Nature-based solutions for flood mitigation

Discussion Paper

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Content

About this paper

This paper is one of a three-part series of discussion papers produced under the Building Resilience and Adapting to Climate Change (BRACC) programme in Malawi. The papers aim to synthesise existing evidence on nature-based solutions for flood control, watershed management, and early warning systems in Malawi. They also highlight existing knowledge and policy gaps, and identify potential areas for further research on the three topics.

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Acronyms

BRACC	Building Resilience and Adapting to Climate Change
CBA	Cost-Benefit Analysis
DRR	Disaster Risk Reduction
GoM	Government of Malawi
MSRBMP	Malawi Shire River Basin Management Programme
MWSIP	Malawi Watershed Services Improvement Project
NBS	Nature-Based Solutions
NRS	National Resilience Strategy
TDR	Triple Dividend of Resilience
WTP	Willingness To Pay
WWF	World Wide Fund for Nature

1. Introduction

This paper has been commissioned by the BRACC Knowledge and Policy Hub (the Hub) to synthesise evidence on the role that nature-based solutions (NBS) could play in mitigating flood hazard risk in Malawi. Demand for research on this topic emerged from dialogue between the Hub and BRACC's wider stakeholder network – in particular government partners, donors and programme implementing partners.

The paper draws on a wide range of literature – published and grey – from Malawi and further afield to address the research questions set by the Hub (see Box 1). It covers: flood risk and response in Malawi (Section 2); the types and technical features of NBS for flood mitigation, focusing on interventions likely to be most applicable in Malawi (Section 3); current evidence on NBS impacts and implementation challenges, drawing on lessons learned from Malawi, sub-Saharan Africa and elsewhere if relevant (Section 4); methodologies for evaluating NBS for flood mitigation, particularly when part of hybrid, grey-green portfolios (Section 5); and finally (in Section 6) lessons learned and a potential research approach that could be further developed. Key terms and definitions used in the report are described in Box 2.

Box 1. Research questions

This paper aims to deepen understanding of the role NBS could play in flood mitigation in Malawi, drawing on emerging understanding and lessons learned in Malawi and internationally.

Specifically:

1. What kinds of NBS might help mitigate flood hazards?
2. What are the relative resilience dividends of investing in NBS compared with 'grey' infrastructure based on experience to date?
3. What approaches/methods can or could be used to evaluate NBS options for flood mitigation, either separately or as part of a grey-green portfolio?

The desk-based literature review was based on searches in *Google Scholar*, searches in project databases and input from BRACC partners and external experts. Key informant interviews and background conversations with members of the project team and some of their Malawi partner contacts have also informed this report and are acknowledged, though specific attributions are avoided.

This is a Discussion Paper, not a comprehensive critique or appraisal of flood mitigation options in Malawi. The views expressed are the authors' own. The paper builds on a previous briefing note on disaster risk reduction (DDR) experience in Malawi[1], and also links to a separate Discussion Paper on watershed management, including policies and projects, in Malawi.[2]

Box 2. Key terms

There is no agreed definition of NBS, but the most commonly used definitions all allude to the need to consider the multiple benefits provided by NBS and the importance of taking a proactive role in supporting them. The most widely used definition is credited to the International Union for Conservation of Nature (IUCN, 2016):

"Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges, effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits."

All definitions recognise the fundamental role ecosystems play in addressing the challenges associated with improving degraded ecosystems, and 'working with nature' to enhance water security, manage extreme weather events and mitigate and/or adapt to the impacts of climate change.

Extreme weather events include floods and droughts. In this report we focus on fluvial (river) floods which occur when the amount of water in a river exceeds the channel's capacity. They are caused primarily by the downstream flow of run-off generated by heavy rainfall on wet or impermeable ground. A flood hazard is characterised by the depth of water at locations where it may cause harm, and also by the velocity of that water, the rate of rise of water levels, the duration of inundation and flood-induced changes in water quality.

Recent years have seen growing interest in the role NBS can play in reducing the frequency, magnitude and duration of flood hazards, defined here as flood (hazard) mitigation. In broad terms, NBS aim to reduce flood hazard by modifying land use and land management, river channels, floodplains and reservoirs (where present) – restoring or sustaining catchment processes that have been affected by human intervention. Importantly, they also seek to sustain or enhance other potentially significant co-benefits, including ecosystem services (aquatic, riparian, terrestrial) such as biodiversity, soil and water conditions, carbon sequestration, agricultural productivity and improved public health and well-being.[3,4]

2. Country context: flood risk and response in Malawi

Malawi is vulnerable to a variety of natural hazards, most notably floods and droughts, but also strong winds, earthquakes and landslides. In this section we look briefly at flood risk in Malawi, focusing mainly on flood hazard and flood mitigation rather than vulnerability and exposure. We then turn to policy responses and strategies, and finally to projects with a flood mitigation objective.

Context – natural hazards

Among weather-related shocks, droughts and floods have had the greatest impact on the country's economy, livelihoods, and infrastructure. **Between 1946 and 2013, floods accounted for 48% of major disasters, and their frequency and severity is increasing**. They have occurred in 16 out of the country's 28 districts, in both rural and urban areas. The Lower Shire Valley in southern Malawi is the most flood-prone and affected area.[3]

Over the past five decades, the country has experienced more than 19 major flood and drought events, and their intensity and frequency is expected to increase as climate change accelerates.[4]

The country has recently experienced consecutive disasters, with devastating floods between 2014 and 2015 followed by drought, leading to widespread food insecurity, displacement and economic losses. **In March 2019, heavy rains associated with Tropical Cyclone Idai again caused severe flooding, particularly in the south of the country**. Roughly 975,000 people were directly affected across 15 districts and two cities, and 90,000 people were displaced (over 60% of whom were women). The Government of Malawi (GoM) declared a State of Disaster in 13 districts and two cities in the Southern Region and two districts in the Central Region. Loss and damage costs to infrastructure and the economy were estimated at approximately US$ 220 million.[4]

A short and intense rainy season, combined with the loss of forest cover and unsustainable agricultural practices in upper catchments, caused **high surface run-off, erosion, and downstream sedimentation**.[5] Heavy siltation of the Shire and its tributaries is causing: (a) high operating costs across the four major hydro-electric dams for annual dredging and turbine maintenance (approximately US$ 1 million per year); (b) dredging costs (up to US$ 100,000 per year) at Walker's Ferry pumping and water treatment centre, which supplies 95% of the drinking water to Blantyre, and higher average treatment costs to reduce turbidity in urban drinking water; and (c) loss of roughly one-third of the storage capacity of Mudi dam (supplying 5% of drinking water to Blantyre) due to siltation. Expected dredging costs are US$ 225,000 annually.[6]

Policy responses

Against this background, risk reduction, flood control, and early warning and response systems form a key pillar in the GoM's **National Resilience Strategy** (NRS) prepared by the Department of Disaster Management Affairs with support from donors and non-governmental organisations.[7] Under Pillar 2 of the NRS, flood prevention and control emphasises the need to improve (a) community risk assessment, training, and monitoring; (b) the assessment, planning and design of dykes, dams and river training; and (c) the design and implementation of multi-purpose flood-control infrastructure and 'landscape design'. Interventions are aimed primarily at 'high risk' areas in the Southern Region

(Machinga, Nsanje, Zomba, Chikwawa and Phalombe), plus Salima in the Central Region and Karonga and Rumphi in the Northern Region. The NRS builds on the GoM's National Climate Change Management Policy[8] and the National Disaster Risk Management Policy[9], which shifts to a more proactive risk management approach. Approval by Cabinet on the draft Malawi Disaster Risk Management Bill is still awaited.

Digging a little further on intervention *types*, the NRS highlights the importance of **conventional 'grey' infrastructure – dykes, dams, tanks etc. – but also catchment scale (landscape) management** through (for example) hillside stabilisation, riverbank restoration, wetland management and floodplain conveyance and storage, linked to wider policies around land use planning, forest restoration and watershed management. In other words, the role of NBS in flood mitigation (see Section 3), although the term 'NBS' is not used.

In terms of the **wider policy and institutional landscape**, the Ministry of Irrigation and Water Development, the Ministry of Agriculture and Food Security; the Ministry of Environment, Tourism and Wildlife; the Ministry of Natural Resources and Mining; and the Ministry of Energy all highlight interdependencies between flood mitigation / disaster risk management, agricultural production and livelihoods, water and energy security, and natural resource management more broadly.[A]

The wide-ranging **National Forest Landscape Restoration Strategy** prepared by the then Ministry of Natural Resources, Energy and Mining[10] highlights the co-benefits of NBS for flood management across each of its five priority areas: (a) agricultural practices/technologies (including conservation/climate-smart agriculture, inter-cropping with trees); (b) community forests and woodlots (primarily on common land); (c) forest management (mainly forest reserves/natural forests and plantations); (d) soil and water conservation (gully plugs, check dams, infiltration trenches – to increase infiltration and reduce runoff); and (e) river and stream bank restoration (increasing tree cover in denuded buffer zones for sediment control and flood mitigation). Indeed, the foreword of the strategy's sister document, the Forest Landscape Restoration Opportunities Assessment Report for Malawi[11] opens with: "*Nature-based solutions, such as Forest Landscape Restoration (FLR), offer an integrated approach to tackling environmental degradation and enhancing human well-being*." Box 3 highlights one piece of analysis from the Opportunities Assessment on identifying priority areas for flood mitigation interventions.

