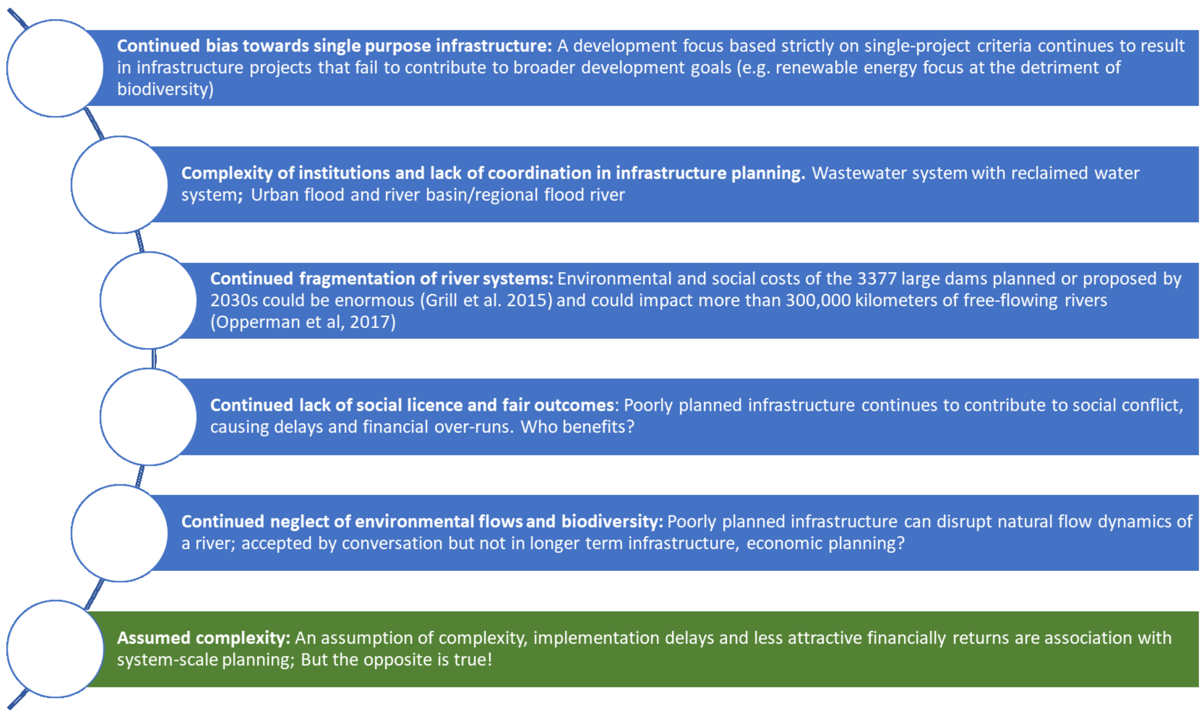
A participatory approach is fundamental to SWI; an approach that builds social capital, adaptive capacity and reduces conflict.

The growing interest in natural and nature-based solutions for water resource management reflects the recognition of the contribution of ecosystems to human well-being (a link reinforced by the WWDR 2018 Report). This connection is highly relevant in Africa, where it is recognized that poorer communities often have a very high and direct dependence on ecosystem services. The co-benefits of providing water infrastructure approaches that promote healthy ecosystem for local communities are well-established and include, for example, providing opportunities for harvested products, local cooling or cultural services. The SWI approach is also fundamentally a participatory one and seeks to engage local communities and all relevant stakeholders from the outset, in identification of the issues and trade-offs, the scoping of potential solutions as well as the design, implementation and monitoring of the chosen approach. This is needed to manage trade-offs between stakeholders, capture local knowledge and ensure the longevity of projects. This participatory process provides long term benefits by building social capital and adaptive capacity and reducing conflict.

3.3 Sustainable water infrastructure: The barriers to take-up

The United Nations 2030 Development Agenda acknowledges the importance of sustainable management of natural resources (*i.e.* ecosystems) as critical to achieving the Sustainable Development Goals (SDGs). There are however many examples of poor infrastructure choices that conflict with this vision (see, for example, the negative impact of irrigation investments in Kenya on wetlands that supported pastoralists, Reid and Orindi, 2018). Neglecting the potential contribution of natural infrastructure in managing water resources alongside built infrastructure also misses significant opportunities to deliver multiple benefits for both *SDG 6 (Water and sanitation)* and the other SDGs (e.g. related to food, energy, health, biodiversity, gender equality, livable cities, education and sustainable economies). **To achieve the SDGs, a paradigm shift in the approach to water infrastructure investment and planning is necessary.**

Achieving this change will require a range of barriers (some real and some perceived) to be overcome (Figure 3-5). Some of these are internationally relevant and some are specific to Africa.



Source: Sayers *et al.,* in press

Figure 3-5 Challenges in delivering sustainable water infrastructure

An embedded bias to build conventional infrastructure

Infrastructure choices are often predisposed towards conventional built infrastructure. The overwhelming dominance of "grey" thinking reflects embedded biases in the enabling environment (including local public policy/building codes, civil engineering or economic instruments, service provider expertise) that make it difficult for more innovative solutions (e.g. based on a notionally more complex combination of nature-based and built infrastructure) to succeed. This bias is despite the emergence of concepts of Integrated Water Resource Management (IWRM) that, although they promote SWI in principle, rarely do so in practice. More strategic water management approaches (as promoted by WWF – see Section 3.1) promote a systems-based long term view that is more explicitly aligned with the concepts of SWI. This is reflected in the limited implementation of deliberate actions to support ecosystem service provision or use of natural or nature-based infrastructure solutions in the water sector across Africa as a core (as opposed to a peripheral) activity (with notable exceptions being increased use of constructed - and sometimes natural - wetlands and some low-level habitat restoration).

An inappropriate decision scale: spatial, temporal and institutional

System-scale planning and management is widely accepted as being capable of reducing the negative environmental and social impacts associated with infrastructure development and ensuring its long-term objectives (Opperman *et al.,* 2017), but system-scale planning is often perceived to be associated with implementation delays and projects that are less attractive financially.

The 'scale' is important in spatial, temporal and institutional terms:

- *Spatial context:* the watershed has often been considered the basis of good planning in the water sector. Increasingly however the notion of the precipitation-shed (WWAP, 2018), that includes both the watershed that receives rainfall as well as the source of the atmospheric moisture (which is often considered as an externality), is promoted as a more appropriate 'scale' as interventions that seek to influence 'atmospheric water' emerge (e.g. cloud seeding).
- *Temporal context:* Many choices are very long-lived but often the decision process fails to adopt a long-term view. In response, the ability of healthy ecosystems and associated natural infrastructure to adapt to changing climates autonomously and the relatively low-cost of purposeful adaptation often fail to feature in the comparison of options. For example, looking at coastal protection options, an unconstrained coast will naturally adapt to changing sea levels; retreating as they rise, advancing as they decline. Few coasts are afforded this opportunity today. Squeezed between rising sea levels and landward development, there is often little room for the mangrove forests, coastal dunes and wetlands to adapt and continue to afford this nature-based protection. Once constrained, a cycle of negative feedback starts. As a coastal habitat degrades, wave attenuation weakens, its ability to trap sediment reduces and foreshores lower and steepen. Any backshore defence is soon undermined and may require significant investment to hold a given shoreline position (Figure 3-6). Avoiding this downward spiral will require better longer-term planning that gives room to coasts to adapt (Sayers, 2017).

Figure 3-6 Gambia: The beach is squeezed between development and the sea; unable to retreat, the beach lowers and protection is lost

- *Institutional scale:* The scale aspect is important as water investors in a transboundary context, perhaps dependent on surface water, will have to base their development assumptions on 'predictable' demand and supply conditions and projections, ameliorated perhaps by climate change, to best fit investment. But concurrently, other decision makers, relying on the same water source, are also making decisions that immediately change baseline conditions. The institutions at the scale that may have the best knowledge for making such decisions, e.g. river basin organisations, are often limited in their mandate by sovereign states to be knowledge keepers. Therefore applying SWI in a transboundary complex may be very difficult. SWI also relies upon a portfolio of actions and as a result it is less centralized, requiring multiple organizations (formal and informal) to act (including through exerting control over land needed to be set aside for natural or nature-based infrastructure, a particular challenge given the pressures of urban growth). The private sector also has important role to play in providing water infrastructure in Africa; but making a case for investment in multi-contributor solutions is often difficult.

An appraisal process that focuses on a narrow set of outcomes and lack of visibility of lost services

Appraisal processes tend to focus on easily described 'internal criteria' – such as the volume of water stored – rather than more complex 'outcomes', such as the improvement in social well-being, economic development or ecosystem health. This narrow focus reinforces the 'bias to build' introduced above. Without wider consideration of the outcomes associated with the different infrastructure development pathways, decisions can be taken without full knowledge of the opportunities missed (e.g. positive impacts on long term project costs and ecosystem services that many be associated with the inclusion of natural infrastructure) and the risk of negative outcomes (e.g. loss of performance, degradation of the freshwater ecosystem, loss of local employment and livelihoods).

Natural and well-planned built infrastructure acts to support productive ecosystems; a contribution that is rarely identified in conventional infrastructure project approaches. For example, one outcome from a poorly considered infrastructure development may be a reduction in water quality or loss of environmental flows, leading to a decrease in fish populations with an associated impact on the local fishing industry, but no or little effort is directed towards creating replacement jobs. These types of local consequences (on fisheries and how best to replace both lost employment and the associated food supply) are too often invisible to the decision and investment processes.

This does not imply that natural and nature-based infrastructure are without potential negative outcomes. For example, inclusion of urban green spaces can create disservices that are considered negative for human well-being. The creation of a small urban forest may be perceived as an unsafe location; wetlands can be a breeding ground for mosquitos; and natural approaches to 'slowing the flow' in an attempt to reduce downstream peak flows may also provide new snake habitat.

There is a view that natural and hybrid infrastructure may consume more land than conventional built infrastructure, and hence it competes with housing and farming that have established business cases and are thus often considered more investable. Establishing the whole-system, whole-life view in the appraisal tools (that enable the full range of benefits of SWI to be reflected in the business case) will be a pre-requisite to wider take-up.

An assumed lack of evidence and uncertainty in outcomes (for people, the economy and ecosystem health)

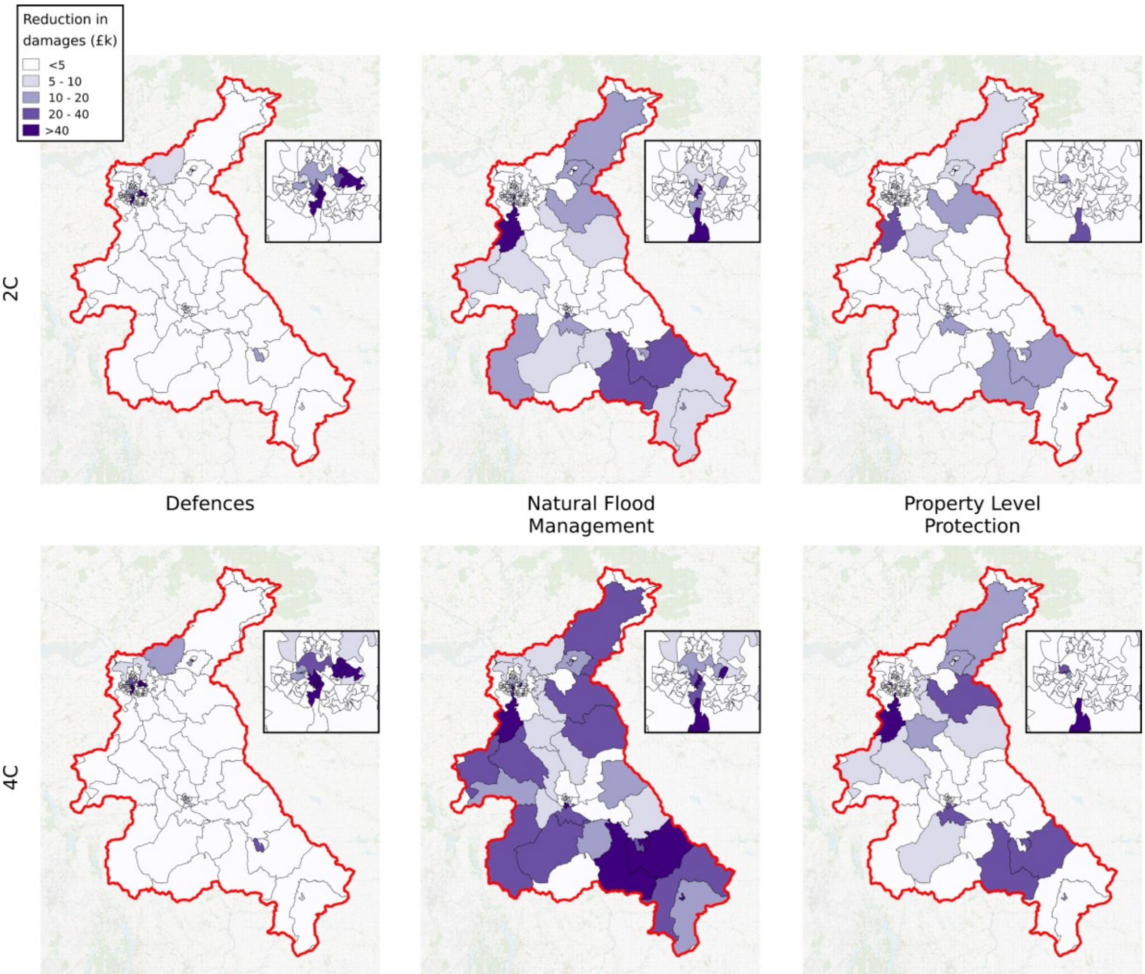
Many SWI pilot projects in Africa (see Chapter 4) are in locations with easily definable performance criteria and stakeholders (upstream and downstream) and a clear connection between the two. Developing the business case in such situations is readily communicated to the stakeholders and potential investors, and hence relatively easy to deliver.

In more complex settings the interactions between ecosystem services and social well-being, in the short to longer term, are less well understood. Although significant advances are being made, and model-based approaches maturing, there continues to be a perception that the uncertainty in both the benefits and costs associated with SWI responses is significantly greater than those associated with more quantifiable (and relatively immediate) returns from built infrastructure. This perceived uncertainty is a key constraint to the wider take-up of SWI noted in the literature. Uncertainty around the specific capacity of green infrastructure to address a particular issue can mean that it is less likely to be properly considered as an option. For example, local, often unknown, soil conditions will affect the performance of SWI that depend on recharge or infiltration.

Three important aspects underlie this barrier:

Uncertainty of performance: Unlike the relative immediacy of conventional infrastructure, natural and hybrid infrastructure typically takes some time to establish (maybe several years). The performance of natural and hybrid infrastructure may also vary on an intra-annual and inter-annual basis, presenting a management challenge that is not (perceived to be) associated with the relatively projectable performance of a conventional infrastructure response. But the natural resilience of natural infrastructure and its inherent ability to adapt to changing climatic conditions is often overlooked. This ability to autonomously adapt does not however imply natural and hybrid infrastructure is maintenance free; as with conventional infrastructure, maintenance is crucial, and performance is likely to rapidly degrade without this (see the example of Ruaha School wetland in Chapter 4).

Inability to attributing benefit (and hence investment opportunities): Establishing the cause and effect relationships between infrastructure choices and outcomes is difficult, and more so in the context of SWI solutions based on multiple infrastructure responses, given the multiple other drivers of change (natural, seasonally or inter-annually and anthropogenic, climate change, development etc.). Disaggregating the benefits of natural infrastructure as part of a portfolio of infrastructure responses is therefore difficult, but not impossible. For example, an analysis of the future flooding studies undertaken in support of the UK Climate Change Risk Assessment (Sayers *et al.,* 2015) was applied to explore the opportunity for natural flood management measures (i.e. natural and nature-based infrastructure) within the Cumbria catchment (UK), and attributed the associated benefits in the context of the portfolio of responses (Figure 3-7).



