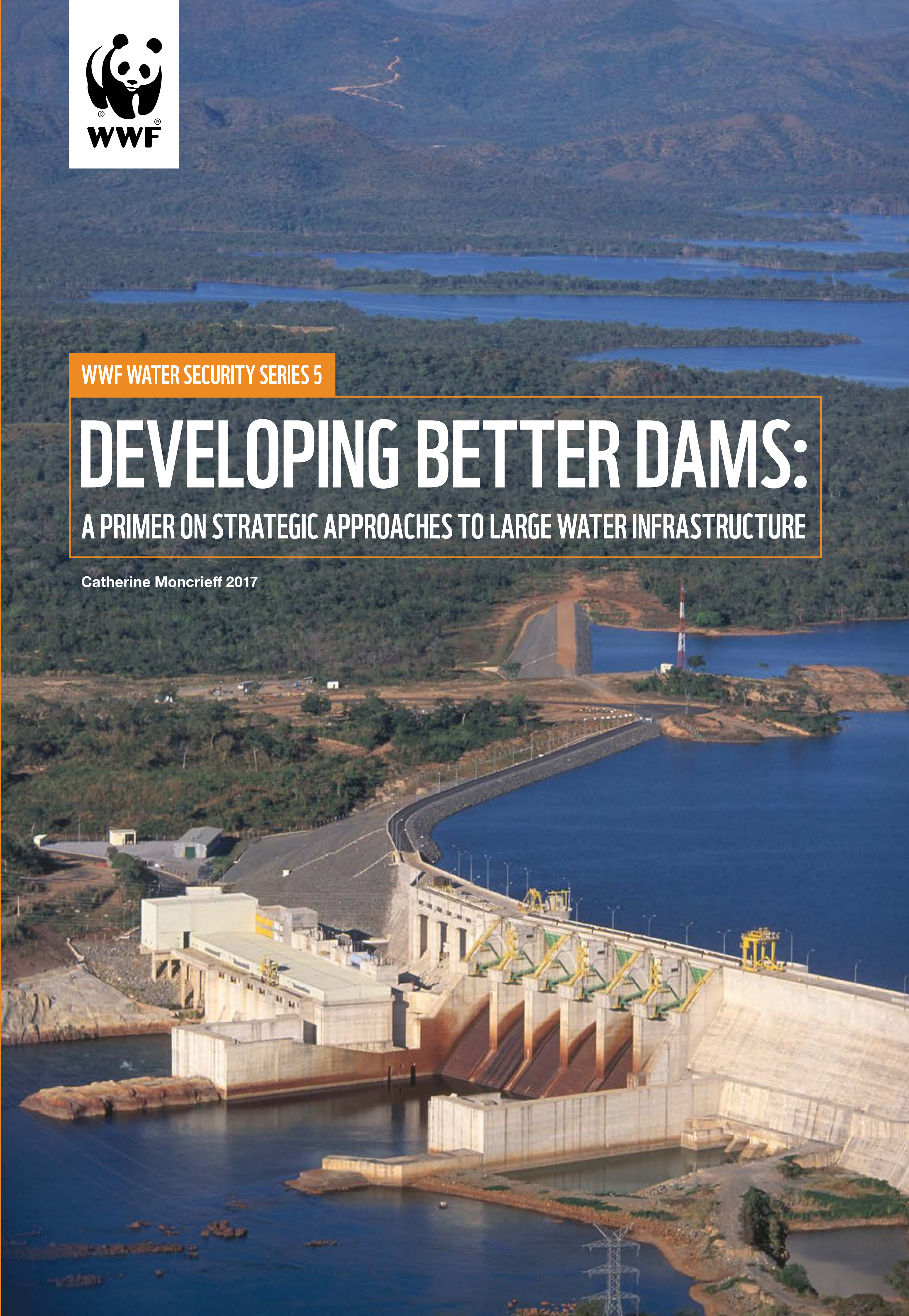

WWF WATER SECURITY SERIES 5

DEVELOPING BETTER DAMS:

A PRIMER ON STRATEGIC APPROACHES TO LARGE WATER INFRASTRUCTURE

Catherine Moncrieff 2017

WWF's Water Security Series sets out key concepts in water management as they relate to environmental sustainability. The series builds on lessons from WWF's work around the globe, and on input from external experts. Each primer in the Water Security Series addresses specific aspects of water management, with a particular focus on the inter-related issues of water scarcity, climate change, infrastructure and risk. Our intention is that the series will help WWF colleagues and other conservation and water management practitioners understand the state-of-the-art on these critical issues.

Understanding Water Security
As an international network, WWF addresses global threats to people and nature such as climate change, the pressures on species and habitats, and the unsustainable consumption of the world's natural resources. We do this by influencing how governments, businesses and people think, learn and act in relation to the world around us, and by working with local communities to improve their livelihoods and the environment upon which we all depend.

Water security is one of the key challenges facing the world in the 21st Century. This is not just WWF's view: world leaders, captains of industry and high profile researchers have said as much in recent years. Influential voices in the global economy, development and security communities are increasingly talking about water-related risk as an emerging threat to businesses, to livelihoods and to peace and stability.

If we manage water badly, nature also suffers from a lack of water security. Indeed, freshwater biodiversity is already suffering acutely from over-abstraction of water, from pollution of rivers, lakes and groundwater and from poorly-planned water infrastructure. WWF's Living Planet Report shows that declines in freshwater biodiversity are the steepest amongst all habitat types.

As the global population grows, lifestyles shift and demand for food and energy increases, the pressure on freshwater ecosystems will intensify. To add to this, the main effects of climate change are likely to be felt through changes to the hydrological cycle.

WWF has been working for many years in many parts of the world to improve the way rivers, lakes, wetlands and aquifers are managed. Ensuring water security for people and nature remains one of our key priorities.

Acknowledgements
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ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
ASCE	American Society of Civil Engineers
BOT	Build-Operate-Transfer
CA	Concession Agreement
CBI	Climate Bonds Initiative
CDM	Clean Development Mechanism
CERs	Certified Emissions Reductions
CSI	Connectivity Status Index
CSR	Corporate Social Responsibility
CTGC	Chinese Three Gorges Corporation
DANIDA	Danish International Development Agency
DoF	Degree of Fragmentation
DoR	Degree of Regulation
ECA	Export Credit Agency
EDF	Électricité de France
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency (US)
ESG	Environmental-Social-Governance
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FEMA	Federal Emergency Management Agency (US)
GHG	Greenhouse Gas Emissions
HIS-ARA	Hydrological Information System and Amazon River Assessment
HPSF	Hydropower Preparation Support Facility
HSAP	Hydropower Sustainability Assessment Protocol or 'the Protocol'
ICOLD	International Commission on Large Dams
ICPDR	International Commission for the Protection of the Danube River
IEA	International Energy Association
IFC	International Finance Cooperation
IHA	International Hydropower Association
IIED	International Institute for Environment and Development
ILO	International Labour Organization
IPP	Independent Power Producer
IWMI	International Water Management Institute
NGOs	Non-Governmental Organisations
OECD	Organisation for Economic Co-operation and Development
PDA	Project Development Agreement
PPA	Project Purchase Agreement
RoR	Run-of-river
RSAT	Rapid Basin-wide Hydropower Sustainability Assessment Tool
SADC-WD	Southern African Development Community – Water Division
SDGs	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SIDA	Swedish International Development Agency
TGD	Three Gorges Dam
TNC	The Nature Conservancy
UN	United Nations
UNDRIP	Unites Nations Declaration on the Rights of Indigenous Peoples
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States of America
WCD	World Commission on Dams
WFD	Water Framework Directive
WIGO	Water Integrity Global Outlook

GLOSSARY

Biodiversity offset: When environmental offsetting is specifically for adverse impacts on biodiversity, is designed proactively, fully counterbalances these impacts, and is 'in kind', it constitutes a 'biodiversity offset'.