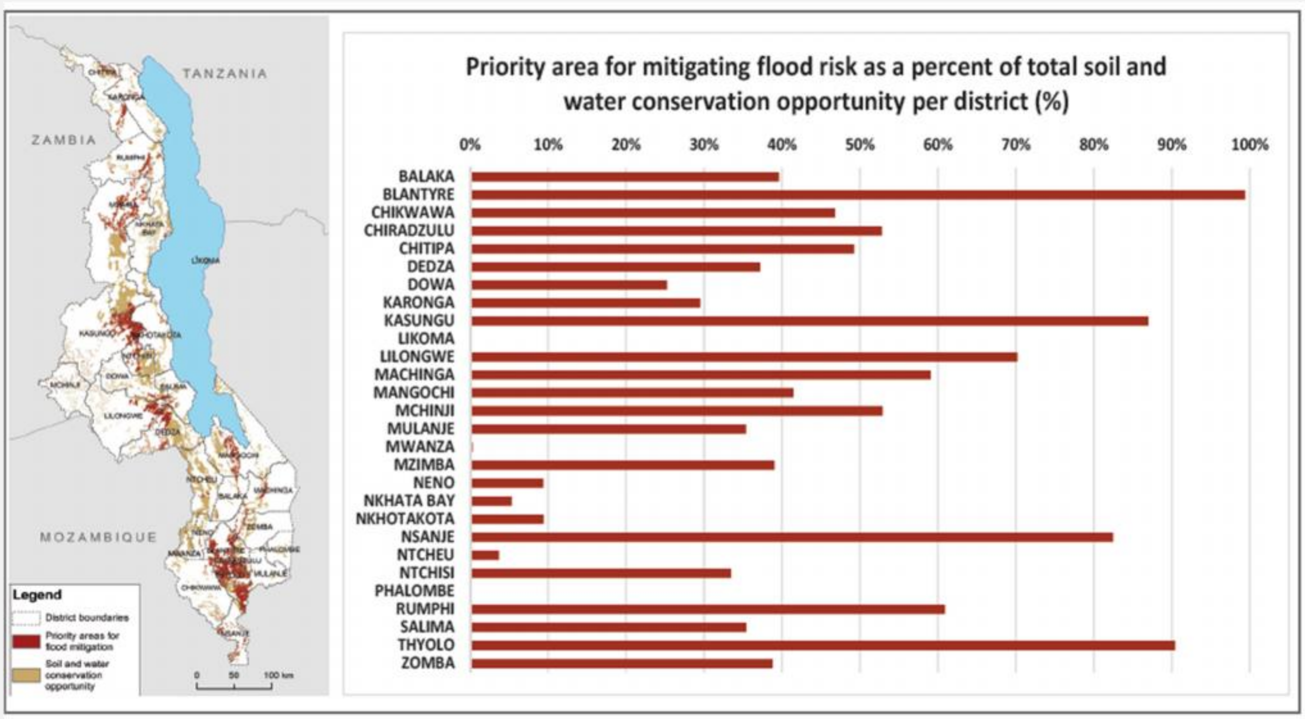
[A] Ministries were reorganised in March 2020. The Ministry of Agriculture, Irrigation and Water Development was split into two ministries – the Ministry of Agriculture and Food Security and the Ministry of Irrigation and Water Development. Meanwhile, the Ministry of Natural Resources, Energy and Mining was split into three ministries: the Ministry of Energy, the Ministry of Natural Resources and Mining and the Ministry of Environment, Tourism and Wildlife.

Box 3. Flood mitigation as a co-benefit of soil and water conservation

Figure 1 below, extracted from the GoM's Restoration Opportunities report, illustrates how multi-criteria analysis and opportunity assessment approaches have been used to identify priority intervention areas for 'forest-landscape restoration'. In this case, areas where soil and water conservation measures can be used in catchments upstream of areas with flood/landslide risk to stabilise water flow and soils to protect downstream crop land.

Soil and water conservation measures focus on small-scale infrastructure (check dams, terraces, infiltration trenches, and contour bunds) along slopes and hillsides aimed at regulating water flow during heavy rains to prevent erosion, gully formation and downstream flooding. More than one million hectares (11% of total country area) meet the criteria set for priority areas.

Figure 1: Priority areas for flood risk mitigation by district



Source[11]

Although the Department of Disaster Management Affairs currently 'owns' the NRS, leads on NRS sub-committees and working groups and leads on (and coordinates across sectors) strategy implementation at district level,[B] the **Ministry of Irrigation and Water Development appears to be the lead agency dealing with river flood forecasting and flood management more broadly**. Malawi's National Guidelines on Community Based Flood Risk Management were prepared under the auspices of its forerunner, the Ministry of Agriculture, Irrigation and Water Development, in 2018 on the back of the World Bank-funded Shire River Basin Management Programme[12] and include detailed guidance on options.

Despite well-considered and comprehensive strategies on DRR and overlapping policies on catchment management, forest landscape restoration, environmental stewardship, water management and agriculture – each with highlighted co-benefits in terms of flood management –

[B] See Section 5 of the NRS.[7]

policy implementation remains weak and poorly coordinated.[1,3] In particular, reliance on donor funding and project-based support, clientelism in how support is divvied up and entrenched problems of state capability and financing – particularly at local levels – have led to patchy progress at best (*ibid*). In other words, a sense that there have been cosmetic improvements in policy and strategy, achieved with significant consultant support, without much improvement in the *ability* of the state to effect lasting change. The lack of dedicated and sustained sources of finance for DRR remains a major problem[13], as does the lack of a 'whole of government' approach to tackling flood management. In addition, there remains a continued funding bias towards response over risk reduction and mitigation, which is reflected in insufficient budget allocations towards DRR.[1,14]

Projects and programmes

In terms of **projects and programmes**, flood mitigation features as either a primary objective or, more typically, a co-benefit of basin planning and watershed management interventions designed to prevent land degradation and erosion. The BRACC discussion paper on catchment protection and management[2] provides an overview of basin planning, watershed management, public works and wider climate-livelihood initiatives that address watershed management issues, including flooding. Here we pick out key flood *mitigation* highlights from those projects that identify flood mitigation as a key objective, looking at the mix of 'grey' and 'green' measures planned or implemented.

Reflecting its size and importance, the **Shire River Basin** has been the focus of most basin planning, watershed management and flood control initiatives. The majority of the country's rivers, including through Lake Malawi, drain into the Shire, which in turn drains into the Zambezi transboundary basin. The Shire is important to energy, water and food security, yet has 'hot spot' status for natural resources degradation, flood risk and soil erosion.[C] By far the biggest investor in these initiatives is the World Bank-International Development Association, through the Ministry of Water Development.

Following the severe flooding associated with Tropical Cyclone Idai in March 2019, the World Bank re-structured an ongoing drought management project into a broader disaster risk management initiative – the **Malawi Resilience and Disaster Risk Management Project**.[15] This includes new components on flood risk management and infrastructure investment updates to the 2012 Flood Risk Management Plan for the Shire River, a national multi-hazard risk atlas that includes flood risk mapping linked to different climate scenarios, a runoff and flood management and investment plan for Blantyre City, and investment in 'no regret' infrastructure for flood management.

Planned **infrastructure investments could be described as 'hybrid' in that they combine different structural measures, including NBS** (see Section 3). Flood defence and control measures include dykes, check dams, and drainage structures, as well as '*…nature-based solutions that will enhance natural habitat and increase biodiversity in addition to controlling siltation and runoff*'. In addition, the project will support restoration and conservation plans in hot spot micro-catchments upstream of critical infrastructure, dovetailing with the World Bank's new watershed services improvement project.

[C] Despite its hot spot status, significant natural habitats remain. Within the middle Shire (between the Kamuzu barrage and the steep escarpment south of Blantyre), scattered patches of mopane and Zambezian woodland remain. Grassland/mopane forest mosaics are also found, including those in the highlands around Zomba and Thyolo, and on Mulanje mountain (drainage from part of which flows into the Shire basin). The lower-middle and lower Shire basin still supports extensive woodlands – mostly under forest reserve, wildlife reserve and national park status, and the lower Shire also supports two extensive riverine wetland systems – the Elephant marshes and the Ndindi marshes – the latter shared with Mozambique.

The World Bank is also supporting the **Malawi Watershed Services Improvement Project** (MWSIP, 2020-31).[16] This follows a 'Series of Projects' approach over 11 years, with an estimated budget envelope of US$ 350-600 million. The aim is to '*…increase the adoption of sustainable landscape management practices and improve watershed services in targeted watersheds.*' Beginning with further work in the Shire River Basin (Phase 1), the project will then target degraded watersheds in the Linthipe, Bua and Dwangwa basins in the Central Region (under Phase 2), and then the North Rukuru and Lufilya basins in the north – Phase 3. In total, around 350,000 people are expected to benefit – mostly smallholder farmers – with a target of restoring at least 50% of degraded landscapes in priority catchments.