Legend: the darker blue indicates a greater contribution to flood risk reduction. Eden catchment, Cumbria, UK (assuming low population growth. (Insert) Carlisle, UK.

Source Sayers and Horrit, 2016.

Figure 3-7 The contribution to flood risk reduction from defence, natural flood management and property level protection, for the 2080s

Uncertainty in stakeholder behaviors: Stakeholder participation and transparency is central to SWI, but there remains a limited understanding amongst investors, national, city and community stakeholders as to how to achieve this. For example, it is recognized that the water development sector in Africa (and elsewhere) faces issues of corruption. Some authors have noted that the use of natural and hybrid infrastructure, and a more strategic system-based development approach, may be less amenable to corruption. The promotion of the use of natural infrastructure in current peri-urban or future urban locations may also present opportunities for resource or land capture for the purposes of future profit sharing as a means of ensuring local communities benefit in the development opportunity. In urban areas a disconnect between users of water and an appreciation of its source may emerge (it may be unclear if water from a tap is from a surface or groundwater source). This disconnect can undermine the appreciation of the potential threats to that source of water, and hence undermine effective management. However, natural infrastructure projects may help to make this link more explicit (e.g. El Zein et al., 2016, argue that constructed wetland systems that recycle water for irrigation help to promote awareness of water scarcity and encourage users to reduce water demand).

SAYERS AND PARTNERS

An approach based on siloed planning processes with capacity to deliver SWI

The use of sustainable water infrastructure requires comparatively more cooperation across a number of different stakeholders than conventional infrastructure approaches, including cross-sectoral or cross-ministerial. This raises two important barriers:

Lack of awareness of emerging funding vehicles and a capacity to access them: The knowledge of sustainable infrastructure, and the potential to blend natural and built infrastructure, is often lacking within Government Ministries, MDB staff and the private sector companies that are involved in investments of water supply and sanitation. This lack of capacity means that opportunities to take advantage of international funding instruments (such as the Global Environment Facility (GEF), Green Climate Funds (GCF) and others) are missed. Instead the majority of funding is sought via conventional routes and the associated investments focused towards conventional infrastructure. In part this reflects the lack of ministerial acceptance of a more strategic approach, but also the background of the staff involved in project preparation and the *a priori* allocation of project development resources that focuses on conventional engineering requirements. Thus, improved awareness is needed, whether technical, financial, and institutional.

Lack of co-operation: SWI typically requires co-operation between many different departments, e.g. water supply, sanitation, waste collection, urban planning, forestry, agriculture or parks / recreation. Without multi-sectoral co-operation, SWI approaches are unlikely to succeed. However, these departments usually operate in their own silos, which limits opportunities for implementation of SWI or undermines its performance. For example:

- Informal settlements build on any available space, including potential green/blue infrastructure such as floodplains, wetlands, river banks and parks (e.g. Douglas, 2016). Even where planning regulations exist, they may not be effectively implemented, leading to uncontrolled development by private developers encroaching onto natural infrastructure such as floodplains and wetlands (e.g. Douglas, 2016; Herslund *et al.,* 2017).
- Lack of effective sanitation and refuse collection services leads to key natural infrastructure assets such as drainage channels and wetlands becoming polluted and clogged with refuse (e.g. Jiusto and Kenney, 2016).
- Over-abstraction of water leads to watercourses and wetlands drying out (sometimes exacerbated by development initiatives such as upstream irrigation schemes to promote agriculture (e.g. Reid and Orindi, 2018)).

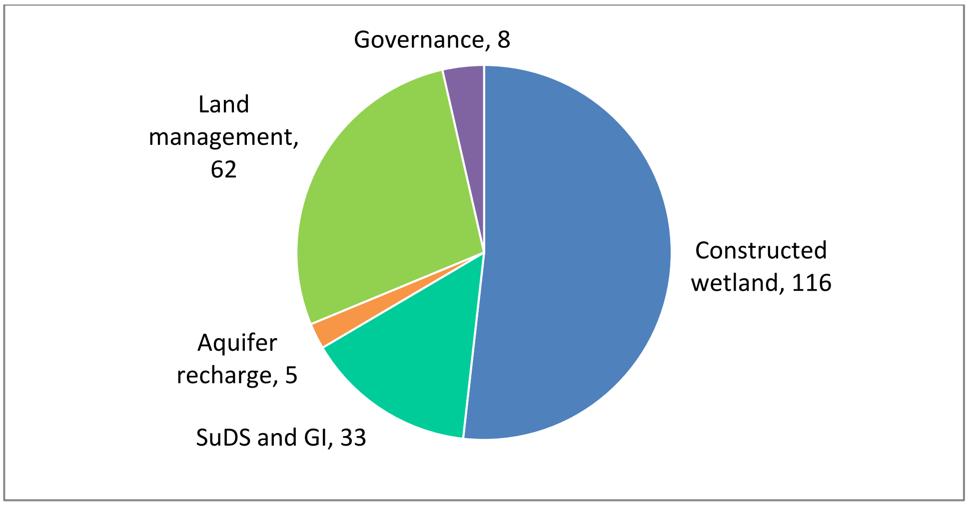
4 Case examples of sustainable water infrastructure in Africa

A systematic search of the academic literature, grey literature and case study databases reveals relatively few case studies where nature-based solutions had been successfully implemented at full scale, rather than as small-scale pilot projects or experiments. Nevertheless, some very promising examples exist and it is clear that the potential for SWI in Africa remains underexploited.

The literature falls into four broad groups (Figure 4-1):

- Constructed wetlands for water supply, wastewater management and pollution control
- Sustainable urban drainage and urban green infrastructure
- Aquifer recharge
- Land management and restoration.

The following sections address each of these broad areas in turn, identifying the strengths and challenges of each technology; opportunities for implementing in different contexts; current status in Africa (according to the literature reviewed); any barriers preventing wider uptake and thoughts on how these barriers could be overcome.



Source: Based on a systematic search of academic references and grey literature references - see Appendix 1 and associated spreadsheet record.

Figure 4-1 Number of references found for each category of sustainable water infrastructure

4.1 Constructed wetlands

Constructed wetlands are artificially created wetlands that use the natural processes of plants, soils and associated micro-organisms to absorb excess nutrients and pollutants and/or break them down into harmless forms.

Interest in constructed wetlands began in South Africa in the mid-1980s and around 30 plants were built or planned by 1990, with further examples being piloted in Egypt, Morocco, Tanzania and Kenya in the late 1990s (Kadlec and Wallace, 2008). Many of these wetlands were experimental or pilot scale, usually built in partnership with university research teams and used for R&D, but there are some examples of full scale wetlands. Kimwaga *et al.,* (2013) lists 27 constructed wetlands operating in East Africa in 2013, including 16 full scale and 5 experimental in Tanzania, two in

Uganda and one each in Kenya, the Seychelles, Zanzibar and Ethiopia. In addition, the Zer0-M project established centres of expertise in Morocco, Tunisia and Egypt in 2009. A tender to build 60 new constructed wetlands across 21 districts has just been issued in Algeria[6]. Most of the pilot and full-scale wetlands demonstrate very effective pollutant removal, though there have been problems with ensuring correct operation and maintenance in the longer term (Kimwaga *et al.,* 2013).

Natural wetlands have also been used for wastewater treatment, although if the input is excessive this can lead to degradation of the wetland (see Section 4.4).

Basic performance characteristics

Use

Constructed wetlands can be used to treat less polluted sources (such as household grey water, stormwater or agricultural runoff) directly, or as part of a chain of treatment options after primary treatment (screens, sediment traps, settling/stabilisation ponds) or secondary treatment (septic tanks/anaerobic digesters or activated sludge systems). They are used to treat a wide range of inputs including stormwater, household greywater, municipal wastewater, sewage, acid mine drainage and the effluent from petroleum refineries, tanneries, breweries, pulp and paper works, food processing plants and other industrial processes. The treated water is often re-used for a variety of purposes such as irrigation, car washing or toilet flushing, so this technology addresses water supply as well as water quality. Constructed wetlands can also form part of a flood mitigation scheme, for slowing the flow of water and treating polluted surface runoff. Although it is relatively unusual for a constructed wetland to be chosen in preference to a conventional wastewater treatment option, in the cases where this has been done it is implemented as a core option, with the primary purpose of treating wastewater using SWI.

Basic types

Constructed wetlands have been in use for over 50 years (Castillo-Valenzuela *et al.,* 2017), starting with research at the Max Planck Institute in Germany in 1952 (Kadlec and Wallace 2008). In 2004 there were around 5000 in Europe and 1000 in the USA (USEPA, 2004).

Constructed wetlands typically consist of a bed of gravel, sand or soil planted with wetland plants such as reeds (Phragmites), bulrushes (Typha) or papyrus (Cyperus papyrus), although a wide range of native plants can be used. They are generally differentiated according to management of water flows:

(i) ***free water surface flow wetlands.*** These resemble a natural wetland function including areas of open water and are typically used to treat stormwater and urban or agricultural runoff (because they can handle fluctuating flows).

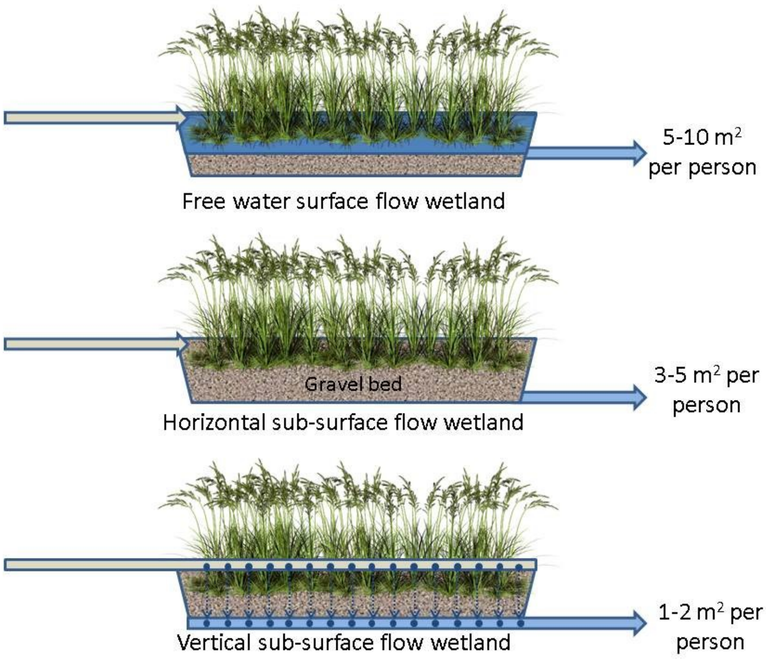
(ii) ***horizontal subsurface flow wetlands.*** Here water flows usually remain below the substrate so that the surface is dry, avoiding odour, mosquitos and the risk of human contact with wastewater. Treatment is efficient because contact with the root zone is maximized, so these take up less space than free water wetlands.

[6] http://www.ona-dz.org/IMG/pdf/-948.pdf

(iii) ***vertical flow wetlands:*** Here wastewater is distributed over the surface (often in single pulses of flooding) and percolates through the surface soils, providing opportunities for oxygenation and ammonia removal but more limited opportunities for nitrates removal. These take up even less space and are typically used for high-ammonia effluent such as landfill leachate or food processing effluent. They can also be adapted to maximize removal of metals and can treat concentrated waste streams including sewage (after primary treatment in a settling pond).

(iv) ***Hybrid wetlands:*** these combine both horizontal and vertical flow wetlands, to maximise nutrient removal (Kadlec and Wallace, 2008).

In addition, floating macrophytes (plants such as duckweed, water hyacinth or water cabbage) may be used on effluent maturation ponds and composting drying beds (such as reedbeds) can be used to treat sludge, which can then be reused for fertilizer (Figure 4-2).



Source: Based on El Zein *et al.,* 2016

Figure 4-2 Different types of constructed wetland showing the space needed to treat household greywater per person

Perceived strengths

The literature highlights various perceived strengths associated with constructed wetlands, namely:

- ***Relatively low capital cost:*** Constructed wetlands are cheaper to build than conventional wastewater treatment plants.
- ***Relatively low operational cost:*** They are technologically far simpler than conventional water treatment and usually have no moving parts, as they can be designed to use gravity rather than pumps or control sluices, so they are relatively cheap and easy to maintain (El Zein *et al.,* 2016; Kimwaga et al., 2012) and last longer (Nelson, pers. comm).
- ***Provision of co-benefits.*** Depending on the quality, the effluent can be used for irrigating parks, gardens, trees, timber plantations, non-food crops, food crops, washing cars, cleaning streets,

flushing toilets, ornamental fountains or even drinking water (Chen *et al.,* 2013). Harvested vegetation can be used as fodder, biofuel or for cut flowers. They provide aesthetic value, biodiversity (especially free water wetlands), educational opportunities (including raising awareness of water supply issues) and contribute to local cooling and urban green space (El Zein *et al.,* 2016).

- ***Lower whole life-cycle costs:*** Following on from the points above, several studies illustrate that total costs over the whole project lifecycle can be cheaper than conventional infrastructure, especially (but not only) when co-benefits are included. An example for Ruaha School in Tanzania is presented below. Another study found that a constructed wetland in Uganda was cheaper than a waste stabilisation pond because it had a 30% lower land requirement (Okurut, 2000, *apud* Kimwaga et al., 2012). Similarly, a scenario analysis based on an Italian wetland found that semi-natural free water surface constructed wetlands were cheaper than activated sludge wastewater treatment plants, despite far higher development costs, because the operating costs were two to eight times lower, giving a 2 to 3 year payback period (Mannino et al., 2008, *apud* Kimwaga et al., 2012).
- ***Locally appropriate:*** They can be built with local materials and local labour.
- ***Relatively scalable:*** They can be applied at a range of scales from individual households to municipal scale or industrial treatment plants. Small decentralised options for individual households or communities can provide in-aggregate outcomes at larger (municipality) scales (El Zein *et al.,* 2016).
- ***Capable of integration:*** They can be flexibly combined with other types of treatment to provide a tailored and cost-effective solution, and this can be targeted to remove specific pollutants (often more effectively than conventional treatment for removing many nutrients, pollutants, pharmaceuticals and pathogens - notably in tertiary treatment units).
- ***Safer and healthier:*** properly built subsurface flow wetlands have no odour, no exposed sewage and no opportunities for mosquitoes to breed – unlike conventional sewage treatment which has open lagoons (Nelson, pers. comm.).
- ***Low impact:*** the natural treatment processes avoid the use of chemicals and have lower energy consumption and greenhouse gas emissions that conventional treatment processes.

Note: Although much of the literature was composed of studies of individual experimental or pilot scale wetlands, it is important to emphasise that their full potential is realized when they are implemented as part of an integrated water management approach (as promoted here). This allows them to be part of a system that combines saving water use at source, reducing the environmental impact of water discharged to the environment, recovering nutrients from wastewater or sludge for use in agriculture and even recovering energy from biogas digesters or harvested vegetation. The Zer0-M project (see below) provides an example of this approach.

Perceived weaknesses

- ***A breeding ground for disease:*** If not appropriately controlled free water surface wetlands attract pests or nuisance animals such as mosquitos, water snails or water snakes (Kivaisi, 2001). However, this is not the case with subsurface wetlands, which offer an advantage over conventional sewage treatment (see above).
- ***Performance can be compromised:*** The misuse of a wetland can undermine its ability to perform. Examples include removal of wetland vegetation by grazing or cutting by local people (Negussie *et al.,* 2012) and the theft of control valves (Kimwaga *et al.,* 2013). Also, they may not function well on waterlogged soils or during the rainy season – 'raised bed' wetlands ('inverted leachdrains') may work better in these conditions (Nelson, pers. comm.).