Catchment: An area of land where precipitation collects and drains off into a common outlet, such as a river, bay, or other body of water.

Dam: A barrier constructed to hold back water and raise its level, forming a reservoir. In this primer we will use the term 'dam' to also cover weirs (a low dam built across a river to raise the level of water upstream or regulate its flow) and barrages (a term often used to refer to large 'run-of-river' dams).

Diversion: A facility, which does not always require the use of a dam, to channel or divert a portion of river water through an intake canal or **penstock** to a user (e.g. hydropower turbines), before being consumed or returned to the river via an outlet further downstream.

Fluvial connectivity: The ability for energy, materials and organisms to be naturally transferred along a river and floodplain without interruption. Fluvial connectivity encompasses longitudinal (river channel), lateral (floodplains), vertical (groundwater and atmosphere) and temporal (intermittency) components.

Free-flowing river: A river or stretch of river where natural aquatic and riparian ecosystem functions and services are largely unaffected by anthropogenic changes to fluvial connectivity, allowing an unobstructed exchange of material, species and energy within the river system and beyond.

Green infrastructure: Natural or semi-natural systems that provide ecosystem services that complement, augment or replace those provided by **grey infrastructure**.

Grey infrastructure: Conventional built infrastructure such as water treatment plants, reservoirs, dams and desalination plants.

Hydropower (or hydroelectric power): Electricity generated from harnessing the energy of flowing water and its head.

Impoundment: A facility that uses a dam to store river water in a reservoir and controls the release of water for the generation of electricity or to manage storage levels; or the process of first filling a reservoir.

Large dam: A dam with a height of 15 metres or more from its foundation; or a dam that is between 5 metres and 15 metres high *and* has a reservoir volume of more than 3 million cubic metres.

Multipurpose dam: A dam designed for more than one specific purpose and providing a range of services from a single investment.

Penstock: An intake pipe that channels water to hydropower turbines or sewerage systems.

Pumped storage: A type of hydropower scheme that stores energy by pumping water from a lower water body to an upper reservoir. During times of peak electricity demand, the water in the upper reservoir is released to the lower reservoir, driving turbines to generate power. During times of low demand and cost, excess power generated (or power from another source) is used to pump water from the lower reservoir back to the upper reservoir.

Reservoir: A natural or artificial lake for the purpose of water storage.

Run-of-river (RoR) dam: A dam where the outflow below is essentially equal to the momentary inflow. The reservoir has no (or little) storage function, but is created to raise the water level to facilitate power generation or the diversion of water. A RoR hydropower scheme therefore uses the flow of the river to produce power.

Sluice gate: A movable gate allowing water to flow through it. Sluice gates are used to supply water from dams, canals and rivers.

Spillway: A spillway releases flood water from a reservoir. The capacity of the spillway is designed to prevent uncontrolled overtopping of the dam.

Storage dams: A dam that impounds water in a reservoir for seasonal, annual or multi-annual storage and regulation of the river.

SUMMARY: TEN PROPOSITIONS FOR DEVELOPING BETTER DAMS

Dams provide significant benefits to people but they are also a primary cause of the loss and degradation of river ecosystems and the services these ecosystems provide to society. Recognising this, several tools and approaches have emerged over the last two decades to promote better dams – i.e. dams that have fewer impacts and deliver greater benefits to society. This primer reviews these new tools and approaches, as well as some of the factors responsible for bad dams, and it offers a pragmatic way forwards. It is intended to prompt dialogue and guide engagement with decision-makers.

While the context and environmental conditions for dams vary considerably around the world, there are a number of concepts that underpin an effective approach to planning, developing, renovating and operating dams.

1. **Construction of new dams is not always the optimal solution to meet development needs**. Dam planning should be part of strategic planning for economic and social needs (such as energy, food, and flood and drought protection). Alternatives such as demand management, green infrastructure, and importing and trading energy or food can reduce the need to build new dams. Depending on context, these alternatives can be less controversial and disruptive and can provide a blend of strategic, economic, social and environmental benefits at lower costs. Governments should consider all possible options to meet societal needs.
2. **System-scale planning of dams helps produce a greater and broader range of benefits to society.** System-scale planning considers the cumulative impacts and benefits of multiple potential infrastructure portfolios[1] against a range of social, environmental and economic objectives. Identifying the best dam locations for the optimised delivery of multiple benefits and minimisation of adverse impacts is at the core of system-scale planning. System-scale planning of dams and other water infrastructure must take place within the context of river basin/landscape planning, which takes into account water and land use, and which is informed by strategic economic planning.
3. **In a rapidly changing world, dams must be adaptable to be effective over the long-term**. Dams must be planned, designed, operated and monitored to allow for adaptive management in response to climate change and resulting hydrological extremes, and shifting societal preferences. Planning must take account of a number of different climate and societal scenarios, and upfront capital investment is needed to build in design features that allow for flexible operation.
4. **Provision of environmental flows and maintenance of fluvial connectivity should be prioritised to safeguard aquatic biodiversity and ecosystem services to downstream communities.** Dam developers should undertake an environmental flow needs assessment as part of the Environmental Impact Assessment (EIA), and dam features and operation rules should be designed to enable these needs to be met. Dams should be sited and designed to maximise fluvial connectivity within river systems.
5. **Planning processes are most effective when they involve meaningful participation of representatives of different economic sectors, interest groups and affected communities in order to balance the benefits and costs of dams.** Participation is required throughout the whole planning, construction and operational lifespan of dam projects. A key component is sharing of knowledge and perspectives about how dams affect local communities, indigenous peoples, ecosystem services and biodiversity. Local perspectives and needs must be balanced with basin, national and transboundary perspectives and needs.
6. **Governance reform will often be required if dams are to effectively balance a range of societal interests.** Strong institutional frameworks are needed that enable independent regulation of all actors, that guard against capture by interests of powerful players, and that ensure transparent decision-making, which takes account public interests, including those of marginalised and underprivileged groups.
7. **In addition to system-scale planning, reducing adverse environmental and social impacts requires meaningful impact assessments at the project scale.** EIAs should be the result of genuine interaction between different interest groups and should be carried out well ahead of key decisions being made. The EIA process must be genuinely independent and peer reviewed. In some countries, policy/regulatory reform is likely to be required to achieve this.
8. **A number of tools exist for assessing and reducing the environmental, social and financial risks of dam projects.** Developers and investors need to consider impacts from dams, but also risks that may affect the dam's performance. WWF's Water Risk Filter helps assess risks linked to the river's catchment – such as low flows – that could affect dam projects; the Hydropower Sustainability Assessment Protocol benchmarks hydropower dams against broadly agreed sustainability criteria. The application of internationally recognised environmental-social-governance (ESG) safeguards (such as the Equator Principles and the World Commission on Dams principles) in conjunction with stakeholder engagement, can reduce several sources of risk, leading to reduced delays and cost overruns and improved financial performance. The application of ESG safeguards can be facilitated by finance sources with ESG commitments, such as green bonds and loans from development banks. New finance models are also emerging which are helping to de-risk projects for financial investment.
9. **System-scale analysis of existing stocks of dams can optimise benefits, reduce impacts and facilitate responses to climate change, societal needs and economic development imperatives.** Such analysis involves basin-scale assessments to determine whether infrastructure should be repaired, reoperated, renovated or removed.
10. **Removal should be considered where obsolete or inefficient dams are preventing the restoration of ecosystems and/or having negative impacts on communities.** Comparing the likely costs and benefits of dam removal against those of renovation and ongoing maintenance can inform decisions. Dam removal costs should incorporate a budget for multi-year monitoring and evaluation of environmental, social and economic impacts before and after the event.

[1] A combination of project locations and management options.

The Serra da Mesa dam near Minacu, Goias State, Brazil.