Although the project has no specific flood-related objective or key performance indicators, **flood mitigation is clearly viewed as an important secondary or co-benefit of watershed management**. As the World Bank states, both projects address two of the main structural weaknesses within Malawi: land degradation and flood and drought risk. Hence under the MWSIP, increases in vegetative cover, strengthened soil and water conservation practices (and physical structures) and riverbank protection/restoration are all expected to help mitigate the impacts of climate extremes. This is implemented through plans developed by Village Natural Resource Management Committees (at micro-catchment level) and their interface with higher-level Catchment Management Committees, the latter with mixed community, government and civil society organisation representation, but essentially government-convened. The suitability of such NBS-type interventions is likely to vary between the upper, middle and lower Shire due to differences in hydrology, topography and agro-ecology, a point highlighted by the World Bank in its project document annexes.

These ongoing projects draw many of their lessons from the **Malawi Shire River Basin Management Programme** (MSRBMP, 2012-18)[6], aimed at strengthening land and water management in a fast-degrading basin. This was the first project to support the GoM's long-term, multi-sectoral vision for the basin, laying the foundations for further work in the Shire and other basins (e.g. under the MWSIP). The project supported the development of new national guidelines on (a) integrated catchment management and rural infrastructure[17], and (b) community-based flood-risk management.[12] The latter includes an excellent overview of flood management considerations and international experience, and detailed guidance (via a 'toolkit' report) on prevention, protection, preparedness, early warning and response. Many of the measures considered could be viewed as hybrid solutions, mixing green and grey interventions (see Section 3).

The MSRBMP had three main components: (a) development of a river basin plan and supporting institution (the basin authority) to take on basin planning and management functions, including flood prevention and preparedness; (b) watershed management, aimed at the rehabilitation and management of four priority catchments and protected areas (c130,000 ha, or 5% of the basin area); and (c) infrastructure improvements aimed at improving the regulation of Shire River flows and flood mitigation. As in the projects above, flood mitigation was viewed as an important co-benefit of watershed management interventions under (b) aimed primarily at arresting land degradation and soil loss. However, the project also had a more overt flood mitigation objective under (c). Investment here was directed primarily at traditional flood management measures (the grey infrastructure of dykes, culverts, flood diversion structures and upgrades to the Kamuzu Barrage). **Hybrid interventions mixing grey-green (NBS-type) interventions were considered but discounted because of the need to generate quick wins, and because of the greater performance uncertainties associated with NBS** (personal communication).

The final evaluation of the programme was broadly positive, highlighting the numbers of structures built, restorative measures actioned, village action plans prepared, farmer field-schools set up, and areas under sustainable land and water management meeting or exceeding targets. Soil erosion was not directly measured despite an initial plan to do so, and there was **no direct measurement of hydrological baselines or impacts**.

Importantly, both the catchment management and flood-risk management guidelines continue to be used by the World Bank, at least. Both are viewed as comprehensive and fit for purpose (personal communication with external experts). The guidelines are unequivocal in stating that (a) watershed management is a long-term process that can take decades to generate catchment-level outcomes and impacts; and (b) **watershed rehabilitation through forest management and soil-water conservation can generate multiple benefits, but it is unlikely to have any noticeable impact on medium to very large floods**. Expectations around the long-term performance of watershed management and the NBS it embeds should be viewed in this light.

3. Types and technical features of NBS for flood mitigation

Nature-based solutions are **strategies that can protect, sustainably manage, and restore natural and modified ecosystems**. They harness natural processes and ecosystem services for functional purposes, such as managing the impacts of natural hazards and climate change.[18,19] Nature-based solutions encompass a wide range of actions and applications, including the protection and management of natural and semi-natural ecosystems, increasing green space in urban areas for cooling and flood abatement, and the application of ecosystem-based principles to agricultural systems, for example through conservation agriculture.[20]

The term NBS is synonymous with, or closely related to, a number of other terms commonly used to describe the same or similar measures. These include **natural infrastructure, green infrastructure, nature-based flood management, ecosystem-based approaches, engineering with nature, and building with nature**. For a more detailed exploration of the different terms, and the evolution in thinking around NBS, see Browder et al[19], Seddon et al[21], and Roe.[22]

Over recent years interest in NBS has grown rapidly, primarily out of concerns around **climate change and environmental degradation**, and the role NBS can play in climate adaptation (e.g. in mitigating drought and flood risk) and climate mitigation (carbon capture and storage – sequestration). As a result, NBS have been endorsed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services Global Assessment[23], the Climate Change and Land Report of the Intergovernmental Panel on Climate Change[24], and the Global Adaptation Commission Report[25], among other fora/institutions. At least 66% of Paris Agreement signatories include NBS in some form to help achieve their climate change mitigation and/or adaptation goals, though a recent synthesis of nationally determined contributions suggests much more could be done to harness their potential and 'up' the level of ambition.[20]

Drilling down further, there is growing interest in the **role NBS can play in reducing the frequency, magnitude and duration of flood hazards, defined here as flood mitigation**.[D] The latest World Economic Forum report ranks extreme weather events as the greatest risk to the global economy and human wellbeing.[26] Flooding is the most damaging disaster in the world, accounting for nearly half of all weather-related disasters worldwide since 1995.

In broad terms, **NBS aim to reduce flood hazards by managing land use, river channels, floodplains and reservoirs (where present) within the wider catchmen**t, rather than managing flood hazard locally at the point where flooding occurs. Importantly, they also seek to sustain or enhance other potentially significant co-benefits: enhancing ecosystem services (aquatic, riparian, terrestrial) including soil and water status, carbon sequestration, agricultural productivity and biodiversity[27]. In contrast, grey infrastructure generally provides a single benefit, e.g. a dyke that prevents floodwaters inundating a community.[28] Dams are an exception, as they can combine flood protection with hydropower generation, irrigation and drinking water supply.

Table 1 summarises catchment-based NBS that can contribute to flood mitigation, split broadly into measures that **(a) manage water infiltration and run-off; (b) manage water connectivity and**

[D] We follow Intergovernmental Panel on Climate Change convention here by distinguishing between hazard, exposure and vulnerability. Risk is a product of all three.

conveyance; and (c) make space for water in the landscape. The measures can be described as 'structural NBS' in that they involve physical assets (created, protected or restored) in the landscape that can mitigate hazard, in contrast to 'non-structural' interventions such as policy-institutional reform (e.g. land use planning, early warning and response systems) that aim to create an enabling environment for adoption, or address other elements of the risk equation. A distinction can also be made between conventional, 'hard' structural measures (dams, levees, bypasses etc. – often called 'grey' infrastructure) and the 'softer' NBS-type measures described in Table 1, often termed 'green'.

Many of the measures listed in Table 1 (highlighted in bold) also form part of the suite of interventions adopted by the **basin planning and watershed management programmes** discussed in Section 2 (see also the BRACC discussion paper on catchment protection and management[2]). In particular, measures aimed at retaining water in the landscape have co-benefits related to preventing soil erosion and land degradation – key objectives in the Shire River Basin and other rapidly degrading catchments.

Flood management strategies typically include a **portfolio of green and grey** measures aimed at landscape-scale and more localised flood mitigation (so-called 'hybrid' solutions), respectively, together with policy, institutional and economic reforms aimed at incentivising adoption. The aim is to match the benefits of natural infrastructure with the security and greater performance certainty associated with built infrastructure.[28]

Figure 2 provides a stylised representation of how such measures can be combined at different scales, taken from the World Wide Fund for Nature (WWF)'s Green Guide.[29]