- ***A large space requirement:*** More space is required per household treated using constructed wetlands than for conventional treatment options. In densely populated areas, including informal settlements or where land costs are high, this is a challenge but in the context of the SWI promoted here, this is a false choice; the choice is not between conventional and nature-based infrastructure but how these can be used in concert.
- ***Lack of data.*** There is often a lack of basic hydrology data and data on the proposed wastewater stream, which hinders optimum design (Kimwaga *et al.,* 2013).
- ***Lack of capacity.*** Private companies and consultants have not yet developed the capacity to design and install constructed wetlands, so this task often falls to university researchers (AEE-INTEC, 2009; Kimwaga *et al.,* 2013). Even when following detailed instructions, local contractors may make errors such as positioning the inlet and output pipes at the wrong level or providing the wrong type of substrate (Kimwaga *et al.,* 2013). Training is essential to ensure correct design, construction and maintenance.

Examples of implementation

Lake Manzala Engineered Wetland, Egypt

Lake Manzala is a large coastal lake in the Nile Delta. The Lake became increasingly polluted due to influx of untreated wastewater with dramatic impacts on the fishing industry (the Lake once supplied 30% of Egypt's fish but by 2001 the catch was considered inedible). In 2001, construction started on a pilot scale engineered wetland funded by the Global Environment Facility (GEF), and operation commenced in 2004. The wetland was designed to treat 25,000 m^3 per day of water taken from the Bahr el Baqar drain, a highly polluted drain flowing into the lake (this is 0.8% of the total flow in the drain).

Designed as a demonstration project, the treatment process consisted of ten parallel free water surface flow wetlands with a portion of the water receiving further treatment (passing through two subsurface flow wetlands) for use in a fish rearing facility.

When completed the wetland system was considered a success, removing 80% of suspended solids, 15% of total phosphorous, 51% of total nitrogen and 97% of total coliform bacteria at just one-quarter of the cost of conventional methods (GEF; El Sheik *et al.,* 2010). Early in 2018, the wetland was handed over to the National Water Research Centre of the Ministry of Water Resources and Irrigation, for use as a Centre of Excellence in teaching, replicating and disseminating low cost wastewater treatment technologies, as well as providing jobs and training opportunities for local people.

Ruaha School, Tanzania

Many community buildings across Africa are served by a conventional septic tank. Due to waterlogged soil the soakaway at Ruaha School frequently overflowed. Working with the University of Dar es Salaam the School installed two horizontal-flow constructed wetlands planted with reeds (phragmites) between 2004 and 2005, to treat the overflow from the septic tank (Figure 4-3). They have operated well since then, with capacity to serve 1200 people. The treated water is used to irrigate a field of elephant grass, which is used as fodder for cattle owned by the school, and the wetland is used to educate pupils on environmental management. The wetland cost $2500 in construction materials, as the university provided the design for free and the staff and students did the construction, and costs $340 per year to operate (wages and analysis of water samples). A cost-benefit analysis found that there was a net present value (NPV) of $2250 over ten years with an internal rate of return of 33% (compared to a nominal interest rate of 16%) and a payback period of 4 to 5 years (Kimwaga et al., 2012). This hinged largely on the fact that after the wetland was constructed, the septic tank had to be emptied only once a year compared to four times a month before (at a cost of $20 each time). Taking into account the health benefits from improved sanitation, the NPV increases to $8880, the IRR is 106% and the payback period is one year.

In the early years the project was considered a success (in terms of avoided health impacts and lower operating costs due to the reduced frequency of emptying the septic tank, Kimwaga *et al.,* 2013). The success was attributed to the motivation of the school staff, including the formal designation of responsibility for operation and maintenance. A visit by researchers early in 2018 found that the wetland condition had deteriorated due to a change in school management and lack of maintenance, although it was still functioning – demonstrating the robustness of the system. However it took only one day to clear the wetlands of excessive vegetation growth, so that new vegetation can grow, and the site is now being used for further research (van Deun, pers. comm.).

Other wetlands in the region have failed due to poor maintenance or design or both. For example, another school failed to install a septic tank as planned (due to resource constraints) and the wetland inevitably failed after being overloaded with raw sewage (Kimwaga *et al.,* 2013).

Credit: SI VLRUOS-project, TMK Belgium, with permission. See http://www.constructedwetlands.net/cwruaha.html

Figure 4-3 The constructed wetlands at Ruaha School in Tanzania

Banana winery, Tanzania

Agro-processing industries create effluent rich in organic matter, which is damaging when discharged to the environment but also represents a potential source of nutrients that could be recovered. A treatment system was built at a banana winery (Banana Investment Limited) in Arusha, which was previously discharging untreated effluent. Processing effluent was treated initially in an up-flow activated sludge blanket (UASB) reactor, and the effluent was polished in a subsurface flow constructed wetland planted with papyrus(Figure 4-4). After 17 months of operation the system was removing 99% of chemical oxygen demand, 98.6% of biological oxygen demand, 96% of suspended solids, 88% of nitrates and 50% of phosphates. The biogas produced in the UASB is used in the boiler, and the dried sludge and the treated water are used for irrigation (Paschal *et al.,* 2017). Another successful example of a papyrus wetland in Arusha is treating the wastewater from the student hostel at Nelson Mandela African Institute for Science and Technology (van Deun, pers. comm.).

Credit: SI VLRUOS-project, TMK Belgium, with permission.

Figure 4-4 Papyrus wetlands at Banana Investment Limited (left) and Nelson Mandela African Institute for Science and Technology (right) in Arusha, Tanzania.

Chorfech Village and School, Tunisia

As part of the Zer0-M project, a sustainable water management system was implemented for the village of Chorfech 24, with 350 inhabitants. An Imhoff tank (a type of septic tank) was followed by a series of horizontal and vertical subsurface flow wetlands, with a total area of 1800m^2, and a composting reed bed for drying the sludge (Figure 4-5). A separate system was set up at Chorfech primary school, which had 60 pupils and 10 staff. The school was not connected to the village sewage system and had no sanitation system, limited water supply and limited financial resources. A comprehensive system was installed, including water-saving equipment (push-button taps, waterless urinals and rainwater harvesting) as well as a sanitation system consisting of a septic tank followed by a small horizontal subsurface flow constructed wetland (3 x 5m). The treated water was used for irrigation of the school yard, especially trees (AEE-INTEC, 2009). After three years the wetland was performing well, with high removal rates for suspended solids (93%), nutrients and pathogens (Ben Saad et al. 2015). The wetland is still operating successfully today (Ghrabi, pers. comm.) and similar wetlands have now been created at three other schools in Kasserine. This is viewed as a good solution for small rural communities with limited financial resources for sanitation.

Photo: Macgulf. http://www.macgulf.com/application-examples/experiences

Figure 4-5 Constructed wetlands at the village of Chorfech 24

Témacine, Algeria

The company Wastewater Gardens International has installed a number of wetlands in Africa, including one at Témacine in Algeria (Figure 4-6). This was installed in 2007 at a historic site including a mosque and a group of houses and was designed to treat 15 m^3 per day of effluent (mixed grey and blackwater) from 100-150 people. After primary treatment in a septic tank, water flows into a 400m^2 horizontal subsurface flow constructed wetland designed as a crescent shaped garden and planted with a mix of ornamental plants. Dry gravel covers the wastewater to prevent odour or human contact. High quality effluent is produced, which is used to irrigate fruit trees planted in drainage trenches next to the wetland.

Although most constructed wetlands use reeds (Phragmites) or rushes (Typha), these plants can be invasive if they escape into the local environment. Wastewater Gardens International have pioneered a different approach which aims to use a diverse mix of plants, preferably local species. They work with around 200 plants which are adapted to wetland conditions in different countries, of which about 80% have additional uses (e.g. ornamental, animal fodder, fast growing timber, weaving material, medicinal use, cut flowers, biodiversity value). For the Termacine wetland a mix of 25 plant species were tested, of which 7 were found to be suitable including oleander, canna and bluegrass (Nelson and Cattin 2014; Saggaï *et al.,* 2017).

The system has been highly successful and led to requests for the company to design three further wastewater treatment gardens. A tender has just been issued by the Office National de l'Assainissement in Algeria for the construction of 50 new wetlands across 21 Wilyas (counties), based on these designs (Cattin, pers. comm.).

Credit: Wastewater Gardens International

Figure 4-6 Wastewater Garden in Témacine, Algeria on construction (left) and after six years of operation (right)

Opportunities and barriers to wider take-up in Africa

Opportunities

Constructed wetlands are well suited to Africa's climate (in warm climates wetland plants grow more rapidly and microbial processes are faster) and offer a cost-effective means of tackling problems of both water supply and water quality (Kivaisi, 2001). They have the potential to contribute positively to integrated water management approaches in urban and peri-urban areas, and also have a range of uses in rural areas. In this context Africa *'can take the lead'* with the greatest opportunities for constructed wetlands as:

- ***Supplementary treatment for poorly performing municipal wastewater treatment plants.*** Many of the conventional wastewater treatment plants (WWTP) across Africa are ageing or overloaded and their effluent fails to meet water quality standards. For example, the Bugolobi WWTP in Kampala failed discharge standards 100% of the time for a whole year of monitoring (Bateganya *et al.,* 2016). CWs can be used as a cost-effective method to treat the effluent before it is discharged to the environment; reducing pollution, biodiversity loss and public health problems.
- ***Low-cost, small-scale, secondary treatment:*** Secondary treatment of wastewater for small communities, e.g. villages of up to 2,000 people, or in association with septic tanks (which fail to remove nitrogen from sewage) to bring water quality up to a level where it can safely be discharged to the environment (Kadlec and Wallace, 2008). Due to their small footprint, vertical subsurface flow wetlands connected to septic tanks can be suitable for use in informal settlements that are far from the sewer system (Buckley and Aramugam, 2016).
- ***Urban grey-water treatment*** *(Decentralized systems for individual houses or clusters).* El Zein et al. (2016) describes a design suitable for new towns in Egypt (such as the eastern Port Said region, New Ismailia City and Technology Valley), based on plans for a sustainable community in Iran. This follows the traditional form of dense low-rise development with houses clustered around central courtyards. Greywater from sinks passes through small constructed wetlands that provide water for gardens, while blackwater from toilets is treated centrally. This design reduces the cost of piping, leakage and energy required for centralized treatment while providing attractive green space for recreation. Small scale decentralized systems built into new developments can be provided with private finance, saving money for municipalities.
- ***Support in the treatment of agricultural and industrial effluents:*** Treating agricultural runoff or landfill leachates (where landfills are lined) and treating effluent from industrial processes.
- ***Tertiary treatment***: Where higher water quality is required, e.g. for vulnerable biodiversity sites or where discharge is used for agriculture or as a water source.

Barriers

Wider uptake is held back by a number of barriers, mainly linked to a lack of awareness of the technology and its costs and benefits, by planners, policymakers, practitioners and the wider public (Kimwaga *et al.,* 2013).

- ***Assumption of no maintenance:*** Constructed wetlands are sometimes treated as *'set and forget'* systems, both in Africa and elsewhere, but in reality regular maintenance is essential (van Deun, pers. comm.). For example, sediment and litter must be removed from traps; leaks and cracks must be fixed; blocked pipes must be cleared; vegetation should be replanted if it fails to establish in places; and usually the vegetation should be cut or harvested regularly to remove nutrients that have been absorbed and stimulate new growth. The effluent should also be monitored to check its quality. Inadequate maintenance or incorrect operation due to lack of resources or training can lead to problems such as over-flooding or leakage (Kimwaga *et al.,* 2012).
- ***Perceived credibility.*** Constructed wetlands are mechanically simple but biologically complex, and their efficiency in removing pollutants may not be appreciated by conventional water engineers who associate high performance with advanced engineered technology.
- ***Bias towards conventional projects.*** There can be preference for large, expensive conventional engineering projects – sometimes linked to corrupt governance. Cheap, small scale solutions

give less opportunity for misappropriation of funds, which is an advantage but can also be a barrier to implementation.

- ***Interdisciplinary knowledge barriers.*** Design of wetlands requires knowledge of different disciplines beyond traditional engineering (WWG, n.d.). Implementation of full sustainable treatment systems requires partners from water engineering, agriculture, urban planning, architecture and possibly others, e.g. sociology to work together (AEE-INTEC, 2009).
- ***Lack of commercial capacity***. It can be very difficult or even impossible to find consultants who can design sustainable water systems on a commercial basis, because the systems are so novel (AEE-INTEC, 2009).
- ***Need for maintenance.*** Some existing schemes have failed due to lack of knowledge, resources or commitment to maintaining the schemes correctly (Kimwaga *et al.,* 2018).
- ***Unconventional sanitation systems.*** For optimal design of sustainable treatment systems, it is usually necessary to collect greywater (from bathrooms) and blackwater (from toilets and kitchen sinks) separately, which is not a standard approach in many places in Africa. There can also be cultural objections or professional reservations about novel sanitation solutions such as dry composting toilets or re-use of treated blackwater (AEE-INTEC, 2009).
- ***Inappropriate regulations.*** Regulations designed for conventional treatment systems may not be appropriate for novel sustainable systems. For example, at Chorfech village the optimal design for the wetland (which left nutrients in the effluent to boost plant growth when used for irrigation) could not be used because the standards for nutrient levels were too strict (AEE INTEC, 2009).
- ***Lack of monitoring data.*** Even when constructed wetlands are built and are operating successfully, it is time-consuming and costly to monitor their performance (beyond basic water sampling to meet regulatory requirements) and so many operating wetlands may be 'invisible' to the wider public (Cattin, pers. comm.).

To overcome these barriers, wider promotion of existing successful schemes is needed. Practitioners have found that natural systems always require a product "champion" in a decision-making position who understands that behind the apparent simplicity, purification levels are as high as with conventional grey infrastructure, and appreciates the added value of using such systems (Cattin, pers. comm.). Funding for a series of well-monitored full-scale exemplar schemes could demonstrate the benefits for a range of different applications and in different regions. In particular, there is great potential to demonstrate the use of decentralized systems in a residential new town as envisaged in El Zein *et al.,* (2016), but there are also many other opportunities such as application in rural communities, for centralized municipal wastewater treatment, and for treating industrial effluent.

4.2 Urban green infrastructure

Urban green infrastructure can manage runoff using natural processes of infiltration into the ground, storage in water bodies and filtration by vegetation.

Conventional stormwater management uses grey infrastructure such as concrete drainage channels and storm sewers to collect water and channel it as quickly as possible to a point where it can be discharged into a watercourse or water body. This approach however often results in pollution of watercourses and can also result in a sudden increase in flood risk further downstream. It also loses the opportunity for productive use of the water. As a result, there is growing interest in alternative green and blue infrastructure-based approaches which slow the flow of water and allow it to gradually infiltrate into the soil, as well as providing multiple co-benefits. A family of overlapping approaches has evolved in different countries, including ‘Sustainable drainage systems’ (SuDS) in the UK; Integrated urban water management (IUWM) in the USA; Water-sensitive (urban) design (WSUD/WSD) in Australia; Low-Impact Design (LID) in the USA (Lottering *et al.,* 2015), Best Management Practices (BMP) for stormwater treatment in the USA and Canada, and ‘Sponge City’ in China. Here we group them all under the category of ‘Urban Green Infrastructure’ (UGI), although we recognise that the term ‘Green Infrastructure’ has a much wider usage and that much urban green space is seen as being primarily for other purposes (e.g. recreation) rather than water management. These approaches are increasingly being incorporated into new developments in developed countries, but application in Africa so far has been limited.

Basic performance characteristics

Use

Urban green infrastructure (UGI) can be applied in new developments or retrofitted to existing developments at any scale, from an individual building to an entire municipality. The primary aim is to manage surface water runoff and thus protect against flooding, but unlike grey infrastructure UGI can also improve water quality, store water for potential re-use and allow groundwater recharge through infiltration as well as providing biodiversity and amenity benefits. Some types of UGI, including SuDS features such as bioswales and retention ponds, are specifically aimed at managing surface water runoff sustainably and thus are core SWI investments, but other types of UGI such as parks, gardens, sports fields or landscaping are aimed primarily at other goals such as recreation or aesthetic value.