INTRODUCTION

Dams are among the most significant pieces of water infrastructure. For almost 5,000 years dams have served to ensure an adequate supply of water by storing water in times of surplus and releasing it in times of scarcity, thereby also mitigating floods. Today, dams continue to be used to store and control water, and are also used for navigation, energy generation and recreation. Smaller weirs and check-dams control water levels and facilitate abstraction of water from rivers. A dam can be seen as the cornerstone in the development and management of water resources in a river basin.

But dams have significant, complex and far-reaching impacts on both humans and nature. There are trade-offs associated with the benefits and costs of dams, and these play out differently for different groups: a dam may bring electrification for some, but may cause loss of downstream river benefits, such as fisheries, for others. The distribution of costs and benefits of dams among economic sectors and societal groups causes conflicts; dams are likely to become more controversial as resources provided by rivers become scarcer. Public policy, planning and regulation must ensure that dams meet a broad range of societal objectives, including the protection of river ecosystems and the services they provide.

Existing or emerging tools and approaches can go a long way towards achieving more balanced outcomes from dams, including basin-scale assessments to aid planning and rehabilitation of infrastructure; analysis of trade-offs between options; and tools to uphold and benchmark social and environmental performance. However, implementing these approaches can often be hampered by weak governance.

This primer explores the interface between the development and management of dams and the protection of rivers and associated ecosystems such as floodplains, estuaries and deltas. Its purpose is to prompt and guide decision-making to achieve better dams. It reviews key issues and approaches and offers a pragmatic way forward. It is not intended to be a position paper, but it does build on WWF's Position on Dams (WWF, 2014a) which sets out in broad terms our views on dam development. This primer is primarily intended for WWF staff but is also directed at other professionals in the public and private sectors who are engaged in dam processes and are seeking to improve dams for society and nature.

While many of the concepts discussed are relevant to all types of water infrastructure, the primary focus is on dams. The term 'dam' is used broadly to cover any built infrastructure that breaks the longitudinal connectivity of rivers, including barrages and weirs. While the primer covers dams with all purposes, significant focus is given to hydropower dams. Hydropower is experiencing significant growth, and thus many of the emerging tools and financing mechanisms have been developed through collaboration with hydropower sector stakeholders.

Part A provides an overview of the benefits, impacts and trends of dams. Part B explores the complexities of decision-making around dams, explaining how these have often resulted in inappropriate dams. Part C sets out key approaches, tools and principles for guiding decision-making to achieve better dams. These draw on lessons from WWF's work as well as cutting-edge practice from other organisations and experts.

PART A
DAMS: PROS, CONS AND TRENDS

Part A explores the major types of dams, their benefits and impacts, and current trends. The focus is on dams for irrigation and hydropower.

A dam is a barrier constructed to hold back water and raise its level, forming a reservoir (Oxford Dictionaries). In this primer the term 'dam' includes weirs (a low dam built across a river to raise the level of water upstream or regulate its flow) and barrages (a term often used to refer to large 'run-of-river' dams).

The two main categories of dams are (WCD, 2000):

1. Storage dams – impound water behind the dam in a reservoir for seasonal, annual or multi-annual storage and regulation of the river.
2. Run-of-river dams – raise the water level but have no (or little) storage function. The outflow below a RoR dam is essentially equal to the momentary inflow. RoR dams include weirs, barrages and diversion dams.

There are various definitions of large dams. The International Commission on Large Dams (ICOLD), established in 1928, defines a large dam as a dam with a height of 15 metres or more from its foundation. If dams are between 5 metres and 15 metres high and have a reservoir volume of more than 3 million cubic metres, they are also classified as large dams.

Dams can have single or multiple purposes. Of the 58,519 large dams in ICOLD's register, 49% are for irrigation, 20% for hydropower production, 11% for water supply, 9% for flood control, 5% for recreation and less than 1% for navigation and fish farming (ICOLD, 2017a). Most dams are single purpose, but there a growing number of multipurpose dams – approximately one quarter of the dams on the ICOLD database fall into this category.

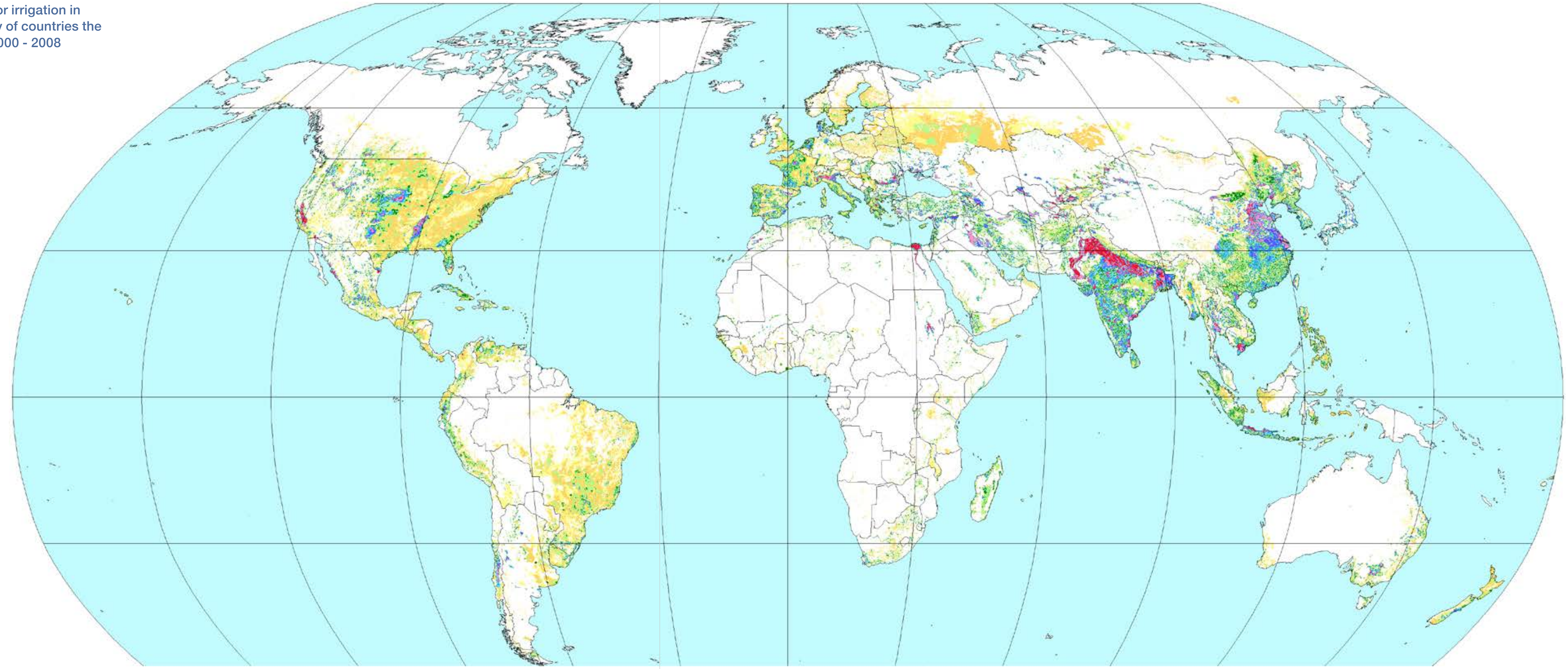
Dams play an important role in managing water resources that are subject to hydro-climatic variability, often limited and unevenly distributed in time and space. Dams enable water to be stored, supporting downstream water availability during dry periods. Construction of large dams increased dramatically in the second half of the 20th century with rising global demand for power and food (WWF, 2013) and advances in technology.