Table 1: Catchment-based NBS that can contribute to flood mitigation

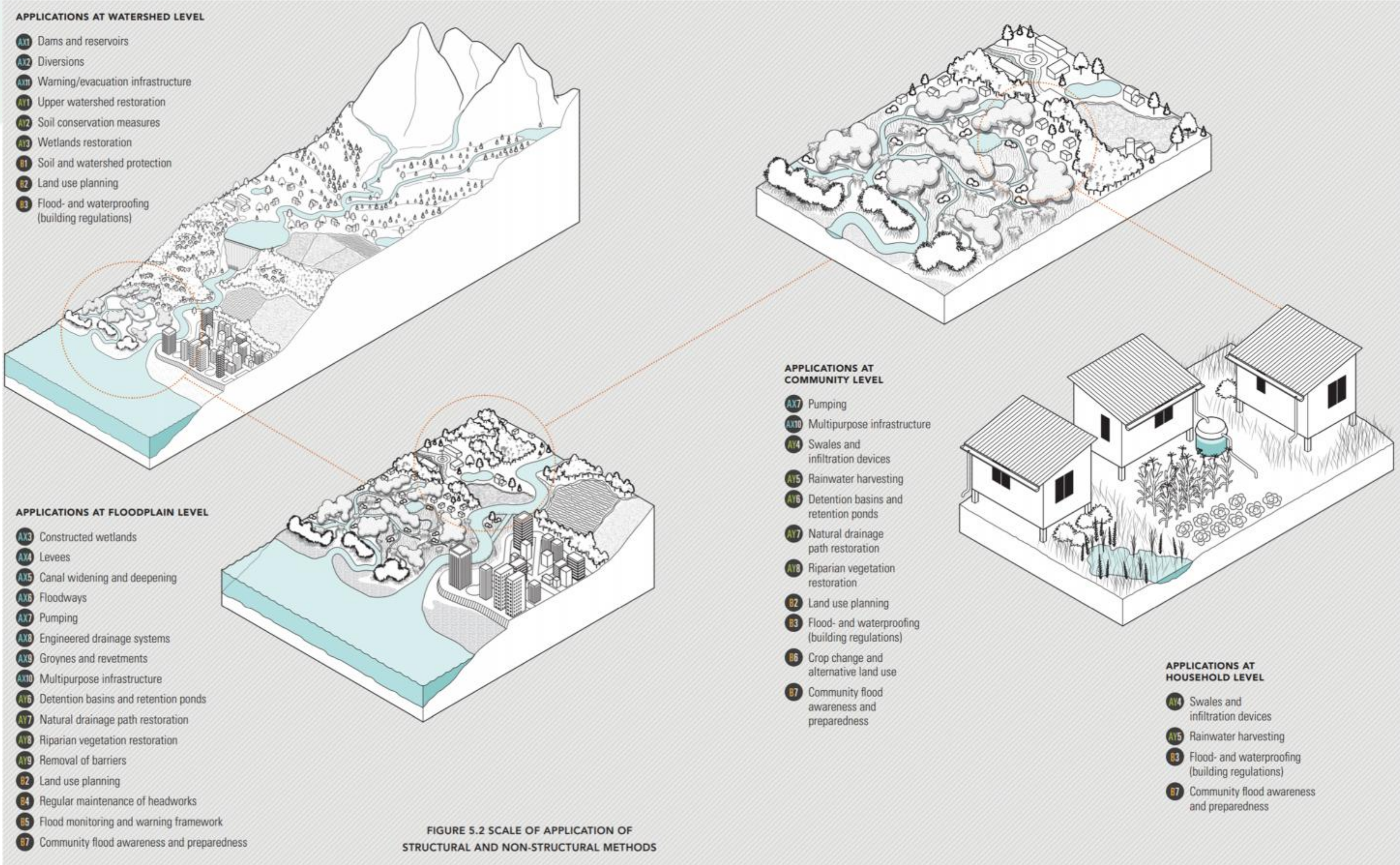
Objective	Measures	Examples
Retaining water in the landscape: water retention through management of infiltration & overland flow	Land-use change	**Forestry and woodland planting/restoration, restrictions on hillslope cropping**, arable to grassland conversion
	Arable land-use practices	**Conservation agriculture**
	Livestock land practices	Lower stocking rates; **restriction of grazing** on steep slopes
	Tillage practices	Conservation tillage, contour/cross-slope ploughing
	Field drainage (to increase storage)	Deep cultivations & drainage to reduce impermeability
	Buffer strips and buffer zones	**Contour strips**, shelter belts, **bunds, riparian buffer strips, controls on bank erosion**
	Machinery management	Low ground pressures, avoiding wet conditions (e.g. for road building)
	Urban land-use	Increase permeable areas and surface storage
Retaining water in the landscape: managing connectivity & conveyance	Management of hillslope connectivity	Blockage of farm ditches
	Buffer strips and buffer zones to reduce connectivity	**Contour strips**, shelter belts, **bunds**, field margins, **riparian buffer strips**
	Channel maintenance	Modifications to ditches and channels
	Upland retention	**Retention ponds and ditches**
	River protection or restoration	**Restoration of river profile and cross-sections**, channel realignment and changes to planform pattern
Making space for water: floodplain conveyance & storage	Water storage areas	On-or-off-line storage, washlands, polders, impoundment reservoirs
	Wetlands	Wetland maintenance, restoration or creation, engineered storage scrapes, controlled water levels
	River restoration/retraining	River re-profiling, channel works, riparian works
	River & water course management	**Vegetation clearance, channel maintenance, riparian works**
	Floodplain restoration	Setback of embankments, reconnecting rivers and floodplains

Source[27]

Notes:

a) Description and explanation of individual measures.[29]
b) Examples in **bold** indicate measures used in Malawi projects (see Section 2) based on authors' analysis of project documents.

Figure 2: Scale of application for structural and non-structural methods for managing floods



Source[29]. Note: The WWF makes a distinction between 'hard' (engineering, or grey) and 'soft' (NBS, or green) structural measures. Non-structural measures relate to policies, institutions, and processes.

4. NBS for flood mitigation – strength of the evidence

Reviews of the **biophysical evidence for NBS** providing flood mitigation benefits, including from the UK where there has been comparatively extensive implementation, monitoring and research[27] and Zambezi basin[30], point to complex, site-specific relationships between NBS and flood mitigation. This complexity is not well represented in the populist discourse on NBS that draws simple cause-effect relationships between (for example) forest cover and flooding.[31]

Insofar as the evolving and sometimes contradictory evidence can be summarised here, research suggests that the nature of the rainfall event (magnitude, duration, timing, distribution-scale) and the size of the catchment, as well as the type of nature-based measures employed (alongside others) are the most critical variables shaping direct, flood-related (dis)benefits.[E] However, **differences between river catchments make it difficult to transfer empirical evidence from one location to another**. This is because the relative importance of the *multiple* factors that influence flooding varies spatially and with time, meaning that even if an intervention is beneficial locally, a positive impact on flooding downstream cannot be guaranteed for all possible events in all locations.[27,32] In part this is an attribution problem: because NBS interventions typically occur alongside other factors that influence flooding, including spatial and temporal variability in rainfall and run-off, assessing the effectiveness of interventions becomes very difficult. In the paragraphs that follow, we pick out some key findings and uncertainties.

Not all NBS are positive for flood mitigation in all locations and circumstances. Evidence from the UK and northern Europe suggests that **NBS are most suitable for reducing flood hazards at local catchment scale and for small and moderate events**. This conclusion appears in Malawi's own national flood management guidelines.[12] The effect of multiple, small NBS-type interventions may not aggregate as expected, for example because flows are likely to be slowed in different catchments at different rates, and do not therefore affect downstream peaks in a linear fashion. However, there is a general lack of interventions and corresponding evidence at large-catchment and basin scales to confirm these limited flood mitigation effects.[27]

Drilling down further, empirical evidence assembled globally and from sub-Saharan Africa most relevant to Malawi suggests the following:

(a) **Wetlands** are complex, integrated systems that may increase flood flows as well as reduce them depending on context – location, relationship with surrounding vegetation, underlying geology and hydrological function/connectivity.[30,33] In general, river-fed floodplain wetlands have a greater potential for water capture, storage and slow release than upland rain-fed wetlands. The latter typically remain saturated year-round, and lack the capacity to store significant amounts of rainfall. This can generate overland flow for long periods after rainfall has stopped, with the potential to generate floods.[34]

(b) **Natural forests and woodlands** with an understory of vegetation and relatively porous soils

[E] Relevant literature does not always use the term 'NBS'. Dadson et al.[27], for example, refer to 'Natural Flood Management' but identify this as synonymous with NBS.

can reduce flood flows, particularly at the scale of smaller catchments, but the effect depends, *inter alia*, on the size of storm and the extent of forest cover relative to catchment size.[28] Modelling across several catchments in the Zambezi basin suggests that miombo forest can decrease flood flows where it covers *more than 70%* of the catchment.[30] Overall, forest management is most effective at retaining and slowing moderate floods of short duration. During very large or very long floods, soils become saturated with water and thereafter have limited or no further influence on the flood.[31,35,36]

(c) **Plantation forestry**, particularly where there is no natural understory of vegetation or where management activities (site preparation, drainage, roads, logging) affect soil conditions, may increase surface runoff during storm conditions and exacerbate flooding and soil erosion.[31]

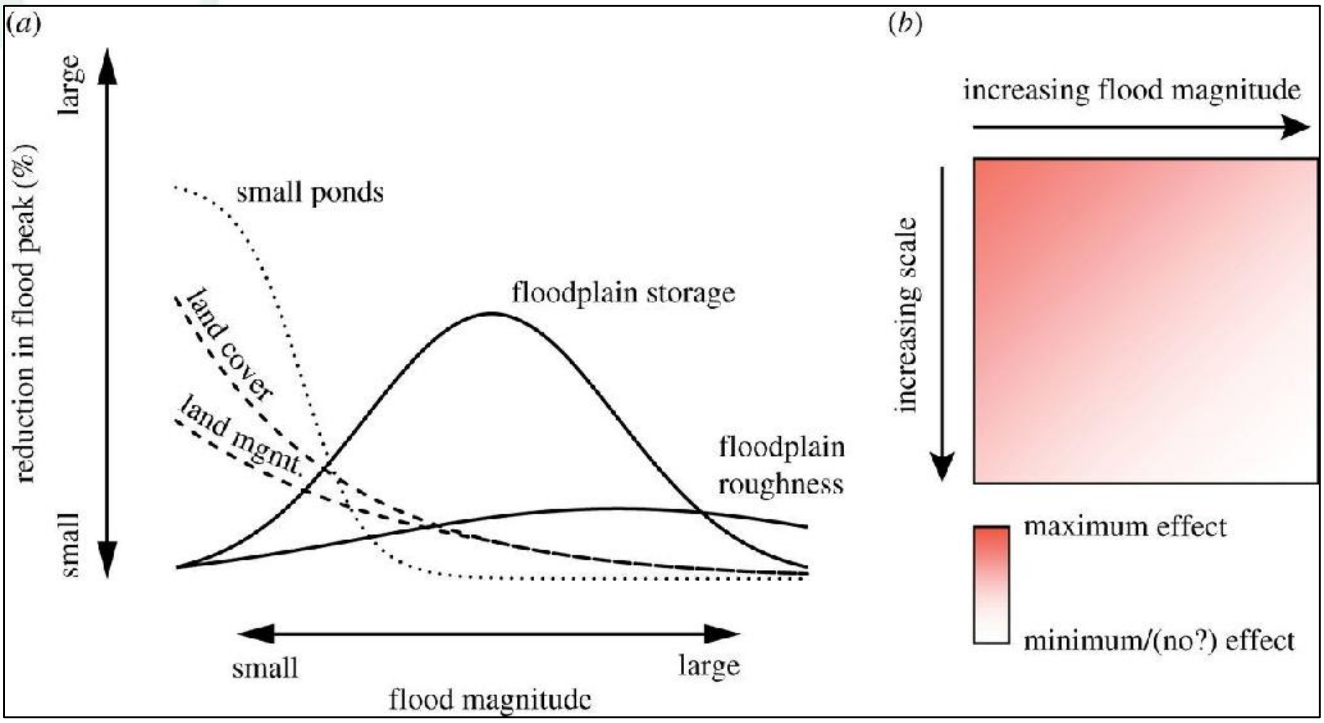
(d) Changes in **land use and land management practices** (aside from forest management) can reduce local peak water flows after moderate rainfall events if the ability of soils to absorb and retain water is increased. Once soils become saturated, the effect tails off, hence the evidence points to limited effects for more extreme events. Available evidence for aggregated impacts at large catchment scales is very limited, however, and simple extrapolations of small-scale changes to larger catchment areas are not possible. In part, this is because local benefits are attenuated downstream by the channel network. But also because interactions among local flood events and interventions (including channel modifications) can mean that slowing water flow in one catchment can make a flood *worse* further downstream when waters from several catchments meet.[27] Inappropriately located interventions may worsen flooding if they 'synchronise' flood peaks from different catchments.