Basic types

UGI uses natural processes of infiltration to the soil and filtration by vegetation to reduce runoff and remove pollutants. It includes features such as bioswales (vegetated ditches), ponds, retention and detention basins, raingardens / wetlands, green roofs, permeable paving, and general green spaces such as parks, gardens, street trees and green/blue corridors. It can also make use of existing natural and semi-natural features such as urban streams, rivers, wetlands and woodlands.

Perceived strengths

- **UGI and SuDS allows groundwater recharge**, stores water for potential re-use and filters out pollutants, unlike impermeable grey infrastructure (e.g. concrete drainage channels).
- **UGI and SuDS provides multiple co-benefits** including aesthetic value, recreational opportunities, urban cooling and enhanced biodiversity.
- **UGI and SUDS typically has lower environmental impacts** compared to grey infrastructure (no or little concrete used in construction; no or reduced need for energy-intensive pumping or water treatment).
- **Small-scale or micro-scale SuDS can be implemented, monitored and maintained by local communities** using simple tools and local or recycled materials, even in informal settlements (Fitchett 2017; Jiusto and Kenney 2016). This makes SuDS suitable for community-based adaptation, with the added benefit of fostering improved social cohesion and resilience. In contrast, grey infrastructure solutions generally lead to community dependence on government funding for implementation and maintenance, which may not always be forthcoming.
- **UGI and SuDS are flexible** and can be more readily adapted over time to suit changing circumstances, e.g. changes in water level or ground level due to subsidence or erosion (Fitchett

2017). Where litter is a problem, open channels typical of **SuDS are more easily cleared** than conventional underground pipework.

Perceived weaknesses

- **Lack of effective sanitation and refuse collection** services can lead to SuDS features such as swales, ponds and wetlands becoming clogged with refuse (e.g. Jiusto and Kenney, 2016), although this can also apply to grey drainage infrastructure (Mguni *et al.,* 2016). It is essential to address both litter and drainage together as each problem can make the other worse (Fitchett, 2017).
- **Maintenance requirements.** Permeable paving can become clogged with sediment and requires maintenance. Vegetated SuDS features may also need maintenance to remove litter and build-up of fatty acids from domestic wastewater (Fitchett 2017), and poorly maintained SuDS could become a health and safety risk, for example if there is stagnant water which is a breeding ground for mosquitos (Mguni *et al.,* 2016).
- **Space requirements.** UGI and SuDS features can take up more space than a grey drainage system, although this space can also double up as green space for recreation, biodiversity or urban agriculture.
- **Green roofs may not be feasible** in informal settlements where building strength may not be able to take the weight of the soil and plants.

Examples of implementation

Century City wetland, Cape Town, South Africa

Century City is an upmarket development with the largest shopping centre in the Southern Hemisphere and Cape Town's only theme park. It was built in 1995, on the site of a degraded wetland area, and it incorporated a sustainable drainage system including a large (16 ha) constructed wetland with four treatment cells and a number of salt pans, as well as a network of canals and ponds (**Error! Reference source not found.**). The system collects the stormwater runoff from the Century City and neighbouring Summer Greens developments, and channels it into the adjoining Tygerhof Detention Pond, from where it passes into the Atlantic Ocean. The wetland acts as the 'lungs' of the system, purifying the water before it is discharged to the detention pond. It also performs an important biodiversity function, aiming to conserve a rare mix of habitats found on the site. It is home to 177 indigenous plant species and 120 bird species and has been awarded conservation status for its educational nature trails (Vice and Armitage, 2011).

The system has generally been very successful, but it is fairly complex and there have been management problems arising from fluctuations in the quantity and quality of effluent and runoff. Since 2008, it has received effluent from the nearby Potsdam WWTW in summer when runoff and groundwater levels are low, but this has led to a build-up of phosphorous levels, causing sudden growth of an invasive fern and associated blue-green algae which covered the water surfaces and prevented aerobic treatment of the runoff. Eventually this was controlled using a frond-eating weevil, but there are still concerns about eutrophication and a build-up of dead organic matter. This emphasises the need for systems thinking and adaptive management for maintaining complex ecological systems (Vice and Armitage, 2011).

Photos: Top http://www.uwm.uct.ac.za/uwm/wc/century-city-wetland. bottom Michael Vice (Vice and Armitage, 2011

Figure 4-7 Century City, Cape Town: SuDS basin (top) and constructed wetland system (bottom)

Green roof, Durban

A demonstration green roof of 550m^2 was constructed on a municipal building in Durban in 2008, at the City Engineers complex, as part of the eThekwini Municipality's Municipal Climate Protection Programme (MCPP). It covers two flat slabs on either side of an arched roof and is highly visible to visitors. Part of the area was set up as a direct green roof and the rest was modular, with plants grown in plastic trays (**Error! Reference source not found.**). A range of 81 indigenous plant species were tested, mostly sourced from within 50km of the site, of which 37 were found to be suitable. Tests showed benefits for biodiversity, significantly reduced runoff and a cooling effect, and the attractive mix of plants provided high aesthetic value. The roof was also used for growing food. A range of vegetables were tested and those that were found to be suitable included eggplant, tomato, spinach, green peppers, spring onion and chilli peppers. The project was used to produce guidance on installing green roofs in the region (Van Niekerk *et al.,* 2011.)

Source: van Niekerk *et al.,* 2011. Credit Clive Greenstone and Mike Hickman.

Figure 4-8 Demonstration green roof on a municipal building in Durban: Direct roof (left) and modular (right)

Participatory micro-scale SuDS in Johannesburg, Cape Town and Nairobi

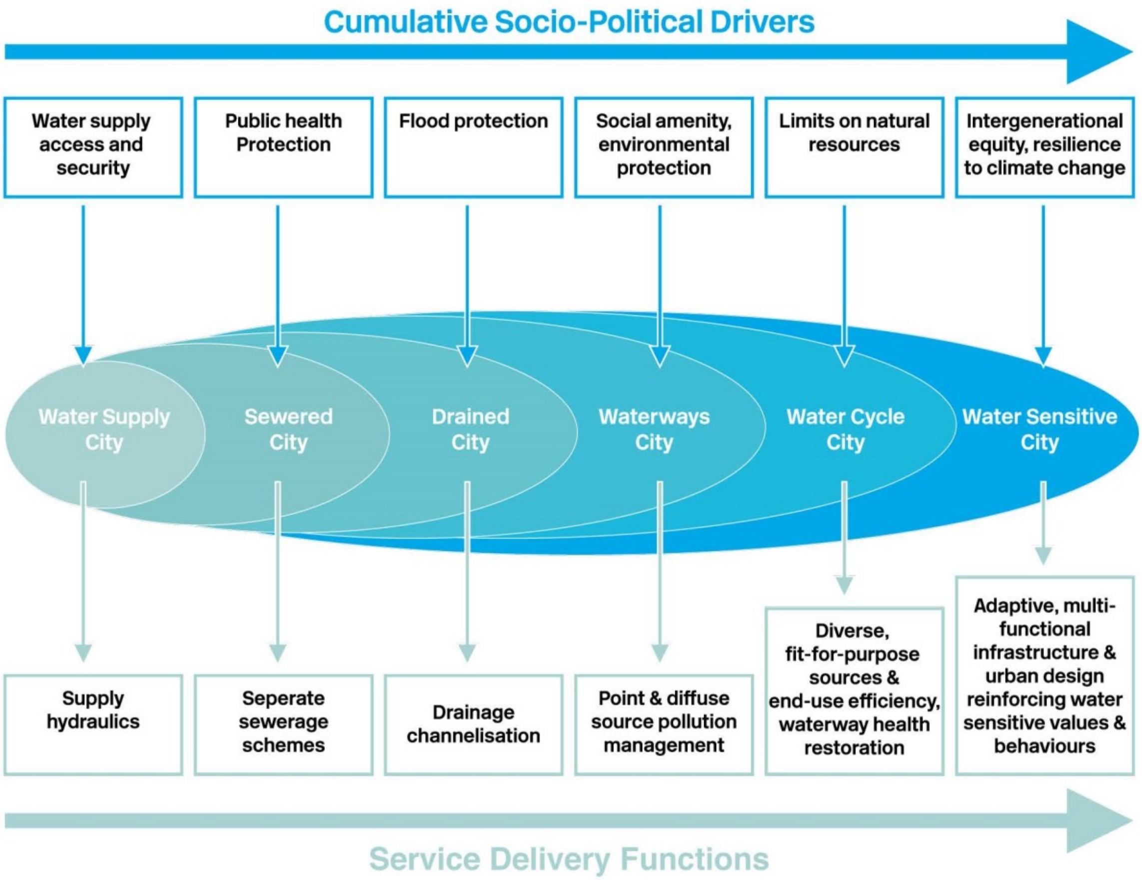
Informal settlements suffer severe drainage and sanitation problems. Two studies have investigated the potential for researchers, government, NGOs and residents to work together to co-design and implement a series of small scale SuDS measures (Fitchett, 2017; Jiusto and Kenney, 2016). Small-scale interventions including permeable channels, soakaways and vegetation barriers were designed, constructed and refined at several sites, using local materials such as construction waste. Tests showed that runoff problems were reduced and water quality improved. The projects were implemented as 'co-learning' exercises to see what works. This incremental and participatory approach offers the potential for in-situ upgrading of informal settlements without the need to 'raze and replace'.

Further work has taken place in Nairobi, Kenya, facilitated by a local NGO called Kounkey. Despite minimal funding, the Kounkey Design Initiative engaged local government, professionals, the private sector and community groups to successfully create a series of small multifunctional green spaces in the informal settlement of Kibera. These spaces provide flood defence as well as recreational and livelihood benefits (as spaces for urban agriculture). The community was engaged from the start of the process, in mapping flood risk, designing and implementing the schemes. Residents emphasise that such projects should always be carried out by the community rather than being imposed from above (Douglas, 2016; Tauhid and Zawani, 2018).

Opportunities and barriers to wider take-up in Africa

Opportunities

Poor practices in urban water management have been a significant contributor to the degradation and pollution of urban rivers. Urban Green Infrastructure has great potential to contribute cost-effectively to the multiple challenges of flooding, water pollution and water scarcity in Africa, as well as providing green and blue space for amenity and biodiversity. Integrating UGI into urban water management, including retrofitting existing urban areas, will be a critical tool for reducing the drivers of poor health in urban rivers/water systems. UGI can be readily integrated with water-saving and water-re-use technologies (e.g. rainwater collection and storage tanks). Integrated frameworks (such as IWRM, and Integrated Urban Water Management) treat wastewater and stormwater as resources, and match water quality to the intended use (Bahri *et al.,* 2016). However, many existing strategies fail to use the potential for green infrastructure and continue to focus on grey measures. To make the transition to a water-sensitive urban design (as set out in Figure 4-9) will require MDBs to be proactive in their promotion.



Source: Brown *et al.,* 2009

Figure 4-9 Typology of different city states in the transition towards water-sensitive city management

There is growing interest in the potential of SuDS, IUWM and GI in African countries including Ethiopia and Tanzania (Herslund *et al.,* 2017), including a detailed plan for IUWM in Addis Ababa (Worku, 2017). In South Africa, a cost-benefit analysis for the World Bank analysed potential 'Green Urban Development' interventions in eThekwini, Durban and found that large scale options such as detention basins and constructed wetlands, as well as the retention of large natural green spaces and riparian buffers (enabled by more compact development), were highly cost-effective compared to grey infrastructure, due partly to co-benefits for recreation and amenity. However, small-scale source control options such as residential soakaways were found to be very costly (Turpie et al. 2016b).

Barriers

This review found only a few examples of implementation in Africa to date, mainly confined to a handful of schemes in South Africa. This reflects the fact that SuDS is a relatively untested technology, which gives rise to a number of barriers to wider uptake (Mguni *et al.,* 2016):

- **entrenched attitudes** that favour conventional technologies;
- **lack of awareness and evidence** on the benefits of SuDS and uncertainty over costs, maintenance requirements and effectiveness; leading to difficulty in convincing policy makers of viability;
- **lack of skills and knowledge** to implement SuDS;
- **lack of basic maps and data** e.g. on existing green space and hydrology;

- **the need for co-ordination and joint decision-making** by multiple stakeholders (e.g. different departments for green space, housing, roads, water supply, waste disposal, stormwater management, energy, parks etc.) (Bahri *et al.,* 2016);
- **lack of effective urban planning**, including rapid and uncontrolled development with masterplans, where they exist, becoming out of date faster than they can be implemented (Herslund *et al.,* 2017).

These barriers can be addressed through funding well-designed and monitored exemplar systems and evaluating and publicising the wider benefits for ecosystem services. For new developments, SuDS should be tailored to local conditions rather than copied from examples in developed cities (Mguni *et al.,* 2016). When retrofitting existing settlements, SuDS installation should be incremental and adaptive so that performance can be optimised for the local conditions. Local people can be empowered to monitor, maintain and adapt SuDS to meet changing conditions over time (Fitchett, 2017). It is also important to ensure that SuDS benefits the urban poor, for example by providing space for rainwater harvesting and informal urban agriculture, and avoids the risk of 'aestheticising poverty' or leading to gentrification that displaces vulnerable people (Douglas, 2016; Mguni *et al.,* 2016). If resettlement is necessary (e.g. to move informal settlers from floodplains), this should be done in close consultation with the community so that new dwellings are provided close to jobs (Tauhid and Zawani, 2018).

4.3 Aquifer recharge

Aquifer recharge involves purposefully diverting surface water flows to underground aquifers for storage.

The first groundwater recharge scheme was in Berlin in the 1870s. There are now over 40 recharge schemes in California, and several in Australia and the Middle East. In Africa there are three schemes in operation, plus one pilot plant (discussed below).

Basic performance characteristics

Use

The aim of aquifer recharge is to store surplus water in underground aquifers, so that it can be reused when surface supplies are low. This helps to smooth out peaks and troughs in supply due to fluctuations in rainfall or other factors. Aquifer recharge can also be used to mitigate problems caused by over-abstraction of groundwater, such as subsidence and saline intrusion. There is some overlap with the previous category of Urban Green Infrastructure, because this also encourages infiltration (and thus groundwater recharge) rather than conveying water off-site as fast as possible. However, in this section we focus on larger scale schemes that specifically target recharge in particular aquifers, often using treated wastewater rather than just runoff.

Basic types

Recharge can use either surplus surface water (from rivers or reservoirs) or recycled water (such as treated wastewater, storm water or greywater). Water can be returned to the aquifer through various methods (Murray, 2017):

- **direct injection** into boreholes, either using the same borehole that is used for abstraction (Aquifer Storage and Recovery), or injecting into one borehole and recovering from another (Aquifer Storage, Transfer and Recovery);
- **spreading in infiltration basins** and allowing the water to percolate naturally into the aquifer (this only works for unconfined aquifers, i.e. where the aquifer meets the land surface);
- **local water harvesting** (e.g. from the roof of a building) and injection into a gravel-filled pit or well, for percolation to the water table, from which it can be recovered using another well or borehole;
- **sand dams**, which trap water in ephemeral rivers when they are in flood and allow it to percolate into the ground.

Perceived strengths

- **Aquifer recharge avoids evaporative losses** compared to conventional storage in reservoirs, which is particularly important in arid regions;
- **It prevents contamination**, compared to surface storage (provided that the aquifer is not polluted);
- **It stores much larger volumes** than can be achieved in reservoirs, without involving loss of land for reservoir construction;
- **It can be used to improve groundwater quality** (e.g. where the aquifer has become saline);
- **It can be used to dilute and filter recycled water** (when allowed to percolate from the injection point to the recovery point).

Perceived weaknesses

- **Water quality.** Aquifer recharge is only feasible where aquifers are not irretrievably polluted, e.g. by mining activities (Kings, 2017). The quality of water that is injected should be controlled, to avoid polluting or blocking the aquifer.
- **Public opinion** may prevent use of recycled water for recharge (Kings, 2017).
- **Schemes are costly and require energy** for pumping. In many areas there may be no need for aquifer recharge as surface water storage may be adequate.