A.1 TYPES AND BENEFITS OF DAMS

Figure 1. Map showing area equipped for irrigation in percentage of cell area. For the majority of countries the base year of statistics is in the period 2000 - 2008

Area equipped for irrigation in percentage of land area

- 75-100
- 50-75
- 35-50
- 20-35
- 10-20
- 5-10
- 1-5
- 0.1 - 1
- < 0.1
- 0



Source: FAO Aquastat (2017)

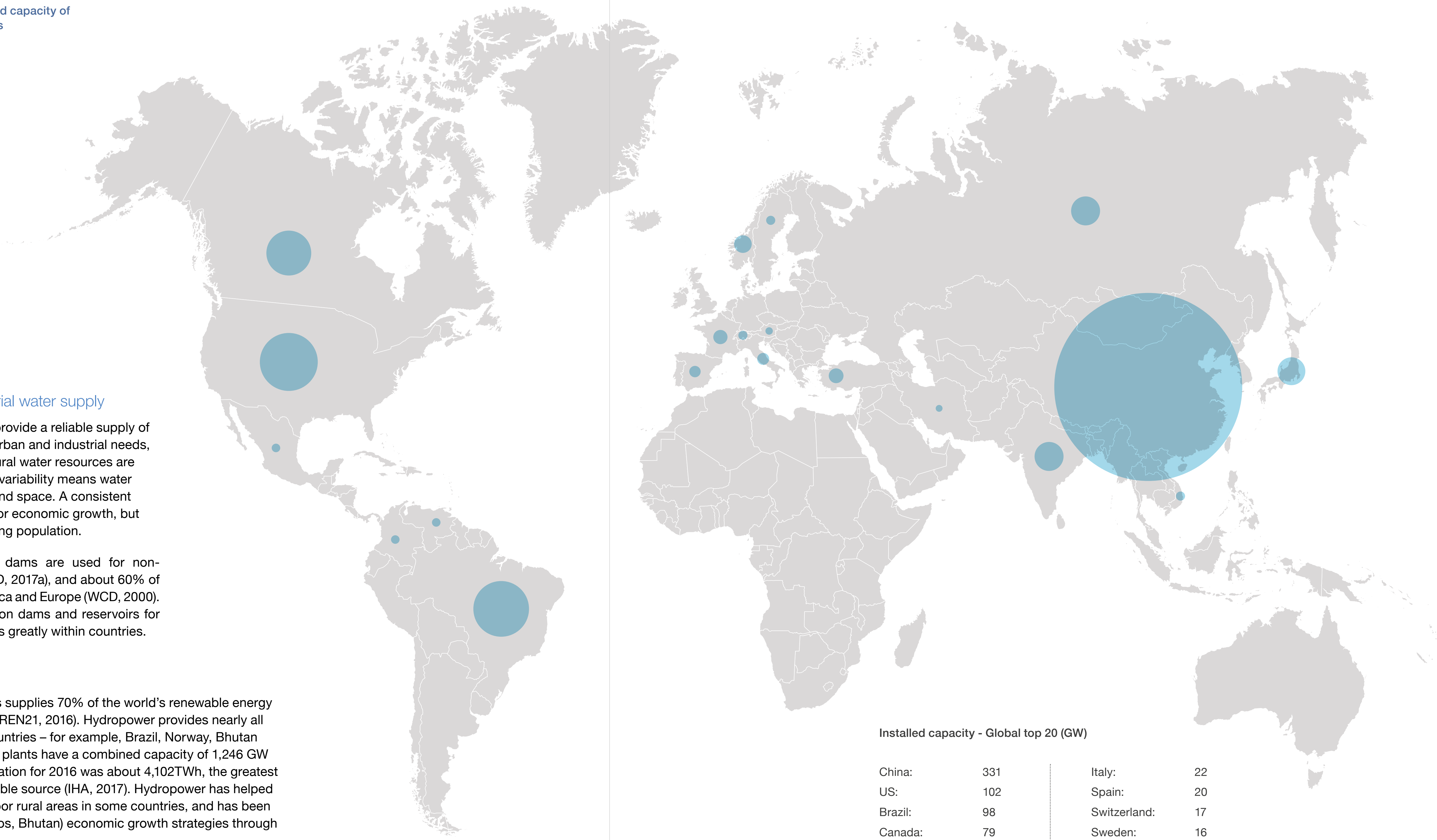
Dams for irrigation

Irrigation is the single largest consumptive use of fresh water globally and is the principle purpose for nearly half of the world's large dams (ICOLD, 2017a). Storing water behind dams enables water to be delivered consistently to irrigation systems, reducing the vulnerability of agricultural production to dry spells and droughts. Irrigation gives farmers the confidence to invest in agriculture, increasing the stability of yields and farm incomes; in turn resulting in more affordable food prices and economic growth in non-farming sectors (IWMI, 2007). The early 1960s saw massive investment in large surface irrigation schemes by international development banks, donor agencies and national governments, establishing the foundation of food security in much of the developing world (IWMI, 2007).

Large dams are estimated to support 12-16% of global food production (UNEP-DDP, 2005). Smaller dams and barrages are often used to manage off-takes of water from rivers into irrigation canals. The scale and significance of large dams for irrigation varies significantly from country to country. For example, dams supply almost 100% of irrigated production in Egypt (WCD, 2000). Meanwhile, dams were estimated to provide only about 1% of irrigation water in Nepal (WCD, 2000) and supply only 10% of cropland in the US (FEMA, 2017). In India and China, the two countries with the largest irrigated areas, large dams were estimated to supply 30-35% of irrigation water (WCD, 2000).

Donor spending on irrigation reached a peak in the late 1970s and early 1980s. The decline since is due to a number of issues including the growing recognition of the poor performance of large-scale irrigation and the adverse impacts of the dams required (IWMI, 2007). However, rapidly rising global food demand necessitates more productive agriculture through the expansion of irrigation, but also through rehabilitating degraded irrigation schemes (Alexandratos & Bruinsma, 2012). It is estimated that by 2025, 80% of additional food production will need to come from irrigated land, requiring construction of more storage dams (ICOLD, 2017b). The expansion of irrigation is likely to be strongest in land-scarce regions, hard-pressed to raise crop production through more intensive cultivation practices – for example, East Asia, South Asia, the Near East and North Africa.

Figure 2. Map showing the installed capacity of hydropower in the top 20 countries



Dams for urban and industrial water supply

Many dams have been built to provide a reliable supply of water to meet rapidly growing urban and industrial needs, especially in regions where natural water resources are limited or where hydro-climatic variability means water is unevenly distributed in time and space. A consistent supply of water can be critical for economic growth, but also for the survival of the existing population.

Globally, about 11% of large dams are used for non-agricultural water supply (ICOLD, 2017a), and about 60% of these dams were in North America and Europe (WCD, 2000). The extent to which cities rely on dams and reservoirs for urban and industrial water varies greatly within countries.

Dams for hydropower

Electricity generated from dams supplies 70% of the world's renewable energy and 16.6% of global electricity (REN21, 2016). Hydropower provides nearly all the electrical power in some countries – for example, Brazil, Norway, Bhutan and Albania. World hydropower plants have a combined capacity of 1,246 GW and the total hydropower generation for 2016 was about 4,102TWh, the greatest ever contribution from a renewable source (IHA, 2017). Hydropower has helped facilitate the electrification of poor rural areas in some countries, and has been a central part of others' (e.g. Laos, Bhutan) economic growth strategies through the export of electricity.

Some 20% of single purpose dams and 15% of multipurpose dams on the ICOLD registry are used for hydropower (ICOLD, 2017a). These figures do not include the huge number of small dams with hydropower functions that are not included on any global registry. Hydropower schemes range in size from small schemes for households and decentralised grids, to large schemes which supply national or regional power grids. Types of hydropower scheme include storage, run-of-river, pumped storage and combinations of these; most schemes include some kind of dam.