(e) **River channels, beds and banks** all influence flow volumes and velocities. For example, naturally flowing rivers meander along a curved path, increasing the river's length and slowing flows. Vegetation along the path provides hydraulic roughness or resistance to flow, also reducing velocity. By slowing floodwaters, these natural or restored processes can reduce downstream flood risk, though the effects are likely to be modest compared with larger NBS interventions (e.g. floodplain management).

(f) **Floodplains and flood storage,** both natural and restored/created, can take many different forms, from widespread small-scale impoundments and trenches to larger-scale retention ponds, reservoirs, wetlands and flood plains. All of these 'structures' can store water upstream then release it slowly over varying lengths of time depending on capacity and flood conditions. However, their contribution to downstream flood mitigation depends on whether stored water would have contributed to the flood peak. Small stores may fill up quickly and have little if any effect in a large flood. Larger stores, e.g. floodplains with a large cross-sectional area, can reduce peak river flows and flood water levels, though obviously require a lot of space. The integration of built features adjacent to rivers, such as flood bypasses and polder systems, can provide greater control of floodwaters.

The broad conclusion – that NBS which alter flood storage and floodplain conveyance have clearer effects on flood mitigation than changes in land cover and management practices – is corroborated by evidence from the UK. Here, a review of the best available scientific evidence[27] found that the flood mitigation effects of interventions altering land-use / land management (from forest cover to agricultural practices) and channel form were relatively subtle and clearer for smaller rainfall events in smaller catchments, especially compared to increasing floodplain storage (Figure 3).

Figure 3: Schematic showing relative effects of catchment-scale interventions on flood peaks



Source[27]. Note: (a) Effect of different types of intervention on flood peak reduction [Exp_op]; (b) combined effect of flood management interventions with flood magnitude and catchment scale [Exp_op]. The effects achievable in practice will depend on the details of the particular intervention and the context in which it is deployed.

What about the **other impacts of NBS beyond flooding**? NBS can deliver multiple co-benefits, including carbon sequestration, biodiversity enhancement, sediment reduction and water quality improvements, but there may also be unintended or unwanted trade-offs.

First, NBS may **decrease overall water availability within a catchment**. For example, forests typically evaporate more water than other land uses, leading to an overall reduction in catchment flows.[31] This may be welcome in the wet season, but a reduction in *dry season flows* may adversely affect downstream hydropower, irrigation and domestic uses. Groundwater recharge and baseflows may also decline since these typically fall under tree canopies and in the presence of deep-rooted perennial vegetation; groundwater recharge under grassland and annual crops is greater.[37]

Second, water conservation/storage structures can usefully capture water (and sediment) that would otherwise flow downstream, but then **downstream flows are reduced**. Again, that might be an important objective – to reduce downstream floods and soil erosion (with caveats above). But where water is scarce or becoming scarcer, the effect of upstream water conservation – especially when combined with tree planting – will be an overall reduction in water availability downstream. Such is the case in parts of India where the ‘success’ of watershed conservation in upland catchments has created serious water shortages for downstream users – including urban, irrigation and hydropower.[38,39]

5. Methodologies for evaluating NBS for flood risk mitigation

Evaluation approaches and results

Despite the limitations of the natural science evidence regarding the flood mitigation and related co-benefits of NBS, there have been attempts to evaluate these direct and indirect benefits in economic terms, both for advocacy and for more specific applications such as options appraisal, often alongside conventional infrastructure solutions. **A powerful argument for economic appraisal is that it confronts decision-makers with monetary values for services that might otherwise go unvalued.** Without it, so the argument goes, the value of those services becomes zero by default.[40]

Properly accounting for nature therefore has its advantages. The ability to quantify the economic values associated with NBS encourages decision-makers to incorporate NBS in planning decisions. A better understanding of the breadth of benefits and co-benefits can facilitate adoption and encourage further use. **And valuation can be helpful in attracting investment and financing opportunities, as valuations enable NBS to demonstrate returns on investment and financial viability**. While there is no commonly accepted standard for economic valuation, there have been varied attempts to articulate the multiple benefits of NBS[40,41], which we look at below. Annex A from Shiao et al. (2020)[42] lists the benefit identification and accounting approaches developed by different organisations.

The first step in economic assessment typically employs cost-benefit analysis (CBA) or cost-effectiveness analysis to appraise options. Depending on the NBS being appraised, assigning costs can be relatively straightforward, assuming here that intervention (as opposed to leaving a service intact) is required: design and construction costs (CAPEX), any operation and maintenance costs (OPEX), and transaction costs are estimated. However, **attributing impact(s) and then assigning a monetary value is more challenging**. A project or intervention may generate direct benefits (to the project beneficiary or beneficiaries) but also co-benefits that may be more diffuse and difficult to measure.[41,43] Box 4 summarises some of the different methods used for assessing co-benefits, particularly ecosystem services drawn from natural features.

Box 4. Valuation methods: NBS-related ecosystem services[40,41,44]

Different methodologies have emerged to estimate the value of services provided by NBS. Some examples are included below:

Contingent valuation. This method measures willingness-to-pay for a service and often uses surveys to directly elicit a user's willingness to pay.

Replacement cost. The replacement cost measures the cost of the service provided in the absence of the ecosystem or natural resource. It could also refer to the calculation of the cost of an alternative means to provide that good or service.

Damage cost avoidance. This involves measuring the cost that would be incurred if the environmental service or function were absent.

Choice modelling or choice experiment. Respondents choose among different policy scenarios with different attributes such as environmental outcomes and monetary cost. The revealed preferences of people allow researchers to gauge how much the respondents value different characteristics such as environmental outcomes.

Benefit value transfer. Allows researchers to use the benefit values from other sites and transfer them to another as a proxy indicator. Researchers can choose to transfer an economic function or try to adjust estimates based on differences in context.

Market evaluation. Through market evaluation, market prices or market information are used to assign value to goods and services provided by nature.

Hedonic price studies. The hedonic method assumes that the price of a good reflects all attributes of that good, including environmental qualities. Once all attributes are controlled for, the remainder can be considered the value of the environmental attribute.

Production function. This method estimates a production function for a final marketed good or service, wherein the resulting output is a product of contributing factors or indirect inputs used to create it.

The choice of methodology is largely dependent on the type of NBS solution, anticipated outcomes and data available. For example, hedonic pricing methods often work best in urban contexts where land and house price data are more readily available, while market-based methods are more suitable for benefits that have market prices or can be easily quantified in terms of cost or value.[41,43] **To evaluate the economic value of flood mitigation, approaches have favoured contingent valuation**, as well as replacement cost, damage avoidance, benefit transfer and choice modelling.

Looking at **valuation studies for water-related ecosystem services in Africa**, Pettinotti et al. (2018) conclude that most employ direct market pricing, contingent valuation and/or replacement cost methods.[45] Looking more specifically at flood protection, only two studies were identified in the literature review (from Uganda), both using contingent valuation techniques:

- Wasswa, Mugagga, and Kakembo (2013) valued the flood control functions of the Kampala-Mukono wetland system using a contingent valuation approach in which people could estimate the value of flood mitigation to them in a hypothetical market. The total economic value of flood control was estimated at over US$ 500,000 annually, although how the wetlands actually attenuated floods and the consequences of drainage is unclear.[46]
- Kakuru, Turyahabwe, and Mugisha (2013) used contingent valuation to estimate the 'non-use' contribution of wetlands to flood attenuation, among other functions. They estimated the wetland value for flood control across Uganda at US$ 1.70 billion per year, though again the precise relationship between wetland storage and flood control is not made clear.[47]

The international **Ecosystem Service Valuation Database**[F] also provides useful information on valuation studies using a range of different methods. Papers addressing flood control include:

- Carson et al. (2011) study willingness-to-pay (WTP) to protect against logging and poaching, but also factor in the imputed flood mitigation benefits of retaining forests.[48]

[F] Last updated in December 2020 – see here: https://www.es-partnership.org/esvd/

- Brander et al. (2018) use avoided damage costs and choice experiment to value the moderation of extreme events such as flooding. Their study included data on flood frequency and damage costs to longhouses collected through household surveys. Willingness to pay for changes in flood frequency were estimated for downstream residents and tourists.[49]
- Chen et al. (2009) use a replacement cost method to assess the value of the water regulation service provided by a wetland. The service included both flood control and drought storage.[50]
- Christie et al. (2011) use a choice experiment study. Water regulation – the reduced likelihood of flooding events – was one of the ecosystem services valued in the paper.[51]
- Van Beukering, Cesar, and Janssen (2003) use the damage cost avoided method for flood mitigation. In their study, damage functions were calculated for residential houses, infrastructure (roads, bridges), and flood-related mortality.[52]

Our light touch literature review for this report identified **no academic studies of NBS valuation for Malawi, and no project-level applications of NBS valuation for flood-risk reduction**. Rather, project-level CBA (confined to World Bank-funded projects) was limited to conventional infrastructure for flood mitigation. In the Shire River Basin Management Programme, for example, somewhat blunt comparisons were made between 2015 and 2019 flood losses (pre- and post-infrastructure).