Examples of implementation

Atlantis, South Africa

The aquifer recharge scheme in Atlantis, South Africa, has been operating since 1979 (Figure 4-10). About 3 GL/year of tertiary treated domestic wastewater and stormwater is recharged into an unconfined sand aquifer. After six months the water is extracted and used to supply 25–40% of the town's drinking water. About 1 GL/year of lower quality industrial wastewater is infiltrated through coastal basins and used as a barrier against saline intrusion (Fisher-Jeffes *et al.,* 2016).

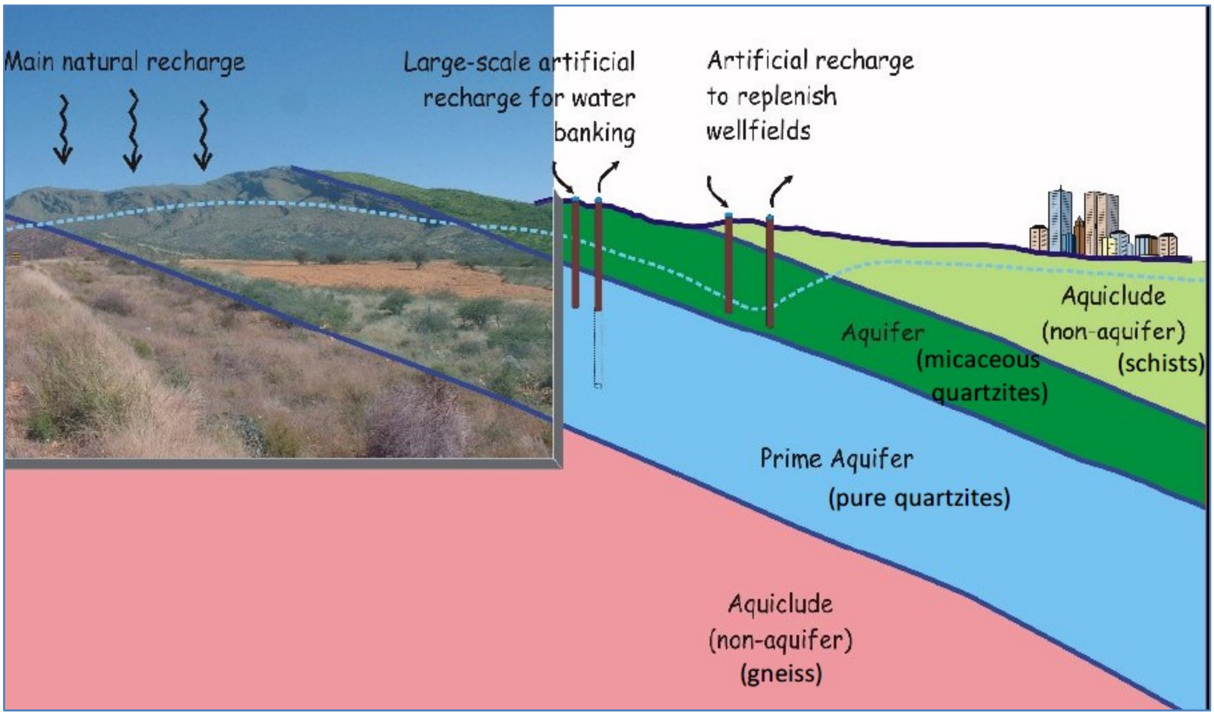
Photo credit: Ricky Murray, Groundwater Africa (Murray, 2017)

Figure 4-10 Infiltration basin, Atlantis

Windhoek, Namibia

Windhoek, which suffers from severe water shortages, pioneered the technique of recycling potable water from wastewater treatment plants. At the Goreangab WWTW, which treats water from most of the 350,000 residents, water has been recycled since 1968. The plant uses a series of treatment stages including activated sludge ponds, bioreactors, aeration tanks, ozonation, activated carbon filters and ultraviolet disinfection (Gross, 2017). Recycled water is mixed in a ratio of 1:3 with water from reservoirs. The technique is very successful and has been copied in other locations in the USA and Malaysia, but public protests due to cultural rejection of the concept (the ‘yuck’ factor) have limited uptake elsewhere, including in eThekwini (Kings, 2016).

High evaporation rates in Namibia result in large losses of water stored in reservoirs. Annual rainfall is 360 mm and evaporation is 2170 mm (Murray, 2017). As a result, surplus rainwater and recycled water is now injected into a groundwater aquifer for storage (Figure 4-11). This aquifer is the main groundwater source for Windhoek, but over-abstraction since the 1950s led to a drop in water levels by over 40m, with the aquifer taking decades to recover. Four existing boreholes were equipped for recharge in 2004 and two more by 2011, with a recharge capacity of 420 m^3/hour. Prior to injection, the water (which is about one third reclaimed water and two thirds dam water) is treated by chlorination and carbon filtration to remove bacteria. Between 2006-12, 3.3 million m^3 were pumped into these boreholes – about twice the normal rate of recharge, and the aquifer in this area was fully recharged. Since then, 20 new boreholes were drilled and further boreholes are now being drilled to access deeper parts of the aquifer, which is expected to provide sufficient water storage capacity for a three-year drought (when fully recharged) (Murray, 2017).



Source: Ricky Murray, Groundwater Africa (Murray, 2017)

Figure 4-11 The Windhoek aquifer recharge scheme, Namibia

Ben Sergao, Agadir, Morocco

At Ben Sergao, 750 ML/day of treated effluent is supplied to five infiltration basins (after screening, pretreatment in an anaerobic pond, and an oxidation pond). After groundwater recharge and wastewater retention, the water is used for irrigation of grass, alfalfa, wheat, and corn (Chen *et al.,* 2013).

Souhil Wadi, Tunisia

Souhil Wadi is a pilot scale facility which has been operating since the early 1980s, investigating the safety of using treated wastewater for aquifer recharge. The scheme has been controversial because there have been concerns about the impacts on water quality. However, improvements to the process may improve its acceptability (Kalalli *et al.,* 2013).

Opportunities and barriers to wider take-up in Africa

Aquifer recharge shows great potential for contributing to water supply in hot, arid areas where surface water storage (in reservoirs) would lead to large evaporative losses. This is also one of the only options available for preventing saline intrusion due to groundwater depletion. For recharge via infiltration basins, treated wastewater receives additional filtration as it passes through soil and rock into the aquifer. Africa has gained considerable expertise from the schemes in South Africa and Namibia. In South Africa, the Ministry of Water Affairs has a policy to expand the use of recharge and has mapped all the suitable areas. Their website lists case studies as well as potential future opportunities that have been taken to the planning stage (http://www.artificialrecharge.co.za/).

However, there have been concerns (for the Souhil Wadi scheme) over the impact of treated wastewater on groundwater quality. Cultural barriers to using treated wastewater for drinking have also prevented some schemes from going ahead. This technology needs to go hand in hand with advanced wastewater treatment and groundwater monitoring, as for the Windhoek scheme.

4.4 Land management and restoration

Land management and restoration encompasses a variety of approaches aimed at maintaining healthy ecosystems that can deliver a wide range of services, including flood and erosion protection, fresh water supply, water quality regulation and other provisioning, regulating and cultural services.

Although this paper focuses primarily on blending natural and built infrastructure solutions in urban and peri-urban areas, cities cannot be isolated from their surrounding landscapes. Sustainable management of the wider catchment is essential to ensure a supply of freshwater, to provide flood and erosion protection and to protect water quality. Land management and restoration is thus essential both within urban areas, as part of a blended urban system, and in the wider catchment through minimizing loads on downstream urban systems.

Basic performance characteristics

Use

Land management and restoration is used to achieve a variety of goals:

- **To protect against flooding, erosion and landslides** (e.g. through afforestation);
- **To protect water quality** (e.g. through afforestation, planting riparian buffers; terracing to prevent soil erosion; protecting or restoring natural wetlands);
- **To improve drought resistance** and water retention (e.g. through adding organic matter to the soil or building sand dams);
- **To improve productivity** and protect livelihoods (e.g. by reseeding bare ground).

Water-related services are not always the main focus – sometimes the action might be driven by biodiversity conservation, carbon storage (e.g. via forest carbon credits), or sustainable livelihoods. Many actions are geared towards climate change adaptation, which includes a large component of water-related services in terms of managing drought and flood risk.

Basic types

This category includes a wide range of approaches based on land management or restoration, including catchment management, ecosystem-based adaptation, soil-water conservation and natural flood management. It includes a wide range of measures:

- protecting natural ecosystems (including forests, grasslands, wetlands, mangroves, reefs and dunes);
- reforestation / afforestation;
- agroforestry;
- conservation agriculture (no-till or low till; mulching; adding organic matter to soil);
- terracing; bunds; sand dams; zai pits; contour strips; riparian buffers;
- clearing invasive alien vegetation; reseeding;
- managing or reducing grazing pressure; reverting from arable to grassland;
- restoring wetland hydrology and vegetation; reconnecting rivers with flood plains.

Perceived strengths

- **Land management and restoration approaches are the essential foundation for long term sustainability**. A well-functioning upper catchment with good vegetation cover and healthy soils will provide a degree of protection against flooding, soil erosion and landslides in both rural and urban areas, and encourage water retention and groundwater recharge, which helps to maintain year-round water supply. This will reduce the need for (and costs of) grey infrastructure, e.g. water treatment plant, reservoirs, dams and levées. Conversely, a degraded upper catchment could increase the risk of floods and landslides and contribute to poor water quality in urban areas downstream.
- **Co-benefits.** As well as tackling water supply, water quality and flooding simultaneously, land management and restoration can offer multiple co-benefits, especially for biodiversity, carbon sequestration, erosion protection, climate adaptation and rural livelihoods.

Perceived weaknesses

- **It is essential to use a fully participatory approach**, working with multiple stakeholders, to ensure long term ownership and stewardship. It takes time and effort to build trusting relationships.
- **It can be challenging to manage conflicts and trade-offs** between different stakeholders and different objectives. For example, there are often conflicts between productive uses such as agriculture, fishing or forestry and regulating services such as flood protection, carbon storage and biodiversity. There can also be conflicts between different stakeholders making use of land-based resources, such as people involved in arable farming, livestock farming, or fishing. Management of these conflicts requires lengthy processes of mediation and consensus-building to reach a sustainable solution.

Examples of implementation

South Africa 'Working for Water' and other Natural Resource Management programmes

The Working for Water programme was set up by the South African government in 1995. It is a job creation and poverty alleviation scheme where people are paid to clear invasive plants such as mesquite and acacia, which are thought to contribute to water shortages. It grew from supporting ten projects with an annual budget of USD$2.3 million in 1995, to over 300 projects with an annual budget of USD$139 million in 2015, and currently employs around 9,000 people per year of whom half are women (Cumming *et al.,* 2017). In 2004 this became a suite of Natural Resource Management (NRM) programmes including Working for Wetlands (wetland restoration); Working on Fire (clearing invasive vegetation to reduce fire risk), Working for Ecosystems (restoring thickets, savanna and grasslands) and Working for Forests (reforestation). The programme, however, has been criticized for focusing on job creation to the extent that environmental effectiveness is neglected. For example, lack of monitoring led to invasive species building up to unmanageable levels in some areas (Anglestam *et al.,* 2017). Although this is a successful programme, with multiple benefits for jobs, gender equality, poverty alleviation, climate mitigation and adaptation, biodiversity and livelihoods as well as water supply, Anglestam et al. (2017) suggested that it could be improved through deeper stakeholder engagement and co-learning, so that the work could be guided by local knowledge and local needs.

Buffelsdraai Community Reforestation Project

This project originated as a 'Greening Durban' initiative, aimed at making the 2010 World Cup carbon neutral by planting trees in an 800m buffer around Buffelsdraai landfill site, on a former sugar cane plantation (Roberts, 2010). It has now evolved into a major community ecosystem-based adaptation project with multiple benefits for flood and erosion protection, water quality, fire risk reduction and biodiversity, as well as screening local communities from the landfill site (Figure 4-12).

This initiative is interesting for its socio-economic co-benefits. The project uses the 'Indigenous Trees for Life' approach developed by the Wildlands Conservation Trust, who are partners in the project. Local people register as 'Tree-preneurs' and grow seedlings in their own homes using locally collected seed, which they can exchange for food, school fees or other goods. The project has created a total of 635 jobs (99 full-time, 24 part-time, 512 temporary), and has succeeded in raising incomes, increasing school attendance and food security in an area that suffers high unemployment and poverty. As of January 2018, a total of 722,335 trees and other plants of over 72 species have been planted in 602 ha of land, including a 'living fence' of thorny bushes which prevents access to the site by grazing animals. The number of bird species in the area (which is a global biodiversity hotspot) has increased from 80 to 145 (eThekwini Municipality, undated). In 2014, the project received Gold Standard certification from the Climate Community and Biodiversity Alliance (CCBA), for ensuring exceptional climate change adaptation benefits as well as benefits to local communities and biodiversity (Douwes *et al.,* 2015). Two other projects have now been started in eThekwini Municipality, at iNanda Mountain and Paradise Valley Nature Reserve (eThekwini Municipality, undated).

Photos: eThekwini Municipality (Douwes et al., 2015).

Figure 4-12 The tree nursery at Buffelsdraai (left) and part of the reforested site (right)

Succulent Karoo, South Africa

The Climate Resilient Livestock Production on Communal Lands project is an ecosystem-based adaptation project running from 2015 to 2019, by the IIED, the IUCN and the UNEP-WCMC in collaboration with Conservation South Africa. It focuses on Namakwa District Municipality in the Northern Cape Province, a poor region which is likely to become hotter and drier due to climate change, with more intense storms, floods and droughts. The area includes the Succulent Karoo — one of only two biodiversity hotspots in arid regions. Local people rely heavily on livestock farming, but this is very challenging due to the extreme dryness of the area. Farmers rely heavily on ephemeral wetlands in the Kamiesberg uplands for seasonal grazing and fodder, but both the wetlands and the rangelands are degraded.

The project aims to improve livelihood security for 100 farmers by rehabilitating 25,000 hectares of communal rangeland (by reseeding with locally gathered seed, mulching and clearing invasive alien plants) and small wetlands. However, restoration is very challenging in this very fragile landscape, due to slow germination and growth rates, loss of topsoil, low summer rainfall, short growing seasons and low survival rates of plants (Bourne *et al.,* 2016). Restoration outcomes were not apparent at the time of the first evaluation (Reid et al 2018b), but local communities gleaned benefits from engaging in sustainable management and restoration activities. The project featured strong community participation and use of indigenous knowledge, to the extent that the community self-organised to implement the plans. Evaluation showed that the activities carried out were not cost-effective for the landowners to carry out by themselves, but with external funding the activities could form part of a job creation and poverty relief programme, similarly to the Working for Water and Working for Wetlands programmes which were carried out in parallel. The challenges and high cost of restoration of these drylands emphasizes the critical need to avoid further degradation of the remaining intact areas, by managing grazing pressure or promoting alternative livelihoods such as eco-tourism (Bourne *et al.,* 2017).

Mount Elgon, Uganda

Mount Elgon is a major 'water tower' area between Kenya and Uganda, and a centre of outstanding plant diversity. However, increasingly frequent heavy rain coupled with cultivation and deforestation have led to severe landslides and soil erosion, and droughts are also a problem. This ecosystem-based adaptation project, delivered by a partnership involving the government of Uganda, the German Government, UNEP, UNDP, IUCN and IIED, adopted a highly participatory approach (UNDP, 2015). The local community made an adaptation plan and multiple actions were then carried out, including:

- **Grey infrastructure and improved appliances** (a gravity fed river irrigation system feeding a community storage tank, efficient stoves using local materials (mud), solar lamps);
- **Green infrastructure, sustainable agriculture and soil-water conservation** (river bank reforestation, hillside drainage or trenches, terraces, grass bunds and banks, organic and inorganic fertilizers, improved/drought resistant seed varieties, crop diversification, hedgerows, agroforestry, mulching, farming along the contour lines; water storage in ponds);
- **Training, governance and finance** (financial training, and a micro-credit scheme with access to the scheme being conditional on good land management).