Installed capacity - Global top 20 (GW)

China:	331	Italy:	22
US:	102	Spain:	20
Brazil:	98	Switzerland:	17
Canada:	79	Sweden:	16
India:	52	Vietnam:	16
Japan:	50	Venezuela:	15
Russia:	48	Austria:	13
Norway:	32	Mexico:	12
Turkey:	26	Colombia:	12
France:	25	Germany:	11

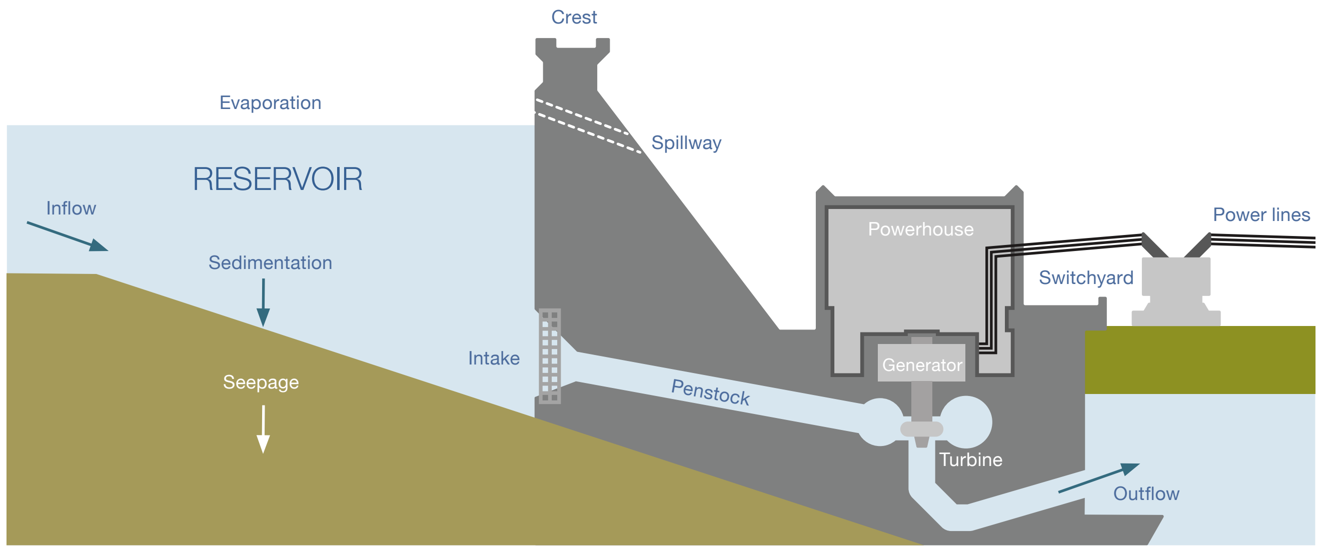
Source: (IHA, 2017).

Gathega Dam supplying the water to power Guthega power station as part of the Snowy mountains hydro scheme, New South Wales, Australia.

Storage schemes

Figure 3 shows the components of a typical hydropower storage scheme. Storage schemes combine a dam and reservoir to regulate power generation over a monthly, seasonal, or even multi-year basis. These schemes affect the river's flow regime downstream; in some places, a downstream 're-regulation' dam can reduce the variation in flow releases from the main dam. Storage schemes are often multipurpose, for example combining power generation with irrigation and flood control.

Figure 3. Components of a typical storage hydropower scheme



Run-of-river schemes

Run-of-river (RoR) schemes have limited storage and therefore their power output depends on the timing and volume of river flows. There are three main types of RoR schemes:

- Pure: without any flow regulation, where the natural river flow passes through the turbines.
- Pondage: with some storage behind a dam, enabling daily or sometimes weekly regulation of flow. Power generation can therefore be maximised during periods of peak electricity demand.
- Diversion: a portion of the river is diverted into tunnels or channels that run through a powerhouse further downstream, where the water is returned to the river. Sometimes water is diverted to another river or basin.

Most RoR schemes require a dam to ensure there is enough water entering the penstock pipes or diversion channel. These dams – even if small – disrupt the river's connectivity, and alter its morphology, velocity and temperature. Those RoR schemes with diversions cause de-watered stretches of river. Even so, RoR schemes are often deemed to have lower social and environmental impacts compared with storage schemes because of their smaller reservoirs and reduced ability to alter the natural flow regime. For this reason many hydropower schemes funded through the Clean Development Mechanism (CDM)[2] are RoR. However, there is no consensus on maximum size or volume of storage for RoR and some schemes labelled as RoR have large reservoirs.

2 The Clean Development Mechanism (CDM), defined in Article 12 of the Kyoto Protocol (UNFCCC, 1997), allows a country with an emission-reduction or emission-limitation commitment under the Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets. A CDM project activity might involve, for example, a rural electrification project using solar panels or the installation of more energy-efficient boilers.

Pumped storage schemes

Pumped storage schemes consist of an upper reservoir and a lower water body, which often is the river itself, or another reservoir. During times of peak electricity demand, the water in the upper reservoir is released to the lower water body, driving turbines to generate power. During times of low demand and cost, excess power generated (or power from another source) is used to pump some water from the lower water body back to the upper reservoir via reversible pump-turbines. These schemes act like an efficient battery, storing energy and responding instantly to fluctuating power supply and demand in the electricity grid.

Hydropower trends

Hydropower development slowed during the 1990s and early 2000s, largely because of resettlement controversies around large dams. Hydropower has since witnessed a resurgence, reflecting its dual role in climate change mitigation, as well as its contribution to energy security and economic growth. Progress in managing environmental and social impacts has also aided its resurgence (World Bank, 2009).

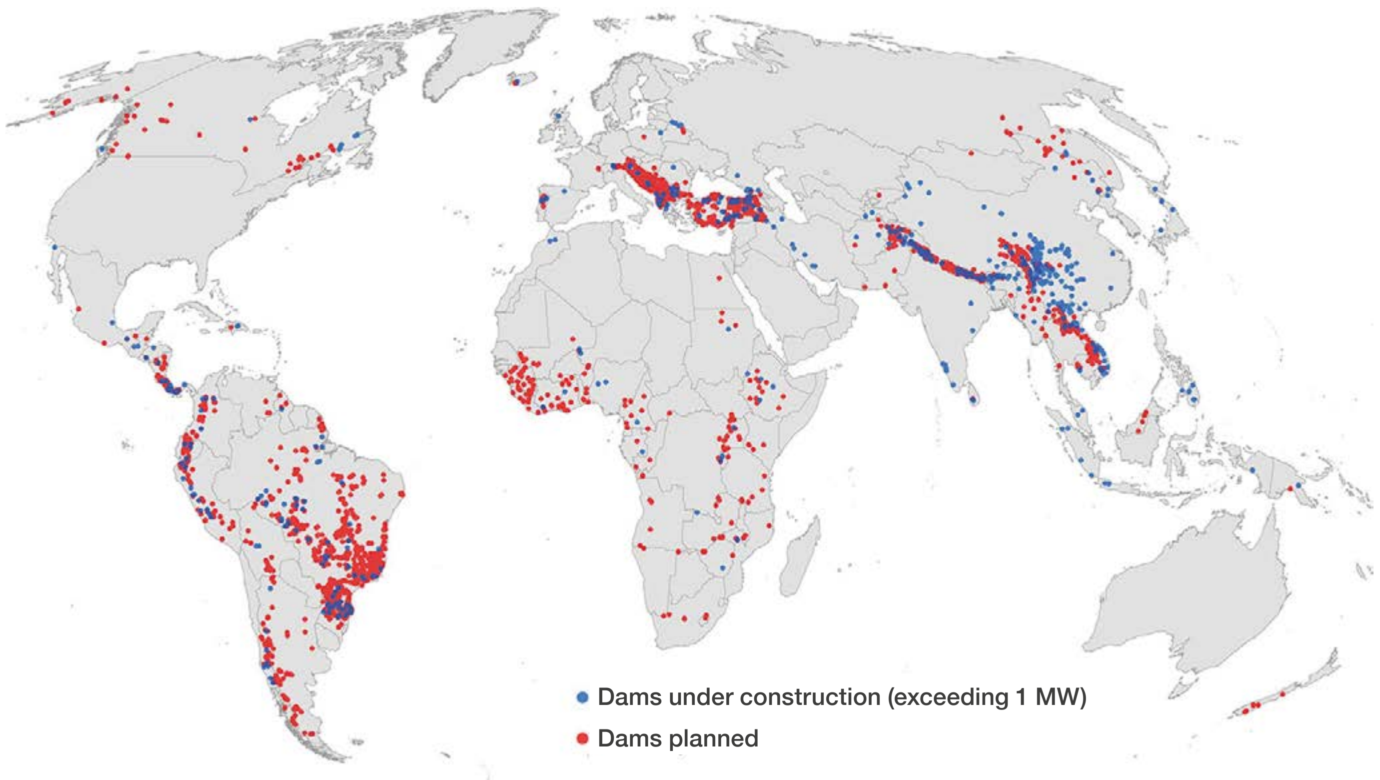
Recent international agreements are likely to drive further growth in the hydropower sector, especially in emerging and developing economies (IHA, 2016): the UN Sustainable Development Goals (SDGs) include a specific goal related to energy: "ensure access to affordable, reliable, sustainable, and modern energy for all", calling for a substantial increase in the share of renewables by 2030 (UN, 2015a). In December 2015, the parties to the UN Framework Convention on Climate Change (UNFCCC) agreed to reduce anthropogenic greenhouse gas emissions in order to limit global warming to "well below 2°C" (UNFCCC, 2015). Meanwhile, organisations such as the World Bank remain committed to supporting well-designed and implemented hydropower projects for climate mitigation as well as local development (REN21, 2016). The newly formed China-led Asia Infrastructure Investment Bank (AIIB) is likely to prioritise hydropower for renewable energy investment.