River flood prevention measures are rarely implemented in isolation, and where NBS have been employed they usually form part of mixed grey-green (hybrid) portfolio (Section 3). This then raises questions around the **appropriate mix of options and how evaluation approaches can inform decision-making**. Here, multi-criteria analysis can help.

Multi-criteria analysis is a method that allows for the use of broad criteria (monetised measures and non-monetary criteria) weighted according to their relative importance, generating a score to rank options. It allows decision-makers to consider a broad range of potential inputs and outcomes – economic and environmental.[43,53–55]

Multi-objective optimisation[G] techniques can also be used to assess combined options and explore trade-offs. For example, Hurford et al (2020) and Alves et al (2020) use this approach to analyse trade-offs between natural and built infrastructure and present those visually, with the aim of helping basin managers understand complex relationships and make better informed decisions.[56,57]

Key methodological challenges

Croci, Lucchitta, and Penati (2021) summarise the **downsides of ecosystem service valuation** as follows: First, values are easily underestimated using market price and travel cost methods. Second, market price, replacement cost and damage avoided methods have heavy data requirements that are difficult to plug. Third, contingent valuation and choice modelling approaches can be susceptible to bias.[41] Some of these challenges are elaborated below.

The replacement cost method works best under **strict criteria**. In particular, the alternative solution chosen should provide the same service as the ecosystem, it should be the least-cost alternative, and it should be feasible in the absence of the ecosystem service.[40] Moreover, the method can only be used to measure one service at a time. Similarly, damage cost avoidance methods need an acceptable substitute for the environmental good.[44]

Methods that use stated preferences (contingent valuation, choice experiments) are also contested because they **do not reflect actual behavioural choices**.[40] The WTP answers have been shown to be dependent on references/context provided during interviews.[58] That said, the robustness of stated

[G] A variant of multi-criteria analysis that uses mathematical optimisation techniques to solve different 'problem functions' simultaneously.

preference approaches has increased significantly.[44]

A challenge facing all methods is the **complexity of ecosystem services provided by NBS in terms of system scale, dynamics and context.**[59] More specifically:

- Cause-effect relationships are often difficult to untangle at a landscape scale, especially if data are scarce. Even in the UK, where catchment monitoring extends over many decades, the impacts of (for example) land cover and land management on downstream floods are difficult to assess. Moreover, differences between river catchments and the multiple factors that influence flooding make it difficult to transfer empirical evidence – hydrological and linked economic – from one location to another.[27]
- The pro-active restoration of watershed functions through NBS may take decades to take effect. For example, reforestation, the construction/rehabilitation of a wetland or the restoration of a riparian vegetation may require a 'run-in' period to establish and perform as intended.[53,60] This raises questions about the time periods used for evaluating options and appropriate discount rates for CBA.
- The timing and distribution of costs and benefits – within and between years, upstream and downstream – also raises methodological challenges. For example, measures designed to capture and retain water in an upland catchment may impose costs on upstream inhabitants for the benefit of downstream ones – at least in a wet year. But that distribution may change over different time periods with (for example) downstream, flood-prone dwellers but facing greater water scarcity in drought years or in the dry season.

Distributional issues are not readily captured or weighted in CBA, though innovative techniques can be used to highlight them. Pettinotti et al. (2017), for example, derive 'econhydrographs' that show how water storage infrastructure changes river flows throughout the year in Pwalugu, Ghana, with attendant changes in a range of ecosystem services and associated values (see Section 6, Figure 5).[61]

6. Synthesis: Lessons learned and research priorities

In this final section, we return to the questions set at the beginning of the report and ask: **What have we learned, and what more do we need to understand?** The section begins with a brief summary of key findings, and then outlines an analytical framework which could be developed as a basis for analysing the 'resilience dividends' of NBS for flood mitigation in Malawi.

Box 5: Recap of the research questions

1. What kinds of NBS might help mitigate flood hazards?
2. What are the relative resilience dividends of investing in NBS compared with 'grey' infrastructure based on experience to date?
3. What approaches/methods can or could be used to evaluate nature-based options for flood mitigation, either separately or as part of a grey-green portfolio?

Lessons learned

We can identify three key features of NBS that need to be considered when appraising them as infrastructure options for flood mitigation, whether in isolation, or more likely in combination with grey infrastructure – so-called hybrid solutions.

First, **NBS effects ripple through catchments, generating benefits, and costs, beyond their primary intention**. Where they are implemented for flood mitigation, for example, they may have positive or negative consequences for baseflow, overall water availability and water quality. Beyond hydrological effects, they may affect crop yields, carbon sequestration, biodiversity, livelihood options, and many other variables. Both hydrological and non-hydrological effects can be highly uneven, affecting individuals and groups very differently. This is also the case for conventional infrastructure of course, but the wider and potentially negative effects of NBS, and the inherent uncertainties associated with their performance, need to be stressed given their current 'silver bullet' status in the climate and environment discourse. The greater performance variability and uncertainty around NBS, together with the sheer volume of flood waters and space limitations, means that purely 'natural' solutions will not be sufficient to deal with large floods.

Second, **water-related benefits are often uncertain.** The evidence on the hydrological benefits of NBS is variable, and drawn largely from small catchments in northern temperate climates. Besides scale and the type of nature-based measures employed, other factors make a considerable difference to how far various NBS affect both flood flows and other catchment dynamics such as groundwater recharge and baseflow. Important considerations include the intensity and duration of the rainfall event, and the nature of the wider catchment. The evidence, such as it is, cautions against simplistic assumptions that directly connect changes in forest cover, land use, land management and storage with flooding, particularly in larger catchments. That said, NBS that create *major* flood storage and manage floodplain conveyance have clearer effects on flood mitigation than changes in land cover, management practices, and small-scale water capture, particularly for large floods, though the latter may have many other benefits. Expectations around the flood control impact of watershed management programmes and the NBS they embed should be viewed in this light.

Third, the **valuation of specific costs and benefits is difficult, not least because isolating and attributing cause and effect is so difficult.** NBS in general, and specifically for flooding, present a number of benefit accounting and valuation challenges. Some, including the spatial distribution of costs and benefits within a catchment, have parallels with conventional infrastructure and need to be addressed when appraising either. Others, such as the temporal variability of NBS and associated ecosystem services, may be much more complex. NBS may also require a longer run-in period to take effect and more ongoing ‘maintenance’ compared to conventional infrastructure – a further accounting challenge. The literature on monetary and non-monetary evaluation of ecosystem services is extensive (though often limited to a single NBS such as a wetland) and solutions are available to address at least some of these challenges, but appraisal remains very resource intensive.

To conclude, we note that floods will continue to have major impacts on lives and livelihoods in Malawi. **Flood management will continue to present a formidable technical and policy challenge, yet the evidence base that might inform choices remains thin.** Major watershed management programmes such as those funded by the World Bank offer an opportunity to collect and synthesise valuable data on catchment dynamics, though have arguably missed this opportunity to date.