The actions were complementary — reinforcing and supporting each other. The use of efficient stoves and solar lamps helped to reduce deforestation caused by fuelwood collection, and the water harvesting and storage systems allowed irrigation to take place and increased yields, and thus incomes and diets. These measures cut the time spent gathering wood and water, and improved health (by reducing wood smoke impacts, improving water quality and improving incomes and diets). The micro-credit scheme and associated training improved financial resilience. All these measures underpinned the sustainable land management initiatives by freeing up time, building human and social capital and making 'economic space' to enable and incentivize further actions by the community. The community established tree nurseries, and 20,000 trees had been planted by 2015 (UNDP, 2015).

There were strong efforts to ensure that the most vulnerable people in the community were targeted by the project, including women, and that the approach was fully participatory. Local knowledge was used in the selection of suitable tree species for reforestation. The community came together to plan the water distribution system, overcoming long-standing ethnic and land conflicts and increasing governance capacity for future adaptation actions.

A major evaluation exercise monitored the benefits and also the actions that did not work so well (Reid *et al.,* 2018a). The main conclusion was that a participatory approach is essential for longevity and community ownership of the project. Some barriers were encountered: for example, government staff turnover threatens continuation of some of the project principles, e.g. the concept that access to the microcredit scheme is conditional on good land management. There were also some trade-offs. For example, the new river-fed irrigation systems could reduce water supply for people outside the area; and river bank rehabilitation entails loss of land for farming or growing pines.

Isiolo region, Kenya

This ecosystem-based adaptation project was funded by the Isiolo County Climate Change Fund (ICCCF) in collaboration with the IIED, IUCN and UNEP-WCMC (Figure 4-13). It included rehabilitation, fencing and/or construction of 11 sand dams, 4 water pans, 2 shallow wells and 1 water tank, with accompanying water governance activities; a new borehole; funding for traditional rangeland management groups; climate services and a radio station. Investments were assessed as very cost-effective with high rates of return (a ratio of 402:1 to local communities; and even higher taking into account other communities outside the area). The work in Isiolo is also informing a similar UK-funded project in Longido, Ngorongoro and Monduli Districts in Tanzania, and proposals for devolved adaption finance in arid areas of Mali and Senegal (Reid *et al.,* 2018a).

Credit Isiolo County Climate Change Fund.

Figure 4-13 A rehabilitated sand dam, to trap ephemeral river flows

Lake Naivasha, Kenya

Lake Naivasha is the major horticulture area in Kenya and is also a RAMSAR site. Over-abstraction is causing the lake level to fall, and there are problems associated with invasive species such as carp and crayfish, polluting runoff from horticulture and lake-front hotels, overharvesting and clearing of Papyrus for agriculture. A programme of engagement with local stakeholders has been running for many years, in partnership with researchers from the University of Leicester in the UK. Small scale restoration initiatives have been undertaken, including planting Cyperus papyrus around lake and on floating islands; establishing educational programmes for local stakeholders and communities such as “Water Friendly Farmers”; restoring dams on small impoundments and building cattle drinking troughs below them. In addition, an Equitable Payment for Watershed Services project was implemented, based on economic modeling of ecosystem service costs and benefits to all users (Wanjala *et al.,* 2018). This encouraged rehabilitation and maintenance of riparian zones; establishment of grass strips/terraces to reduce runoff and erosion on steep slopes; reduced use of fertilizers and pesticides; and agroforestry and the planting of native trees and high-yielding fruit trees and cover crops. This achieved significant land and water management improvements, as well as livelihood benefits (WWAP, 2018).

Drought Resilience and Sustainable Livelihoods Program, Horn of Africa (AfDB)

The Drought Resilience and Sustainable Livelihoods Program (DRSLP) is an ongoing 15-20 year Bank Program to build communities' resilience to drought and climate change, improve their livelihood and promote regional integration in the Horn of Africa. It is expected to develop infrastructure for water mobilization and management, and agriculture and livestock production, health and marketing. It will also build the capacity of the populations and Governments of the participating countries to better cope with the effects of climate change, resource scarcity and resource-related conflicts. It includes natural resource management using a mix of hard infrastructure (boreholes, irrigation schemes, water ponds, pump-based water supply; wells, cisterns, micro-dams), governance (watershed management plans; establishment and training of committees to settle conflicts related to water and grazing land, or funding of existing committees; livestock carrying capacity) and natural infrastructure (rangeland rehabilitation; construction or rehabilitation of soil and water conservation infrastructure).

Lake Tana and Ribb Watershed, Ethiopia

This is a UNESCO-IHP (International Hydrology Programme) ecohydrology demonstration site. It was implemented by Polish Aid and ORDA (Organisation for Rehabilitation and Development in Amhara). The Ribb watershed suffers severe degradation due to a long history of overgrazing, overcultivation and deforestation. This project aims to establish a UNESCO Biosphere Reserve at Lake Tana. Proposed solutions include restitution of eroded soils by application of biodegradable geofibers and replanting with pioneering plants; construction of a sedimentation-biofiltration system in the city of Debre Tabor; creation of woodlots (shelterbelts); and restoration of shore line vegetation. Local societies are being involved in creating sustainable development plans. The project is currently in early stages (http://ecohydrology-ihp.org/demosites/view/172).

Nakivubo and Kirinya wetlands, Uganda

Natural wetlands have been used for wastewater treatment in many places, but this is only a suitable treatment method for low volumes of moderately polluted water. For example, Nakivubo wetland is one of several papyrus wetlands that have been used for 50 years to treat wastewater from Kampala before it passes into Lake Victoria, which is the city's main water supply. The wetland receives effluent from the (poorly functioning) Bugolobi wastewater treatment plant as well as heavily polluted surface runoff and untreated industrial effluent via the Nakivubo channel. However, rapid growth of the city coupled with encroachment onto the wetland by agriculture and uncontrolled urban development has led to shrinkage and degradation of the wetland (Kyambadde 2005; Kyambadde *et al.,* 2016). Similar problems are found for the nearby Kirinya wetland, which serves the city of Jinja but is also suffering agricultural encroachment and degradation (Kansiime *et al.,* 2007). A recent study for the World Bank found that:

"Nakivubo wetland no longer has any positive impact on the ecological condition of Inner Murchison Bay, with the lower wetland and bay having reached a hypertrophic state that is characterised by

frequent, often toxic, algal blooms, as well as being severely contaminated with pathogens that carry a risk to human health. Wetlands cannot substitute for wastewater treatment works and can only improve the quality of low volumes of moderately polluted water" Turpie *et al.,* 2016a.

The study proposed a major investment programme to rehabilitate the wetland, including preventing pollution at source through better sanitation and WWTP upgrades, converting the upper part of the wetland (currently farmland) to a series of free water surface flow treatment wetlands, restoring flow to the lower wetland (currently cut off by a railway line), establishing filter strips at the edge of the wetland and providing recreational facilities such as a visitor centre, bird hides and boardwalks. This would cost $53M plus $3.6M per year for operation and maintenance, but there would be estimated net benefits (a net present value of $80M over 15 years) from reduced water treatment costs and recreational benefits, given that the town has hardly any recreational green space at present (Turpie *et al.,* 2016a). However, the process of reclaiming agricultural land to restore the wetland is likely to be contentious and will have complex socio-economic impacts, as people who have occupied the land will need to be evicted[7].

Opportunities and barriers to wider take-up in Africa

There has been much research on nature-based solutions related to land management, and several interesting initiatives across Africa. In particular, the IIED projects in Kenya, Uganda and South Africa (see above) are notable for their highly participatory approach and sound monitoring and evaluation. There is, however, a very strong need for more investment.

A number of projects have been working for many years at a small scale and offer the potential to be scaled up with an injection of funding e.g. at Lake Naivasha (Wanjala *et al.,* 2018). Other studies have identified potential work programmes to tackle specific problems, e.g. flooding in Mauritania (Senhoury *et al.,* 2016). A study by the Nature Conservancy (TNC) identifies 30 cities in Africa that are mainly dependent on surface water supply and could benefit from watershed conservation practices (TNC, 2016). The study finds that 28 of the 30 cities could significantly reduce sediment or nutrient loads through conservation actions such as forest protection, reforestation, riparian restoration and agricultural best management practices (BMPs). Agricultural BMPs, such as the use of terraces and cover crops, are the most widely applicable measure and could improve water quality for 85 million people. Forest protection and restoration is less widely applicable but could benefit up to 52 and 11 million people, respectively. These cities source their water from 84 catchments covering over 67 million hectares – an area 26 times larger than their urban footprint – yet they represent only a fraction of the potential for watershed conservation in Africa. For eight of these cities, avoided water treatment costs could offset the entire cost of catchment conservation and for four of these (Cape Town, Lubumbashi, Nairobi and Yaoundé) the catchments are also priority wildlife conservation areas, so there would be large co-benefits for biodiversity.

Despite these opportunities, there are significant barriers to action (Reid *et al.,* 2018b; TNC, 2016). These include:

- **Lack of evidence** on the costs and benefits;
- **Governance** requires co-ordination across multiple sectors and administrative boundaries, which is challenging;

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[7] https://ugandaradionetwork.com/story/557-squatters-face-eviction-from-lake-victoria-shores

- **Lack of investors**. Climate change adaptation funds allocate far more funding to grey infrastructure than green infrastructure. The Green Climate Fund and PES are both potential sources of funding, but both are in their infancy;
- **Short term political decision-making** favours photogenic hard engineering projects with immediate and visible benefits over green infrastructure projects that may yield results in the longer term.

To overcome these barriers, TNC proposes establishing Water Funds which provide a stable and transparent investment platform to allow public and private water users downstream to compensate land managers upstream for catchment protection. They are already involved in 60 such funds worldwide, mostly in Latin America, but there are currently only eight similar initiatives, mostly within South Africa's Working for Water program. TNC has launched a new Upper Tana-Nairobi water fund and is exploring options for another fund in Cape Town (TNC, 2016).

Expertise and evidence on costs and benefits is growing, and the Department of Environmental Affairs in South Africa has now published guidelines on Ecosystem-based adaptation (DEA and SANBI, 2017).

Investing in land management nature-based solutions will require new ways of working for large international funding organisations, with a new focus on participatory approaches that take local knowledge into account, and a focus on capacity building for local communities. This type of approach however is already in evidence in some recent projects, especially those geared towards climate change adaptation, e.g. the Drought Resilience and Sustainable Livelihoods Program (DRSLP) in the Horn of Africa (African Development Fund, 2015).

4.5 International examples

Despite the widespread international recognition of the importance of ecosystems and their role in water management, take-up in practice at scale remains slow. There are however some important international initiatives and examples that are starting to accelerate action. Some of these initiatives are introduced below.

Nature-based approaches in urban development and community resilience

Recent examples of nature-based solutions to water insecurity in urban development are emerging around the world. These include (as summarized by Nagabhatla *et al.,* 2018):

- The European Union's Connecting Nature project is being implemented in 11 European cities, one of seven European projects seeking nature-based solutions for smart cities and climate change. The total investment of the suite of projects is EUR 150 million; the aim is to help the transition to more sustainable and resilient cities (Thompson, 2017 *apud* Nagabhatla *et al.,* 2018).
- China is investing heavily in innovative green infrastructure such as green roofs on buildings and urban wetlands, with the central goals of flood control, water conservation and increasing the resilience of city inhabitants (Zweynert, 2017). Shenzhen, an emerging smart city in Guangdong Province, is becoming an icon of international environmental leadership by adopting a "green city" agenda. It is incorporating the concepts of green energy, resilient communities and intelligent city infrastructure in its planning as part of a nature-based solutions approach (Kam Ng, 2017 *apud* Nagabhatla *et al.,* 2018).

- Architects and urban planners in the Syrian Arab Republic are considering "people-centred" housing strategies using local resources and approaches to infrastructure development in an effort to create resilient cities (Zekavat, 2017 *apud* Nagabhatla *et al.,* 2018).
- Taking note of intense weather, devastating hurricanes and frequent flooding episodes in urban spaces, architects in the United States of America are proposing green solutions that will embed and deploy ecological services and the benefits of forested and aquatic landscapes in the management of urban development (Lee, 2017 *apud* Nagabhatla *et al.,* 2018).
- Lima, Peru, is seeking to address significant water security issues through a process of 'greening infrastructure'. In 2015 the Peruvian Government introduced a Mechanism for Ecosystem Service Compensation to encourage the introduction of green infrastructure nationally, in response to analysis that showed that integrating existing grey infrastructure with green infrastructure in the watersheds supplying Lima's water could reduce the dry-season deficit by 90 percent, at a lower cost than by built infrastructure alone. In response, plans are in in progress to deliver a combination of reforestation, pastoral reforms and wetland restoration (Nagabhatla *et al.,* 2018).

There is also a growing number of examples of urban and peri-urban forest planning to achieve various and multiple objectives, including water management. Some of these are illustrated in Table 4-1.

Nature-based approaches in flood management

To make gains in safeguarding and promoting ecosystems through flood management, a shift in emphasis is required. Good practice is emerging. For example, working with natural processes needs to become a much more central consideration – a requirement acknowledged for example with the recent initiative of the Environment Agency in England to promote the concepts of '*working with natural processes in flood risk management'* and the recent adoption of *'natural flood risk management'* into Scottish legislation. The *'Building with Nature'* and the *'Room for the River'* programme in the Netherlands and *'engineering with nature'* in the US as well as more general (but similar) concepts of *'nature-based approaches'*, *'green infrastructure'* (*e.g.* The Floods Green Guide, WWF-US, 2016), *'resilient by nature'* have also started to move centre stage.

Legislation is also starting to reflect the connection between ecosystem health and human well-being, with an influence on flood management. In California, US, the Delta Stewardship Council, created in legislation under the Delta Reform Act (2009), is mandated by the state to achieve so-called *"coequal goals"* for the Delta with the aim of "*providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The coequal goals shall be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place."* (CA Water Code §85054). Improving flood protection by structural and nonstructural methods is planned in the context of this broader framework (Delta Stewardship Council, 2013).

In China, WWF worked with the Yangtze river basin authorities to restore Yangtze floodplain lakes, leading the reconnection of over 50 lakes to the Yangtze river. The lakes had been disconnected by sluice gates to create more land for agriculture and urban development – but this meant a lack of natural flushing of the wetlands, which seriously degraded water quality and biodiversity. WWF persuaded the government of Hubei province to try reopening sluice gates to reconnect one large lake, Zhang Du, to the Yangtze.