From an economic and technical perspective, substantial potential exists for hydropower development, much of it within developing countries (World Bank, 2010). In 2015, it was estimated that at least 3,700 major dams were either planned or under construction (Figure 4), and would increase global hydroelectricity capacity by 73% (Zarfl et al., 2015). Construction is concentrated in parts of South America, China, parts of Sub-Saharan Africa, the Himalayas, Southeast Asia, Eastern Europe and Western Asia. Only modest increases are expected in OECD countries: although remaining potential for hydropower does exist in parts of North America and Europe, regulations and societal expectations limit economic feasibility.

Hydropower effectively complements variable renewables such as solar and wind and is being increasingly used in hybrid projects which work to reduce variability in power supply (REN21, 2016). Pumped storage, as the most practical form of electricity storage available on a large-scale and at a competitive cost, is particularly important for grid services and hybrid projects and is growing in importance, increasing by 6.4 GW in 2016 (IHA, 2017). International cooperation on hydropower and other renewables is increasing, with countries sharing power transmission and creating regional power pools (IHA, 2016). These networks can incentivise the development of hydropower capacity for export (IEA, 2012).

However, the relative reliability of hydropower is being questioned. Wind and solar technologies have progressed rapidly in recent years along with battery capacity, and RoR projects are vulnerable to seasonal river flow fluctuations. Meanwhile climate change is likely to have significant impacts on the timing and quantity of river flows; the performance of hydropower projects will likely decline in those places where precipitation decreases or becomes more variable.

Figure 4. Hydropower dams planned or under construction. Source: Zarfl et al. (2015)



Dams for flood control

Dam reservoirs can temporarily store flood water and release it later, thereby regulating river levels and flooding downstream. Reservoir levels are usually lowered before the flood season to create more storage for flood water. Some 9% of large single purpose dams on the ICOLD registry are used for flood control. Flood control is also a significant purpose of many multipurpose dams. Flood control is actually the main purpose of the Three Gorges Dam in China, the world's largest hydropower scheme.

The United States Army Corps of Engineers estimates that its dams and levees have saved US$387bn in flood damages since 1928 (WCD, 2000). However, this does not take account of damages where its flood control projects encouraged development that was later inundated. In addition to giving a – sometimes – false sense of security, dams can actually create or exacerbate floods due to dam breaks, poor reservoir operation and/or by reducing river channel capacity through modifying downstream sedimentation. As a result, more integrated approaches to flood management are being pursued which constitute a mixture of prevention, defence and mitigation, bringing together engineered and natural solutions (Opperman et al., 2017b).

Dams for other purposes

According to the ICOLD registry, 5% of large single purpose dams are primarily for recreation, and less than 1% for navigation and fish farming (ICOLD, 2017a). However, these purposes are often secondary purposes of hydropower, irrigation and water supply dams.

In terms of navigation, dams are usually part of a suite of navigation infrastructure including locks, ports and canals. These are built and operated to control flow, level and channel geomorphology to facilitate water transport. Inland navigation has existed for centuries as a means to travel and trade, underpinning the growth of many societies. Today, it still offers many advantages compared with road and rail transport, including the high load carrying capacity of boats and barges, the ability to handle cargo with large dimensions, and fuel savings. A river that has been developed for navigation may also provide additional benefits such as flood control, reduced erosion and recreation.

A.2 ENVIRONMENTAL AND SOCIAL IMPACTS OF DAMS

Dams have had significant, complex and far-reaching impacts on both humans and nature. Dams have caused tens of millions of people to be displaced and 48% of river volume globally is moderately to severely impacted by flow regulation and/or fragmentation by dams (Grill et al., 2015).

The most immediate and obvious impacts of dams are found upstream where habitats, productive landscapes, infrastructure and settlements are submerged and flowing rivers become reservoirs. But significant effects also occur downstream. Dams severely modify the river's hydrological and sediment dynamics: high flow releases cause channel erosion downstream (Wisser et al., 2013; Kondolf, 1997); the eroded material (sand, gravel, rock, silt) is not replenished because the dam traps sediment. This causes a change in river depth and velocity and sometimes the erosion of deltas, resulting in land instability and intrusion of sea water into water supplies (Box 1). Farmland downstream is starved of nutrient-rich sediment. Dams also seriously impede the migration of aquatic species and this leads directly to the decline and local extinction of many species.

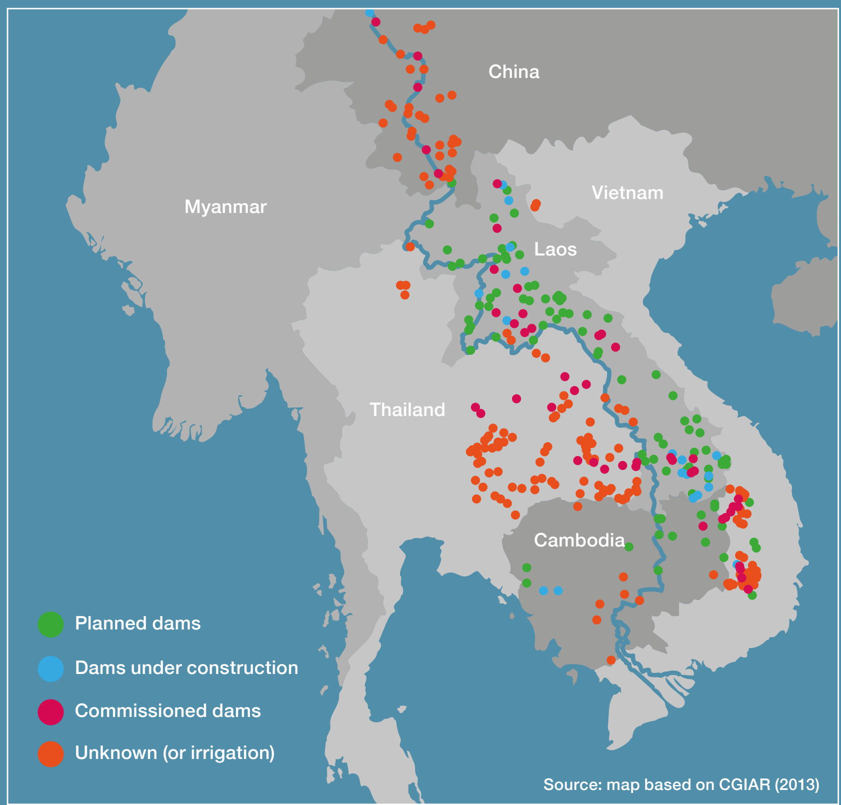
These downstream impacts have contributed to the huge loss seen in freshwater species populations[3]. They also disrupt livelihoods that depend on natural river processes such as fisheries, flood-recession agriculture and floodplain grazing. Essentially, the dam appropriates common property resources such as river and wetlands for other uses, often resulting in a loss of livelihood opportunities (Foster & Briceño-Garmendia, 2010). It is estimated that 472 million river-dependent people are potentially affected by dam-induced changes in river flows and ecological processes (Richter et al., 2010).