Two recommendations follow, echoing those made by Calow (2021) in his wider review of watershed management.[2]

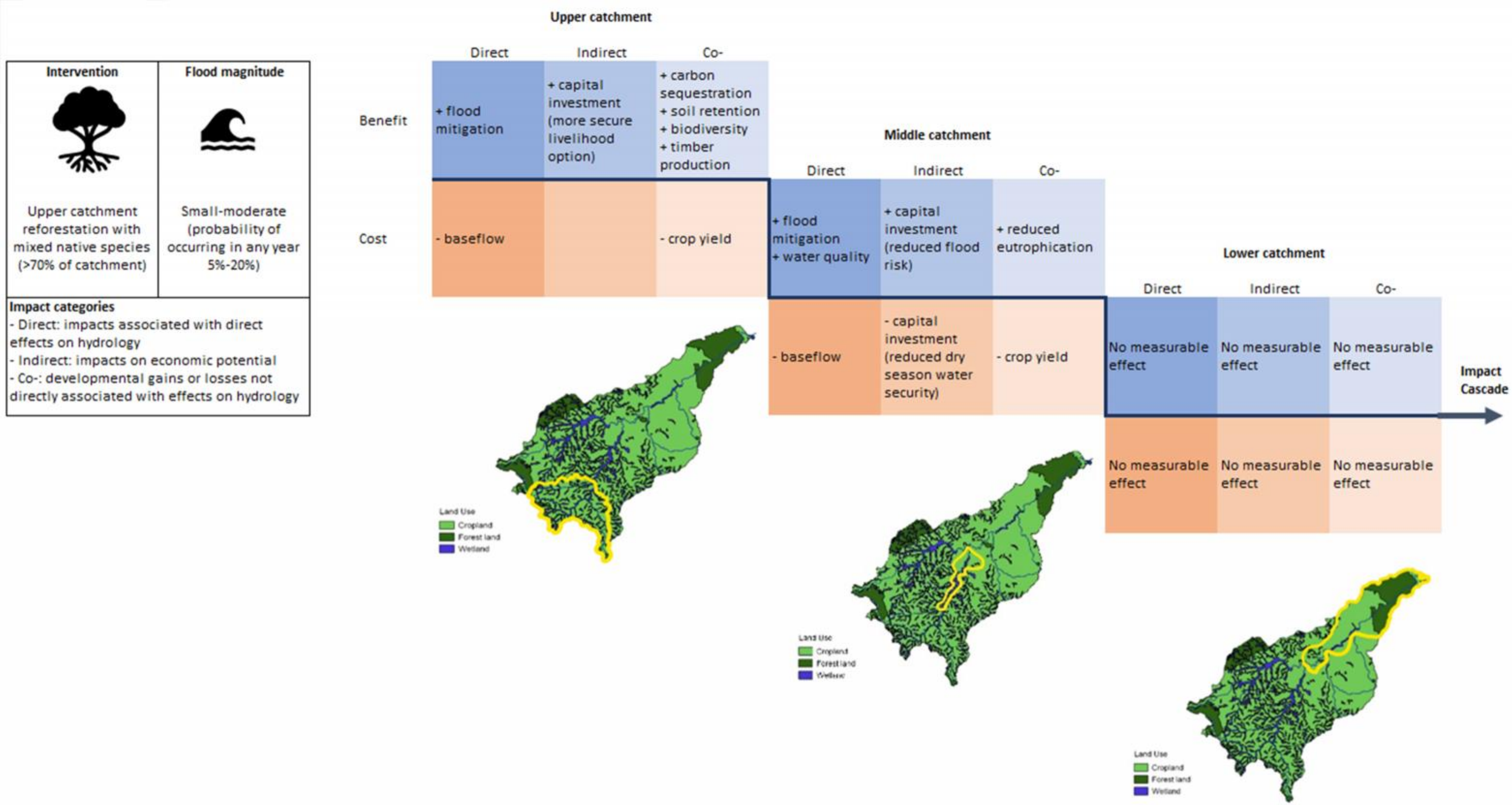
First, a platform for systematic sharing of watershed management experiences, approaches, tools and underpinning science among development partners and research organisations could avoid duplication of effort, and help future programmes take advantage of the latest knowledge.

Second, programmes need to engage and work with the scientific community – not just in programme design, but in programme implementation – to ensure that the complex physical processes linking land and water management with flooding are understood and not just treated as ‘black boxes’.

Analytical framework

Based on these points, we propose an analytical framework that could be further developed to guide research by BRACC consortium members on NBS interventions for flood mitigation. The framework provides a general structure but can be used flexibly, depending on resources. Figure 4 illustrates a potential application of the framework for a stylised, qualitative first assessment of potential costs and benefits arising from a specific NBS intervention: reforestation with native species across the majority of an upstream catchment.

Figure 4: Impact cascade: an analytical framework for evaluating NBS for flood mitigation applied to a hypothetical reforestation measure



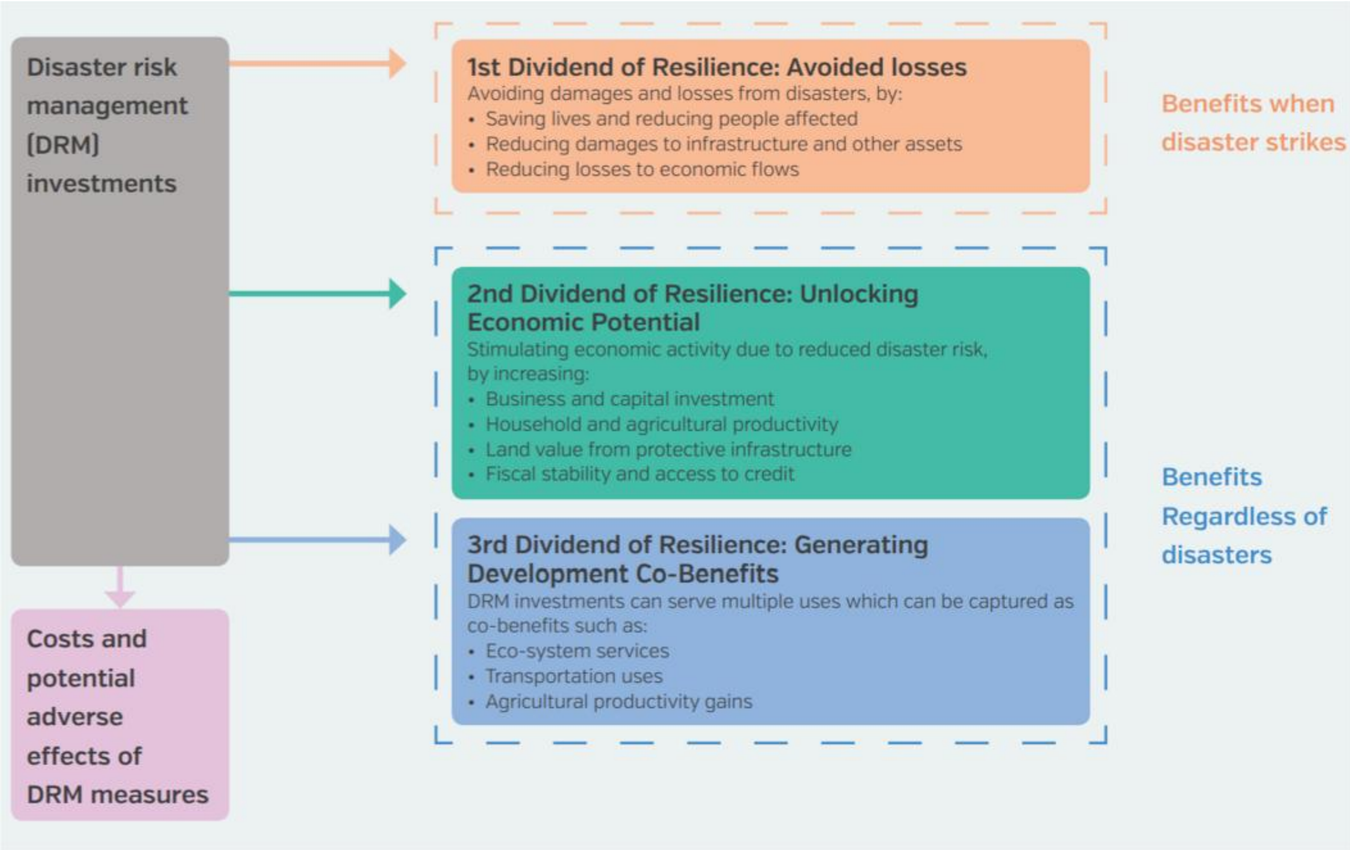
Source: Authors. Maps from Kelly et al.[62] The intervention and potential benefits and costs are hypothetical and do not reflect the situation in the Bua catchment.

The framework addresses each of the three key issues outlined above. First, the framework organises benefits and costs according to the Triple Dividend of Resilience (TDR) framework to capture the spectrum of impacts arising from an NBS intervention, and how these may have consequences for people's resilience both to immediate flood hazards and more generally.

The TDR is a conceptual framework developed by ODI, the World Bank and the London School of Economics to capture the spectrum of benefits associated with investments in DDR.[63] The TDR organises benefits in three categories: direct benefits (avoided losses), indirect benefits (unlocked economic potential), and co-benefits (associated with other development objectives), illustrated in Figure 5. We use these categories to structure the diverse potential benefits arising from NBS designed with a primary (direct) benefit of flood mitigation. Importantly, we also highlight the fact that at each category of 'dividend' (direct/indirect/co-) can imply trade-offs or costs, as well as benefits.

Many other categorisation approaches, such as the provisioning, regulating, cultural, and supporting categories of ecosystem services[64] are available. These could be used to complement TDR as part of a scan of potential impacts arising from NBS, and the biophysical and socio-economic pathways involved.