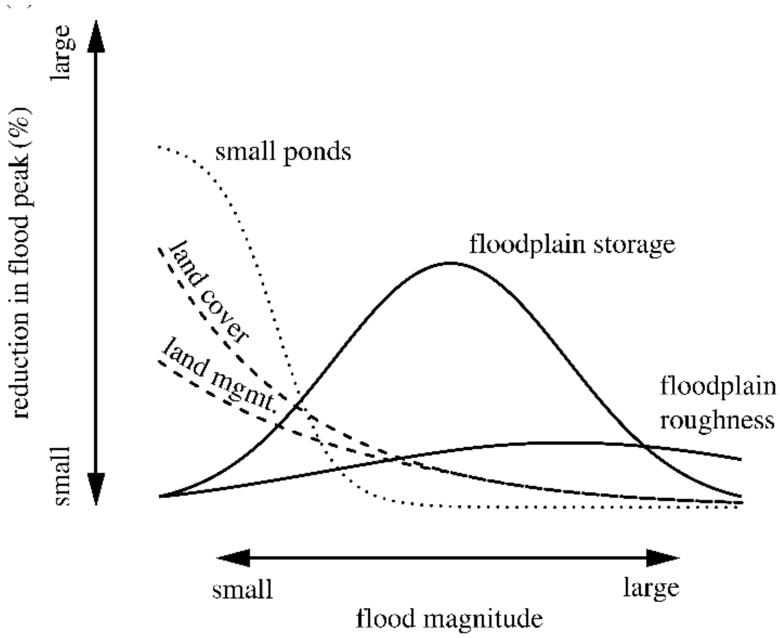
Table 4-1 International experience in urban and peri-urban forests

Country	City	Name	Goal	Description
Germany	Berlin	Biotope Area Factor (1984)	To regulate new urban development with an ecological approach	Part of the area to be developed is to be used for green spaces in which the original vegetation is to be kept or new plant cover planted. Guidelines are provided for landscape planning and design, species protection, and conservation. One of the main advantages of the Biotope Area Factor is that it is flexible in the design of the urban forest and enables stakeholder participation. Since the Biotope Area Factor was introduced in the design and planning of green areas, the provision of vegetation in heavily populated areas has significantly reduced the impacts of climate change, such as heatwaves, flooding and storms
Sweden	Mälmo	Green Space Factor (2001)	To regulate urban development for new urbanization areas using an ecological approach	The approach is similar to the Biotope Area Factor, with various versions and biotopes
USA	Seattle	Urban Forest Stewardship Plan Seattle Green Factor	• To create an ethical model of urban forest management for all stakeholders • To make specific improvements with a view to achieving a net increase in the functions of urban forests and the associated economic, social and environmental benefits • To increase forest cover by 30 percent • To strengthen the health and longevity of urban forests, improve the quality of species and eliminate invasive species	The management plan is framed within the Trees for Seattle Strategy, which brings together all efforts on forests in the city. A section of the strategy focuses on the design and safety of street trees and their role as elements for reducing driving speeds, crime and domestic violence without reducing the important aesthetic values they provide. The Seattle Green Factor is an adaptation of the Mälmo Green Space Factor, which is being incorporated into other cities in the United States of America
Australia	Sydney	Greening Sydney Plan, 2012	• To protect and maintain existing urban forests • To increase canopy cover • To improve biodiversity • To increase knowledge and commitment in the community	Strategy aimed at developing and protecting urban and peri-urban forests
Sweden	Umeå	Young urban forests	To develop new urban forests	Young urban forests have been created by regenerating previous forests or by planting trees, the latter seeking to perform predetermined functions entailing specific forest treatments that need to be permanently maintained. An experimental study was carried out in Umeå on a 2.1-hectare plot that had been reforested 20 years before. In this forest, 12 small forest compartments were created using various thinning methods, with different functions and traditions, creating areas for relaxing and meditating in isolation; children's play areas; natural-looking spaces; areas subject to heavy management for aesthetic purposes; and various samples of local forest types
Norway	Akerselva (Oslo)		To create multisensory environments	A corridor was created along the Akerselva River to enable downtown residents to travel to nearby parks hosting 14 "quiet areas" for contemplation
USA	New York	Program PlaNYC: 2030	To ensure accessibility	The aim is for every inhabitant to have a green area within a 10-minute walking distance
Singapore			To provide opportunities to be outdoors and enjoy nature	The integration of 200 km of pathways through elevated runways to enable inhabitants in different parts of the city to access parks
Japan	Nagoya		To promote actions to actively support nature conservation	Conserve 10 percent of land next to the city boundaries as an unmanaged area and protect it as a nature reserve
USA	Phoenix		To encourage actions to actively support nature conservation	17 000 hectares of desert were purchased to avoid the negative effects of urban expansion, and this area was designated as a nature conservation site
USA	Portland		To invest in social infrastructure that helps urban dwellers understand nature	Investment of more than 5 percent of the annual city budget in biodiversity. The aim is to attain one of the highest tree-canopy covers among the nation's cities (29.9 percent)

Source: Calaza *et al.,* 2018

The trial showed the lake's water quality improved and fish stocks increased – a win for the ecosystem and local communities. Since then, reconnecting lakes then became part of China's national policy, and as a result a further 50 lakes were reconnected in similar ways, helping to restore important wildlife habitats along a large stretch of the central Yangtze river.

The impact on flood flows varies according to the relative scale of the nature-based activity (catchment to individual action) - Figure 4-14 – but even small reductions in peak floods can have positive outcomes for the scale and cost of associated built infrastructure (Sayers *et al.,* 2016).



Source: Dadson *et al.,* 2017

Figure 4-14 Hypothesized impact on flood flow by return period

System based approaches in dams and hydropower

The increasing importance of hydropower, growing concentrations of dams in linked river basins, and potential for more rainfall variability due to climate change, underline the need for effective hydropower planning in Africa. The Nature Conservancy has been developing and demonstrating an approach to hydropower (Hydropower By Design) that adopts a system scale planning approach and combines natural and conventional infrastructure to deliver sustainable hydropower outputs at lower cost. This includes removing dams where possible and embedding a concept of regional environmental flows. Two examples are below.

Dam removal to restore free-flowing rivers: US experience of dam reoperation: FERC (US) has asserted the right to require a dam to be removed if it is in the public interest (Bowman 2002), with the prominent example of Edwards Dam on the Kennebec River (Maine, USA). In other cases, dam owners have decided that the mitigation conditions required for license renewal, particularly for fish passage, were too expensive and so they pursued options for dam removal; examples include the Sandy River (Oregon, USA) and the Klamath River (California, USA). On the Penobscot River (Maine, USA) the FERC relicensing processes was used to implement a basin-scale solution to balancing hydropower generation with dam removal to restore free-flowing river conditions.

Regionalizing environmental flow management: Connecticut – regionalized dam operating rules: Well-considered environmental flows minimize the ecological impacts of new water developments, direct water development to the least-sensitive water bodies, and prioritize flow restoration efforts.

Several states within the United States are accomplishing these objectives through new streamflow criteria or standards, expressed as limits on hydrologic alteration (Kendy *et al.,* 2012). Streamflow standards, which apply to water bodies, are implemented as operating rules that apply to dams or as withdrawal permits that apply to water users (Kendy *et al.,* 2012). Generally, water withdrawal limits protect existing streamflow from future development. Restoring depleted flows may require additional policies, such as Oregon's Conserved Water Statute. By limiting flow alteration, environmental flow standards also catalyze policies that promote water markets and other water sharing mechanisms that reduce stresses on streamflow (Opperman *et al.,* 2017).

4.6 Emerging capabilities across Africa

Our review highlights the growing interest and capability in several aspects of SWI across Africa. Many initiatives have emerged with international support focused on building capacity in sustainable water management systems. For example, the EU-funded Zer0-M project 'Sustainable Concepts Towards a Zero Outflow Municipality' established pilot systems at Chorfech in Tunisia, SEKEM in Egypt and El Attaouia in Morocco, combining constructed wetlands with water saving, water harvesting and re-use technologies, as well as establishing a fully equipped Training and Demonstration Centre in each country to build capacity amongst local officials, researchers and engineers. Programmes such as those supported by the AfDB, networks (such as WWF), international projects such as the Zer0-M centres of expertise, new financing opportunities (e.g. as provided by GEF and GCF) and ongoing research activity (e.g. in Algeria, Botswana, Burkina Faso, Cameroon, Ethiopia, Ghana, Kenya, South Africa and Uganda) demonstrates the significant opportunity that many African countries see for SWI. Some centres of expertise (providing opportunities for capacity development and potential scaling up) are briefly introduced below.

- **Egypt:** The NRC (The National Research Centre) was involved in 11 of the 19 papers we found on constructed wetlands in Egypt. The Water Research & Pollution Control Department of the NRC was involved in the Zer0-M project, and established a Training and Demonstration Centre to treat effluent from an apartment block opposite the NRC compound. This included a range of sustainable water technologies including different types of constructed wetland and a composting reedbed for drying sludge, with the treated effluent used for watering ornamental plants and fruit trees (AEE-INTEC, 2009). NRC then developed a demonstration plant at SEKEM organic farm and school, where the treated effluent was used for irrigation.
- **Morocco:** The IAV (The Institut Agronomique et Vétérinaire Hassan II; Wastewater Treatment and Reuse Unit) in Rabat was the Zer0-M partner in Morocco. They have established a Training and Demonstration Centre at their site, which treats wastewater from a sports centre using a range of constructed wetlands. The treated water is used for landscaping and toilet flushing. They also developed a demonstration plant at El Attaisir Hamman, including a solar water heater and constructed wetland for recycling greywater.
- **Tunisia:** CERTE (The Centre de Recherches et des Technologies des Eaux) established a Training and Demonstration Centre at a student hall of residence as part of the Zer0-M project. This included a range of sustainable water technologies including a constructed wetland, and the technologies are now being used as a basis for the design of efficient water systems of all buildings of the Ministry of Education in Tunisia (AEE-INTEC, 2009). CERTE then developed full scale constructed wetlands at Chorfech.
- **Tanzania:** The Waste Stabilisation Pond (WSP) and Constructed Wetland Research and Development Group at the College of Engineering and Technology, University of Dar es Salaam has been researching wetlands since 1998, in partnership with universities in Denmark and Belgium, and has overseen the construction of 27 full scale wetlands at schools, prisons and

small communities in Tanzania, Kenya and Uganda. They have produced design and operation guidance and also information on the costs, benefits and enabling factors needed for CWs (Kimwaga *et al.,* 2012; 2013; see also material on http://www.constructedwetlands.net/tan_cw.html).

- **South Africa:** The South African Water Research Commission recently established a Community of Practice on Water Sensitive Design (covering both urban and rural applications), which is being run by the University of Cape Town. They have produced guidelines for Sustainable Drainage and Water Sensitive Urban Design (Armitage *et al.,* 2014), and have compiled a database of case studies[8] . The Department of Water Affairs also hosts South Africa's Artificial Recharge Information Centre, with assistance from Groundwater Africa, a consultancy involved with the Windhoek scheme[9]. The Durban Research Action Programme is aiming to establish a centre of excellence on reforestation, based at the Buffelsdraai Community Reforestation Project site.
- **Ethiopia:** The African Regional Centre of Ecohydrology in Addis Ababa is the result of a seven-year collaboration between the Ethiopian students and governmental officers in the UNESCO European Regional Centre for Ecohydrology in Poland, followed by five years of scientific cooperation between that Centre and the Ministry of Water, Irrigation and Electricity of the Federal Democratic Republic of Ethiopia with financial support from the Polish Aid Programme. Staff from the ministry were educated in ecohydrology, and several nature-based solution demonstration sites were constructed. An International Symposium on Ecohydrology for Water, Biodiversity, Ecosystem Services and Resilience in Africa was held in 2016 in Addis Ababa, followed by an Advanced Training Course in Ecohydrology and systemic biotechnology solutions (Zalewski *et al.,* 2018).
- **Kenya.** Lake Naivasha Sustainability Initiative provides a research base around Lake Naivasha, which has been evaluating the complex interactions and trade-offs between different stakeholders around the lake (see example in Section 4.4).

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[8] http://www.uwm.uct.ac.za/

[9] http://www.artificialrecharge.co.za/

5 Conclusions

5.1 Africa: Development context

Recent decades have seen African development against a backdrop of significant losses in biodiversity due to climate change and unsustainable resource exploitation (including the development of large-scale monocultures such as sugar cane, and the loss and fragmentation of very specific habitats needed to sustain unique mega-fauna such as mountain gorillas and cheetahs). These unsustainable practices continue despite the well-established relationships between healthy ecosystems and socioeconomic well-being.

Achieving Sustainable Development across Africa will require bespoke approaches that carefully balance Africa's unique ecosystems and biodiversity with the pressures of industrialisation and shifting demographics, recognizing that healthy ecosystems are needed to underpin sustainable economic growth and human wellbeing in the long term. The health of freshwater ecosystems will be central in enabling these goals, including the maintenance of functioning rivers, wetlands, lakes and aquifers to sustain a reliable and clean water supply to the developing continent. This challenge is recognised globally but Africa has some specific characteristics that make it even harder:

Rapid urban development: An opportunity as well as a challenge: A strong mega-trend for Africa is rapid urbanization. By mid-2030s, it is expected that half of the population will live in cities and towns, with the proportion of urban dwellers peaking at 56% around 2050. This will fuel water demands by the manufacturing and energy sector as well as households. Water demands for food production will remain high. While Africa's rapid urbanization presents many challenges, it also represents an opportunity to turn African cities and towns into engines of positive social, political and economic transformation. Water will be central in this transformation and how water infrastructure, allocation and re-allocation decisions are made will either act to facilitate healthy ecosystems and social well-being or undermine them. These decisions will play out differently across Africa, reflecting the different stages of development and varying water availability in different countries. The relatively low level of water infrastructure and institutional investment in Africa presents a major challenge; but also presents an opportunity for African countries and organisations to learn from global experience and leap frog the expensive water management mistakes made by other countries, making the right investments to deliver sustainable water infrastructure for the benefit of nature, people and business.

Local ecosystem services: The life-blood of many communities: Despite continued formal and informal growth of urban centres in Africa, many communities will continue to be dependent on local ecosystem services drawn from urban, peri-urban and surrounding agricultural landscapes. Ensuring healthy ecosystems in this context will be a pre-requisite of longer term social well-being. Investing in natural infrastructure can ensure the continued provision of a range of ecosystem services that are essential for development, including reduced disaster risks (e.g. stabilising surface soils to reduce the chance of a mud slide; slowing the flows and reducing flood peaks) and providing food and resources for local people (e.g. through urban, peri-urban or rural agriculture; and harvesting of bio-resources for building materials or livelihoods). At the same time, well-planned natural infrastructure can contribute to achievement of biodiversity targets, helping to meet SDGs 14 and 15 (Life below water; Life on land) and climate mitigation and adaptation targets (SDG 13). There is not an exact match between biodiversity hot spots and delivery of ecosystem services, but there is broad evidence that more biodiverse ecosystems are often more productive, deliver higher levels of regulating and cultural ecosystem services and are also more resilient to future shocks

(Smith et al., 2017). Components of sustainable water infrastructure investments may therefore also form part of the investment necessary to meet biodiversity, ecosystems and climate goals of SDGs.

5.2 Emerging lessons from across Africa

Despite many articles stating the urgent need for more sustainable management of water resources, and citing evidence of the potential benefits of adopting sustainable water infrastructure practices to help tackle Africa's development challenges, relatively few examples have been delivered in practice. Those projects that have been delivered, and those that have been attempted and failed, present several important lessons. The most important of these reflect four themes:

Participatory co-design of infrastructure plans: 'Participatory' projects can involve a range of levels of engagement, from a cursory consultation to a fully co-designed project where local communities start to self-organise to continue working towards the objectives even after the end of initial funding. This 'depth' of buy-in is essential to ensure the long-term sustainability of the water infrastructure. In particular, meaningful participation: **(i)** ensures stakeholder buy-in, a pre-requisite to the on-going and correct operation and maintenance in the long term (helping to avoid problems of incorrect operation or vandalism (Kimwaga *et al.,* 2013)) and, **(ii)** enables local and indigenous knowledge to influence the planning processes (often a rich evidence stream, for example local communities often have good knowledge of local drainage problems in informal settlements (Fitchett 2016), or the most appropriate grazing management strategies in drylands (Reid and Orindi, 2018)).

Provision for operation and maintenance funding: Many development aid and loan programmes focus on providing financial support for capital investment only. This unduly biases proposed solutions towards capital intensive, low maintenance, approaches and reinforces a conventional built infrastructure, project-based paradigm, making it difficult to promote more adaptive management responses. This routinely leads to 'stranded assets' that local authorities and communities no longer have the resources to support (often both in terms of operation and maintenance) – such as wastewater treatment plants that cannot be operated because of the high cost of electricity (Kimwaga *et al.,* 2012). Not only does this lead to abandoned structures and technologies and a wasted investment, but it may also have significant negative impacts on associated ecosystems (if polluted effluents are no longer treated or environmental flows no longer maintained). As with conventional built infrastructure, natural and hybrid infrastructure (such as constructed wetlands, SuDS and land management) all require ongoing maintenance to ensure success.