The impacts of individual dams have long-term effects upstream and downstream. These overlap with the impacts of other dams, and other pressures such as pollution, to create basin-scale cumulative impacts on the river's hydrological regime and ecosystem services.

Box 1. Sediment and the Mekong Delta

At least 140 dams are now built, under construction or planned in the Mekong Basin. It is estimated that if all were built as currently planned, sediment trapping would result in a 96% reduction in sediment load to the Mekong Delta. This would have profound effects on the river's productivity and on the persistence of the delta. Satellite imagery analysis indicates that between 2003 and 2012 over half of the once advancing delta shoreline was experiencing land loss. This is leading to saltwater intrusion and increased vulnerability to sea-level rise and typhoons. Land loss is linked to hydropower development as well as riverbed sand mining.

Sources: Kondolf et al. (2014); Anthony et al. (2015).



3 Abundance of freshwater populations has declined by 81% between 1970 and 2012 according to WWF's Living Planet Report (WWF, 2016a).

Dead trees drowned by Itaipu lake created by the Itaipu dam in the Atlantic rainforest, Brazil-Paraguay border.

Reservoir impacts

Dams cause a net loss of water from the river basin through evaporation from their reservoirs. Poor siting and design of dams can leave large, shallow reservoirs exposed to huge levels of wastage, particularly in dry regions (Torcellini et al., 2003). For example, approximately 16% of the Zambezi River's mean annual flow is lost to evaporation from reservoirs, resulting in hydropower being the biggest consumer of water in the basin (Euroconsult Mott MacDonald, 2008).

Another impact is the release of carbon dioxide, methane and nitrous oxide from decaying biomass inundated by reservoirs (St. Louis et al., 2000; Deemer et al., 2016). Reservoirs have been reported to contribute to about 1.3% of human-induced greenhouse gas (GHG) emissions globally, equivalent to that contributed by Canada as a whole nation (Cornwall, 2016). However, there has been a lack of scientific consensus on how to quantify GHG emissions from reservoirs, and this uncertainty has been a significant obstacle for accessing green finance for hydropower projects. For example, a number of green bond issuances exclude all large hydropower investment in tropical zones due to concerns over methane emissions. UNESCO and the International Hydropower Association (IHA) have led a multi-year research project to develop a new conceptual approach, captured in the new G-res tool[4]. The approach takes account of the GHG footprint prior to impoundment; the specific environmental conditions of each reservoir; and the evolution of GHG emissions over the reservoir's lifetime. The research indicates that, on average, 75% of carbon dioxide emissions observed on reservoir surfaces should be considered natural – i.e. they would have occurred even if the reservoir did not exist (IHA, 2017).

Hydropower-specific impacts

Hydropower operation can involve 'hydropeaking', where flow release is increased for a few hours a day in order to respond to times of increased electricity demand. This practice makes hydropower a valuable energy source, but the rapidly fluctuating levels in the reservoir and in the river downstream can be damaging for ecosystems, particularly during times of fish spawning. It can also limit river navigation and is hazardous to hikers, fishers and swimmers downstream. Meanwhile schemes involving a diversion can cause depleted flows along a significant stretch of river, and the returning water is likely to be of a different velocity and temperature.

Benefit distribution

Benefits from dams are not always well distributed. For example, some water storage projects have benefited upstream water users at the expense of downstream users, who lose access to some or all high quality water. In developing countries, the benefits of power generation are often received by urban communities connected to the national grid, or neighbouring countries. Meanwhile local communities, who may be impacted by the project, do not have electricity infrastructure or cannot afford the costs of connection to their homes (Mott MacDonald, 2009).

There has been a long standing debate about how to balance the benefits of dams against the risks of damage to the environment and community (WIGO, 2016). This was addressed by the report of the World Commission on Dams[5] (WCD, 2000) which set out a framework for decision-making around large dams in order to avoid further socio-economic impacts and large-scale biodiversity loss.

4 More information available at: www.hydropower.org/topics/technical/gres
5 Available at: www.internationalrivers.org/sites/default/files/attached-files/world_commission_on_dams_final_report.pdf

A.3 DEBATES AND TRENDS

Is small beautiful?

There is a general assumption that large dams have greater impacts than small dams (Skinner & Haas, 2014). Many countries have specific policies that promote and/or facilitate smaller projects, particularly hydropower schemes, subjecting them to less rigorous scrutiny and regulatory oversight (Opperman, 2014). For example, in the US, several states have disallowed large hydropower schemes, but encourage small schemes, in part due to the assumed lower impacts of small dams. Meanwhile, the CDM promotes small hydropower and subjects it to a less rigorous review.

There is no universal agreement on how to define a small dam. For hydropower, many countries (as well as the EU) define small as having an installed capacity of 20 MW or below (Skinner & Haas, 2014). Other size metrics include dam height (ICOLD, 2011), average annual energy production (GWh), or reservoir area (km^2), but the latter two are less well documented and vary seasonally.

There is evidence to show that numerous small hydropower projects can have significant cumulative impacts, exacerbated by poor design, siting, operation (Skinner & Haas, 2014) and by large numbers. Hy:Con, a tool created in Austria to identify the most economically attractive yet conservation-friendly hydropower, found multiple small dam projects ranked significantly lower than single, large dam projects (Seliger et al., 2015).

Individual small dams have been found to cause significant impacts too. A study on the Nu River in China (the Salween downstream of China) looked at the scaled impacts of a number of hydropower dams across 14 metrics. It found that small dams (< 50 MW, as defined by Chinese Policy) had a greater impact than large dams per MW of installed capacity for nine of the 14 metrics, including length of river channel affected and impact on designated habitat (Kibler & Tullos, 2013). Meanwhile, a study by Schmutz et al. (2010) demonstrated that small hydropower projects can impact a greater length of river than large RoR dams for the amount of energy produced (200 m rather than 42 m per 1G Wh/year).

However, well-planned small dams do have certain advantages – for example, less or no resettlement, less severe construction impacts, more effective fish passage, lower removal costs, and less damaging impacts should they fail. In addition, the distribution of benefits and impacts from small dams is often more appropriate: while the impacts are largely borne by local people, the benefits (such as irrigation water and electrification) are usually accrued by local people too.

Multi-purpose dams

The different objectives of multi-purpose dams are often competing (Kundzewicz et al., 2008). For example, using reservoirs for flood control requires creating empty storage space before the flood season. This reduces the head (the elevation difference between upstream and downstream water levels) available for power generation. If flood flows do not arrive as expected and refill the reservoir the water available for power generation is reduced. The level fluctuations associated with flood control can also be detrimental for other reservoir functions such as navigation, recreation and fisheries. These trade-offs reflect the challenge of integrating water resources management across multiple locations, times, objectives and economic sectors in a river basin.

In practice, most multi-purpose projects cannot fulfil all expectations. This is partly because most dams are managed based on a set of 'rule curves' (bound by licenses or contracts) that guide operations, rather than continuous optimisation based on current or forecasted conditions. In addition, the primary investor and operator usually prioritise a particular function. Often only certain functions (such as power generation) actually generate income for the operator or owner, while other functions (such as flood control) are delivered without compensation – often because they are deemed public goods. This creates an imbalance when negotiating trade-offs between different functions, and effective regulation and/or financial incentives might be needed to accommodate certain functions.