Figure 5: The Triple Dividend Framework



Source[63]

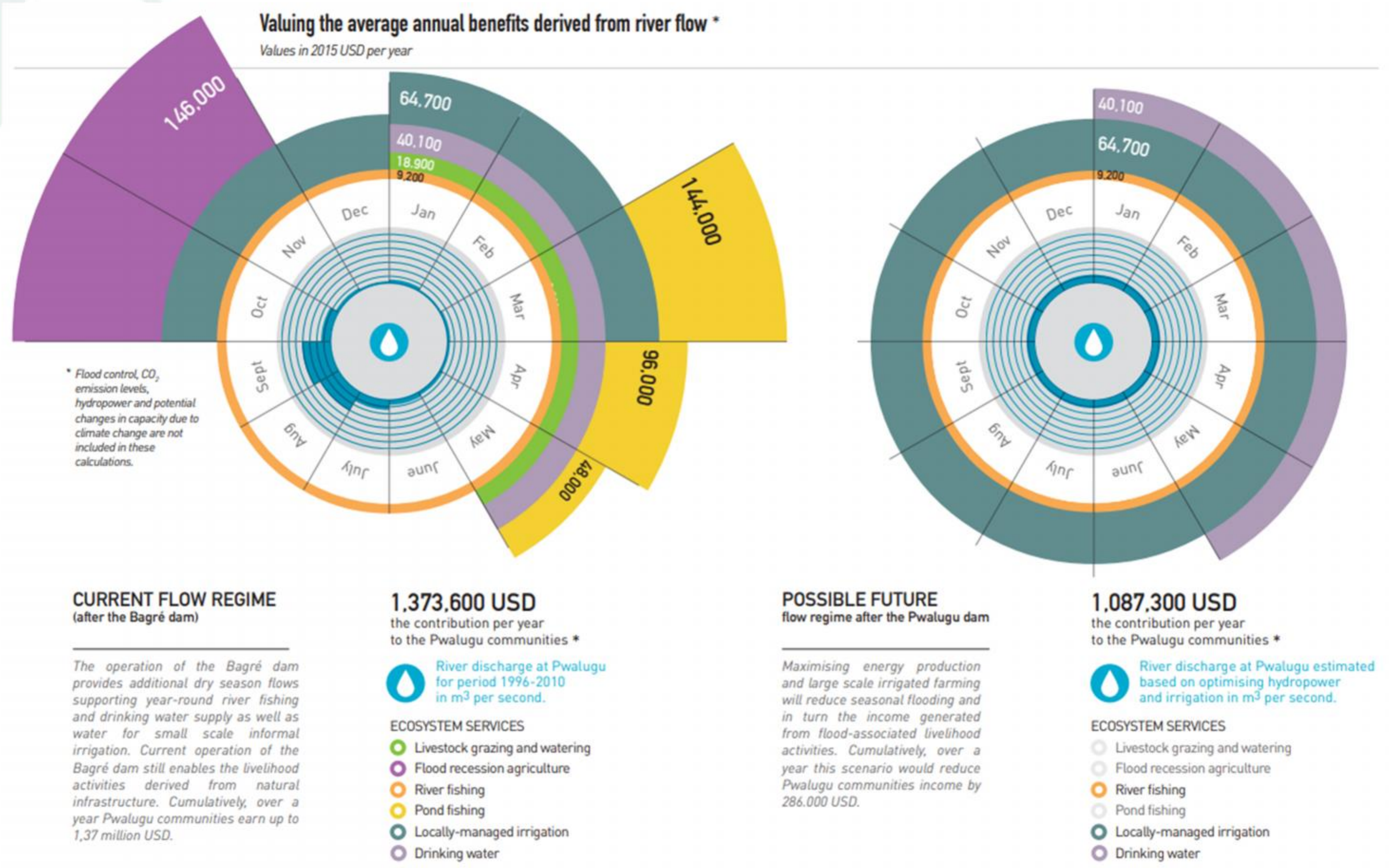
Second, our proposed framework acknowledges the mixed evidence on the hydrological effects of NBS and encourages more context-specific consideration. It does this by:

- Requiring users to specify the **scale as well as the type of intervention**, and the magnitude of the flood hazard that the NBS is intended to mitigate (see Figure 3, Section 4).
- Delineating the catchment schematically to encourage consideration of the **upstream-downstream distribution of costs and benefits** via the 'impact cascade'.

In Figure 4, the cascade is organised simplistically at three levels (upper, middle and lower catchment). Depending on the catchment and intervention, more levels can be added. Maps can be used to give users a further visual prompt on these spatial aspects. As already highlighted, the impact cascade explicitly draws attention to costs as well as benefits – where hydrological (direct) benefits and costs are concerned, this means impacts on dry season flows or water quality, for example, are not overlooked.

Third, the analytical framework helps users confront some of the key conceptual and methodological challenges when evaluating NBS. The distribution of costs and benefits spatially and between different beneficiaries can be schematically set out via the impact cascade. Users can also be encouraged to consider temporal variation, illustrated by the acknowledgement of direct hydrological benefits (reduced flood flow) but also costs (e.g. reduced baseflow), which may arise at different times of year. Where the research team identify potential for significant variation in costs and benefits inter- or intra-annually, supplementary tools such as the econhydrograph approach (see Figure 6 and described briefly in Section 5) could be used to analyse this in more depth.[61]

Figure 6: The econhydrograph, as applied to analyse the temporal distribution of ecosystem service benefits associated with flow regimes at the Bagré dam, Burkina Faso



Source[61]

Applying the framework

The framework can be applied in different ways depending on the resources for data collection and analysis – ranging from qualitative, participatory options appraisal, to a full empirical evaluation of a specific NBS (or mixed NBS and conventional) intervention. The latter would involve significant data collection and multiple disciplines (e.g. economists, hydrologists, social scientists, ecologists). This could be more compelling if the overall goal is to influence significant infrastructure investments by parties such as the World Bank.

In Figure 4 a hypothetical application of the framework to a specific NBS intervention is completed. Potential direct, indirect and co-benefits and costs are identified, and assigned a positive or negative signal, drawing on existing literature. In practice, this kind of qualitative analysis could be completed through participatory methods and expert judgement to screen different intervention options.

The framework also supports empirical assessment of specific interventions in the field. In this scenario, the framework could be completed along the lines already described, as a first step to identify the full range of costs and benefits requiring evaluation. With the scope established, hypotheses/theories of change and data collection protocols can be agreed for each impact of interest. Ultimately, the goal would be to replace each qualitative positive/negative impact statement, with an assessment based on empirical data.

A decision must be made by research partners on whether the analysis will attempt monetisation of costs and benefits (e.g. a CBA) or not (e.g. a multi-criteria analysis) as data requirements will vary. As noted, a range of methodologies for valuation of ecosystem services are available, with each offering different pros and cons. Dedicated economics expertise would likely be needed for successful monetary valuation. Likewise, empirical analysis of hydrological effects will require specific expertise and equipment (it may be possible to use existing hydrometeorological monitoring networks which have recently been improved in Malawi).

The hypothetical example in Figure 4 reflects a specific NBS intervention rather than a mixed (grey-green) portfolio of interventions. The schematic organisation of costs and benefits according to the impact cascade can also support assessment of mixed portfolios. However, establishing the impact cascade for mixed portfolios will be likely be more complex, due both to the wider range of effects and their interactions.

Establishing a counterfactual, especially for landscape-scale NBS interventions, will be challenging. However, modelling may assist. McCartney et al. (2013)[30] for example use streamflow observations and flow duration curves from the historical record to simulate flow in the absence of an ecosystem.

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Annex A: Benefit identification and/or accounting approaches and applications

Approaches	Benefit identification/ accounting	Output/ Outcome/ Impact	Water	Energy	Land and Environment	People and Community	Risk and Resilience	Financial
Aligning Biodiversity Measures for Business	Accounting	Output			●			
Restore the Earth Foundation EcoMetrics	Accounting	Outcome	●		●	●	●	●
American Carbon Registry	Accounting	Output			●			
Autocase Methodologies	Accounting	Output	●	●	●	●	●	●
Center for Neighborhood Technology National Green Values Calculator	Accounting	Output	●	●	●			●
Conservation International Biodiversity Impacts and Benefits Framework	Accounting	Output			●			
Conservation International Landscape Assessment Framework	Identification	Outcome	●		●	●	●	●
Dow and The Nature Conservancy ESII Tool	Accounting	Output	●	●	●	●		●
EKLIPSE Impact Assessment Framework	Accounting	Impact	●		●	●	●	●
Global Biodiversity Framework	Accounting	Outcome			●			
Greenhouse Gas Protocol	Accounting	Output			●	●		
Freshwater Health Index	Identification	Outcome	●		●	●		
Green Infrastructure Leadership Exchange Co-Benefit Valuation Tool	Accounting	Output	●		●			●
InVEST	Accounting	Outcome	●		●			●
i-TREE	Accounting	Output	●	●	●			●
Landscape Architecture Foundation's Landscape Performance System	Accounting	Output	●		●	●	●	
Michigan State and Electric Power Research Institute's Methodology for Quantifying Nitrous Oxide (N2O) Emissions Reductions from Reduced Use of Nitrogen Fertilizer on Agricultural Crops	Accounting	Output			●			
Ocean Health Index	Identification	Output	●		●	●	●	●
Organisation for Economic Co-operation and Development Methods Biodiversity Valuation	Accounting	Output			●			●
Organisation for Economic Co-operation and Development Social Investment Framework	Identification	Impact						●
Pacific Institute's Multi-Benefit Framework	Identification	Output	●	●	●	●	●	●
Soil Water Assessment Tool	Accounting	Output	●					
Sustainable Rice Platform	Identification	Outcome	●		●	●	●	
The Clean Energy Regulator's Carbon Accounting for Avoided Clearing of Native Growth	Accounting				●			
Verra Verified Carbon Standard	Accounting	Output			●			
Volumetric Water Benefit Accounting	Accounting	Output	●				●	
Water Evaluation and Planning System	Accounting	Output	●					
WRI Green-Gray Assessment	Identification	Outcome	●		●		●	●
Total			**18**	**5**	**24**	**11**	**10**	**14**

Source[42]