Upgrading and retrofitting of existing settlements: Designing water sensitive cities in the context of formal urban development represents an important and effective investment opportunity; an opportunity that, subject to capacity and funding, is relatively straightforward (although often not done). Even if successful, these approaches will not address the urgent problems within Africa's vast informal settlements where investment in basic infrastructure is lacking partly because authorities view the settlements as temporary and unauthorized, and do not wish to confer legitimacy on them. In areas that are inherently unsafe (e.g. at high risk of major life-threatening floods or landslides) resettlement in safer areas may be the only option. However, in other areas a new paradigm is emerging, to quote:

"There is growing consensus internationally that slums can best serve citizens and nations if treated not as outlaw places to be eradicated, but as emergent communities to be supported through incremental, in situ slum upgrading processes understood broadly as cooperative efforts among residents, community groups, non-

profit organizations (NGOs), government and businesses aimed at improving basic services and putting into motion the economic, social, institutional and community activities needed to support community well-being. …For example, state policy in South Africa has increasingly embraced upgrading". Jiusto and Kenney 2016.

The *'raze and replace'* approach is often divisive and politically unpopular (Douglas, 2016). More constructive approaches to upgrading involve working with local communities to implement incremental, small scale, projects in an adaptive and flexible way. Jiusto and Kenney (2016) cite an example of a 'reblocking' approach where:

"In 2012, the WPI-CTPC contributed to an ambitious upgrading effort in Mtshini Wam, working closely with community members in partnership with the City of Cape Town and CORC, the Informal Settlement Network, and iKhayalami, a non-profit supplier of improved shack materials. Through an upgrading strategy called reblocking, all 250 shacks in the densely packed neighborhood were replaced and reorganized into two dozen tiny courtyard 'clusters' intended to improve security and allow road and infrastructure provision. In just a few months' time, working cluster by cluster, community members under local leadership replaced all existing shacks with improved quality shacks, without displacing anyone for more than a few days.[…] To improve stormwater drainage, each cluster was placed on a platform of compacted stone, rubble and concrete aggregate approximately 20 centimeters deep, with courtyards and combination walkway-roadway-stormwater channels dug into the aggregate. Substantial improvements have been made in the built environment at comparatively low cost, providing in the process dozens of temporary jobs for residents and many opportunities for skill and leadership development." Jiusto and Kenney 2016.

It is time consuming to engage multiple different groups of citizens to implement small scale and locally adapted solutions, but the results should help to ensure the long term sustainability of the project as well as building local community capacity, resulting in improved resilience, adaptive capacity and other socio-economic benefits.

Catchment-wide ecosystem-based adaptation and land management: Although the focus in this paper is on urban and peri-urban areas, the condition of the wider catchment (or increasingly the precipitation-shed) will directly affect downstream urban areas in terms of both water availability, water quality, disaster management (particularly floods, droughts and mudslides) as well as food security (crop and livestock productivity) and socio-economic factors. Developing strategic approaches to the planning and management of the sustainable water infrastructure that recognizes these multiple scales (from ensuring the continuing functioning and quality of Africa's 'water towers' and transboundary rivers, to local streams, and ditches, to urban homes and gardens) will require radically new ways of working that includes stakeholder participation at all stages of the project, and the transparent consideration of trade-offs e.g. between intensive agriculture with high short term yields and traditional agriculture or pastoralism with long term ecological sustainability and resilience. Good practice frameworks are emerging to guide this process (e.g. Tickner *et al.,* in press) and will need to be operationalized to deliver the potential long-term benefits such an approach promises.

5.3 Can Africa take the lead in sustainable water infrastructure?

Present day urban green space across Africa is low and much of Africa's future urban space is yet to be built. This means the opportunity for SWI is now - but the window of opportunity is finite. Recent years have seen the emergence of of a growing number of regional centres of expertise across Africa that, together with growing international evidence, are helping national, regional and local authorities to understand the need to ensure healthy ecosystems if the well-being of Africa's unique and diverse cultures, habitats and species is to be sustained. Africa can take a lead in the development of sustainable water infrastructure; if it does not, an uncertain future awaits.

6 The way forward

Successful development of a more strategic approach to water management that includes sustainable water infrastructure solutions will require a different way of working (in contrast to the technology-based top-down implementation approach that has characterized most water infrastructure projects in the past).

MDBs have a central role to play in facilitating this transition. As with any mainstreaming activity, this will take time. To make it happen, MDBs (such as the AfDB) will need to inform, influence and invest in sustainable water infrastructure (Figure 6-1).

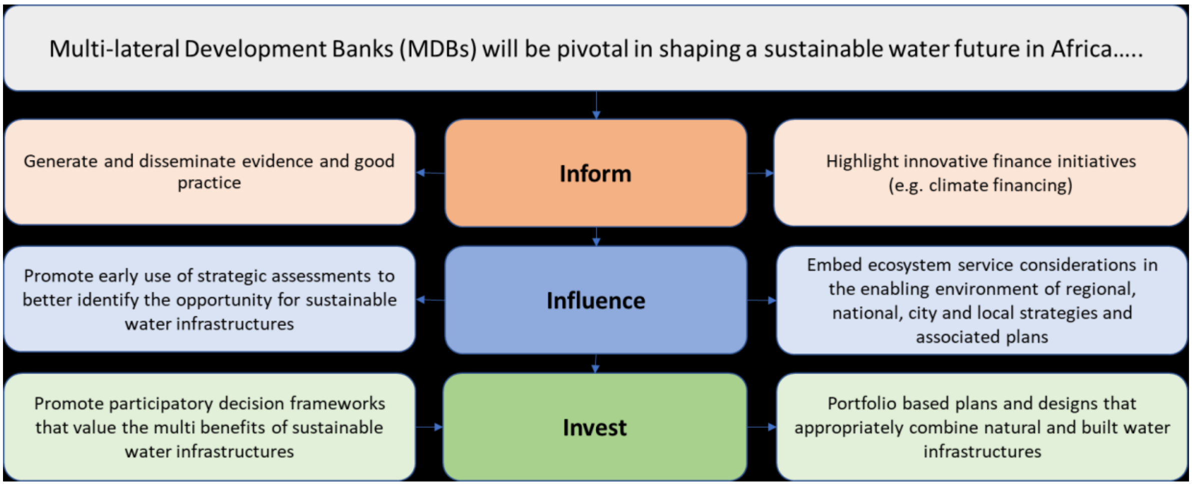


Figure 6-1 Role of Multi-lateral Development Banks in promoting sustainable water infrastructure

The specific activities under these heading are proposed below.

6.1 Informing

MDBs (such as the AfDB) need to continue to promote the concepts of sustainable water infrastructure as widely as possible through various media and networks in Africa (*e.g.* through events such as the Africa Water Week or AfriSan). This process of 'informing' will need to be associated with:

Generate and disseminate evidence: MDBs (working with others) have a central role in gathering and brokerage of authoritative evidence on the value of freshwater ecosystems and the contribution that natural and nature-based infrastructure can play in concert with built infrastructure to support Sustainable Development. This includes developing accepted modelling-based evidence (including for example opportunity mapping) but also highlighting where freshwater ecosystem services have been successfully promoted as part of urban and peri-urban developments, and the contribution they have made (whether in terms of water quality, quantity, flood or pollution management).

Highlight innovative finance initiatives: MDBs are well-placed to help promoters identify the opportunities afforded by emerging financing and regulatory initiatives that support innovative sustainable water infrastructure solutions. New financial and legal mechanisms for the preservation of ecosystem services (such as the GEF and GCF, biodiversity offsetting, payment for ecosystem services, and employment-based initiatives such as Working for Water) are expanding and provide emerging opportunities. Ensuring decision-makers and stakeholders are aware of these opportunities (including within the MDBs themselves) will provide a springboard to take-up.

Disseminate good practice: Promoting good practice in developing infrastructure plans that reflect the value of ecosystem services and water (e.g. in water sensitivity planning – see Figure 4-9 and strategic approaches – see WWF 'golden rules' in Section 3.1). The dissemination of good practice frameworks should be supplemented with pilot examples that build tangible evidence based on African examples and demonstrate the advantages in terms of cost and performance of blended infrastructure responses.

6.2 Influencing

Overall most trends (economic growth, rapid urbanization and population growth, climate changes) point to an increased need for infrastructure development and sharpening of water competition. Consequently, it will be imperative to have effective governance systems in place to manage water allocation and re-allocation within and between countries while working towards country priorities of efficiency, equity and sustainability. Importantly this is not only about allocating water, but also governing the social and economic benefits provided by water resources and related services. MDBs have a powerful voice that can be used to influence these decisions, including:

Embedding ecosystem services in the enabling environment: Whilst different jurisdictions across Africa will operate under different ***policy, legal and regulatory frameworks***, influencing these frameworks presents a significant opportunity to catalyze change. In particular MDBs have a role to influence sustainable management of protected areas and river systems (particularly transboundary rivers). MDBs also have a role to influence institutional co-ordination and the engagement of civil society to ensure ***participation in, and accountability for***, the decisions made. MDBs have a role in ensuring policies and institutional frameworks are capable of delivering WASH services 'on-the-ground' and are capable of reporting on success and failures. MDBs are well-placed to establish standardised systems and processes for open and transparent reporting (building upon initiatives such as the WWF River Report Card) and enabling civil society to help define, analyse and critique monitoring data (e.g. as in Uganda, where CSOs are active in Joint Sector Reviews); a capability that is currently lacking despite initiatives such as the Joint Monitoring Programme.

Developing good practice that enables the early consideration of sustainable infrastructure approaches: An effective means of influencing behaviour is to establish what is considered 'good practice' and encourage decision makers and planners to use it, and investors to demand its use. MDBs have a role in providing these frameworks (with direct internal influence). Such guidance, as a minimum, should promote wide stakeholder participation and ensure that opportunities to embed sustainable water infrastructure practices are considered as early in the planning and project life-cycle as possible (avoiding the common pitfall of adopting conventional built infrastructure approaches as the preferred solutions too early in the options appraisal process).

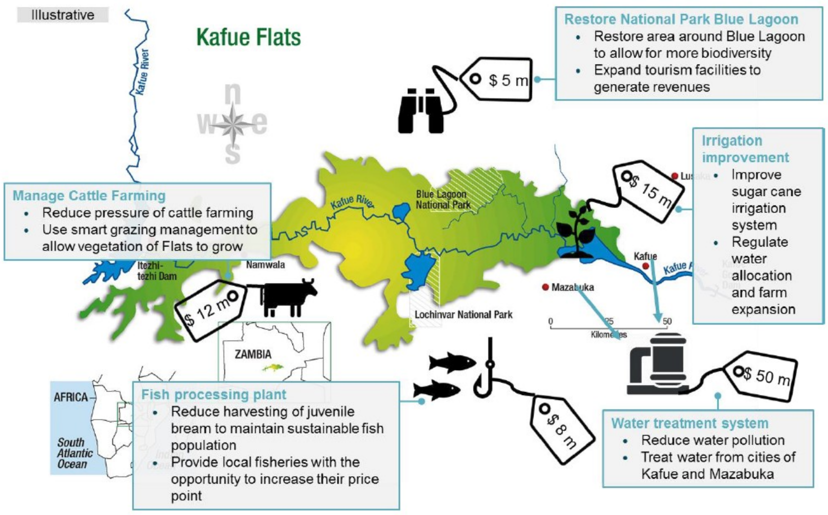
6.3 Investing

The development of mechanisms for innovative financing is central to Africa's future: to enable appropriate water investment (in systems-based approaches across countries, in watersheds and within cities) in a way that fosters new partnerships between business, government and civil society to support the achievement of development goals.

Traditionally, donors and multilateral financing agencies have played an important role in promoting improved approaches to environmental and social issues at the project level, and this leading role is once again needed to promote more strategic portfolios of activities that are necessary to deliver sustainable water infrastructure. Their direct influence may be more limited than it used to be: their role as infrastructure financiers is now often eclipsed by other sources of finance in many countries; technical assistance funds are also limited, and improved practices ultimately depend on client countries' governments' interest in accepting advice. Nevertheless, to the extent that member governments accept the multilaterals' role as 'knowledge banks', MDBs are in a good position to advise on planning reforms and influence the investment case by:

Promoting participatory decision frameworks that appropriately value multi-benefits: Investment seeks to return value. MDBs have a role in promoting the true value of water in investment decisions; a process that relies upon local and regional stakeholders to elicit these values and an investment framework capable of appropriately representing the full range of short and longer-term benefits.

Promoting use of multiple sources of investment to deliver blended infrastructure: Individual investors often bring particular requirements and focus (Figure 6-2). This presents a challenge and an opportunity for MDBs to coordinate investments in the context of a portfolio of natural and built infrastructure measures. As set out in the WWF 'Bankable Projects' initiative, different aspects of portfolio response will have different characteristics (such as asset type, size, funding needs and timelines) and thus will be more suited to different types of funding. Instead of seeking to finance the whole portfolio with the same type of funding (with attendant complexities) MDBs could adopt the role of facilitating a blend of financial mechanisms to deliver sustainable water infrastructure. These may include private sector participation (PSP), commercial finance, micro financing, climate finance (such as the Green Climate Fund). The capacity needed to apply for, and coordinate, funds through multiple mechanisms is however high and often too high for local stakeholders to pursue. MDBs have a pivotal role in supporting proposals to these funds in way that enables a blended portfolio of natural and built infrastructure (supporting ecosystem health and social well-being) to be delivered.



Source: WWF, 2018

Figure 6-2 Illustrative example of a basin's portfolio of projects

The role of MDBs is changing and can transition from lender to leader. This will be challenging but the opportunity is significant to promote international good practice and shape Africa's water future.

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Appendix 1: Literature search

We searched academic and grey literature in July 2018 as well as consulting personal contacts.

For academic literature we used Web of Science to search for the following strings in the title, abstract or keywords:

> (Africa or Algeria or Angola or Benin or Botswana or Burkina or Burundi or Verde or Cameroon or Chad or Comoros or Congo or Ivoire or Djibouti or Egypt or Eritrea or Eswatini or Swaziland or Ethiopia or Gabon or Gambia or Ghana or Guinea or Kenya or Lesotho or Liberia or Libya or Madagascar or Malawi or Mali or Mauritania or Mauritius or Morocco or Mozambique or Namibia or Niger or Nigeria or Rwanda or Principe or Senegal or Seychelles or Leone or Somalia or Sudan or Tanzania or Togo or Tunisia or Uganda or Zambia or Zimbabwe)
>
> AND ("nature-based" or "green infrastructure" or "ecosystem-based" or "suds" or "sustainable drainage" or "sustainable urban" or "green urban" or ecohydrolog* or "constructed wetland" or "constructed wetlands" or "green roof" or "green roofs" or "recharge basin" or "recharge basins" or "natural flood management" or "natural stormwater management" or “water sensitive urban design” or “integrated urban water management”)
>
> AND (*water OR flood*)

This yielded 365 hits. Bibliographic details and abstracts of all references were recorded in a spreadsheet. The abstracts were read to determine if the article was relevant, and for relevant articles further details were extracted and recorded in the spreadsheet, including the location, implementation status, type of intervention, and African or non-African organisations involved in the study (as authors, funders or collaborators). The most relevant articles were followed up by reading the full text (if available), searching for further details online and/or attempting to contact the authors for further details. Of these, around 200 hits were relevant. The majority of these (<100) related to constructed wetlands.

Simpler searches were carried out in Scopus and Google Scholar (where limits on search string length prevent the full query above). Scopus is useful for articles that are still ‘in press’, which are not included in Web of Science, and yielded an additional 7 relevant hits since 2015.

Google Scholar is useful for books, theses, conference proceedings and smaller publications. Time and resources did not permit a full search but a limited search was carried out using:

Africa and ("nature-based solutions" or "green infrastructure") and (*water* or flood*)

This yielded 247 results but most were very general studies of NBS and not specifically relevant to the African context. From the first 100 hits, only one was additional and relevant so the rest were not examined.

Grey literature was searched using the following sources:

- References provided by AfDB in the original concept note and through subsequent discussions and comments on the inception report.
- Search for existing relevant projects on the websites of the African Water Facility and World Bank. This was hindered by the lack of tags for “green infrastructure” or “nature-based solutions”, which were seldom mentioned.
- Search of case study websites such as the Nature-based Solutions Initiative (http://www.naturebasedsolutionsinitiative.org/).
- General search of the www using search terms such as “Africa, nature-based solutions, water”.