Optimising reservoir operation requires a full and transparent appraisal of benefits and trade-offs, involving competing users. Steps are being made towards this – for example, the World Water Council and EDF are developing the SHARE concept[6] to guide the successful implementation of multipurpose hydropower dams (Branche, 2015).

6 The SHARE framework was developed to tackle the challenges of multipurpose hydropower. It offers guidance, based on case studies, on particular issues associated with multi-purpose reservoirs, including governance issues. It also provides tools to avoid/reduce tensions among users and financial/economic models to develop and operate multipurpose reservoirs.

Climate change and hydro-climatic variability

Climate change and growing water demands pose new challenges for water management, and policy makers are once again advocating for water storage dams as a means of addressing perceived risks from unpredictable rainfall and promoting economic growth (Crow-Miller et al., 2017; Perry & Praskievicz, 2017). Storage facilitates the availability of water during prolonged dry periods and can help attenuate floods.

The World Bank has returned to financing large storage dams in developing countries, promoting them as necessary tools for climate adaptation (World Bank, 2016). In the US and other developed countries, the return to supply-side solutions is manifesting itself in auxiliary infrastructure projects such as dam augmentation and aquifer storage and recovery. The environmental and social impacts of these projects are deemed relatively small and so they come under existing environmental and development regulations (Perry & Praskievicz, 2017).

However, dams can also limit climate adaptation and development options due to their inherent inflexibility (Dalton, Murti, & Chandra, 2013), including locking-in significant investment for long periods of time. The viability of many dams is also at risk because of the impacts of climate change on rivers (WCD, 2000):

- Modified and variable inflow due to changes in precipitation, evaporation and glacier melt in the upstream catchment.
- Higher magnitude floods, increasing the risk of dam failure and the likelihood of spills and emergency releases, posing a danger to communities downstream.
- Greater evaporation from reservoirs due to higher temperatures.
- Increased sedimentation in reservoirs due to increased rainfall-runoff and soil erosion in the upstream catchment.
- Increased tensions within multipurpose water systems due to less water, less storage capacity and increased uncertainty.

A global analysis of how climate change will affect hydropower conducted by Hamududu and Killingtveit (2012) suggested that, at the continental scale, the effect on hydropower was relatively small, but this masked larger increases and decreases at the scale of individual countries. RoR schemes will be more vulnerable to hydrological changes than storage reservoirs, as will projects that rely on glacier and snowmelt (Pittock et al., 2015). In the short term, higher rates of glacial melt will increase the availability of water below glaciers, but longer term the decline in glaciers will dramatically reduce summer flows from upper catchment areas.

Overall, infrastructure planning and rehabilitation must take a long-term view, which accepts significant hydro-climatic variability. Existing dams may no longer be fit for purpose and require removal or significant retrofitting (e.g. to increase storage). New dams or alternatives to dams may be needed.

Grey and green infrastructure

While grey infrastructure has long been the primary focus for provision of water management services, planners and practitioners have begun to recognise the importance of green infrastructure such as floodplain wetlands and watershed forests in addressing water management challenges. Green infrastructure constitutes "natural or semi-natural ecosystems that provide water utility services that complement, augment or replace those provided by grey infrastructure" (UNEP, 2014). Typically, green infrastructure involves a deliberate effort to optimise the natural functions of ecosystems and the provision of ecosystem services.

Depending on context, green infrastructure can act as a viable alternative to dams in providing the following services (Campbell et al., 2009; Silva et al., 2010; UNEP, 2014):

- **Flood management.** Forests can help slow down and absorb runoff. Forests also stabilise banks, reducing soil erosion and landslides. Floodplain wetlands store water and create room for the river, thereby increasing channel conveyance and reducing the pressure on levees.
- **Water storage and drought mitigation.** Forests and wetlands can slow down runoff, encouraging infiltration and groundwater recharge. Recharge can be enhanced through techniques such as infiltration ponds. In dry periods, natural storage (including soil, groundwater and wetlands) can slowly release water, augmenting low flows.

In many cases green infrastructure can offer distinct benefits when compared with grey infrastructure, for example (Bouwer, 2011; Dalton, et al., 2013; Russi et al., 2013; Sudmeier-Rieux & Ash, 2009; UNEP, 2014):

- It can be a cost effective investment as it is often cheaper to maintain and modify; grey infrastructure tends to be capital intensive to build, operate, maintain and replace.
- It can appreciate in value and function over time, as vegetation grows and soils regenerate; meanwhile the value and function of grey infrastructure usually decreases over time.
- It can be more adaptive to changes in climate, and can improve resilience of ecosystems and communities; grey infrastructure is often inherently inflexible.
- It generally cannot 'fail' in a catastrophic manner, whereas failure of grey infrastructure – such as the collapse of a dam – can result in sudden and severe impacts.
- It creates a number of secondary benefits – e.g. wetlands support wildlife and provide recreational benefits, as well as recharging groundwater and improving water quality.

In some places restoration of green infrastructure is being incorporated into mainstream water resources management. For example, the Netherlands is setting back levees and recreating natural flood retention and bypass areas through its Room for the River[7] initiative. However, generally the uptake of green infrastructure for water management has been slow, with the majority of projects only implemented at demonstration level. There are some challenges that help explain this, including (Reid, 2011, 2014; Renaud et al., 2013; UNEP, 2014):

- Few countries have funding policies or land use regulations that encourage investment at scale in green infrastructure, or that enable the integration of green and grey infrastructure.
- Green infrastructure often requires significant space: land is scarce and people will not easily give up land, property and associated livelihoods.
- It takes time for forests and wetlands to mature and so longer timescales are required to yield outcomes and returns on investment.
- Ecosystem responses to change are non-linear and unpredictable. When engineers are legally responsible for certain outcomes, they will lean towards tested, codified solutions.
- The ability of green infrastructure to support water management depends on the complex and highly context-specific relationship between forest/wetland cover and water flows[8].
- There is a lack of robust analytical assessments of the cost-effectiveness of green infrastructure – in part due to its inherent complexity and unpredictability.

There are also limits to what green infrastructure can practically do: it cannot provide electricity, and there may not be enough flood plain available to reduce flood risk to large populations. There are also trade-offs with utilising green infrastructure – for example, floodplains can be indispensable for agriculture, which may be more valuable to society than flood control.

There is a need for commonly accepted methodologies that effectively analyse the costs and benefits of green infrastructure. But rather than directly comparing green and grey infrastructure, more emphasis needs to be placed on how they can interact to enhance water-related services.

7 More information available at: www.ruimtevoorderivier.nl/english

8 This relationship needs to be understood and evidenced for each context where green infrastructure is being considered. Overall, the impact of forest cover on flows depends on local climatic conditions, altitude, topography, soil and forest type. For example, native forests have been shown to help maintain and regulate water flows (Dudley & Stolton, 2003); however, it has been demonstrated that tree planting initiatives can increase evapotranspiration and reduce run-off (Jackson 2005; Pittock et al., 2013). Meanwhile, wetlands can help augment low flows (Falkenmark & Rockström, 2008), but in some circumstances can have the opposite effect through increased evapotranspiration (e.g. Bullock & Acreman 2003).

Awareness of risk reduction

Risks to businesses involved in dam development include physical risks in the form of technical difficulties with construction, geology, insufficient river flow for effective operation, or unforeseen natural hazards. Regulatory risks stem from the need to comply with national regulations, which may be subject to change. Reputational risks arise through adverse impacts to communities and the environment, and through the perception of mistakes. Financial risks arise through liability for mistakes and the delay caused by - and the expense of - managing other risks. Failure of corporate or institutional governance (such as corruption) is another source of multiple risks. Anticipating and mitigating these risks can help increase a dam project's performance, reduce long-term costs and maintain financial returns.

In many countries, reputational risks are becoming increasingly important with the rise in corporate social responsibility (CSR), bolstered by increased public scrutiny of corporate decisions and increased availability of information to the public. However, drivers for CSR do not exist in all countries. For example in the Lower Mekong region, market dominance of state-owned electricity companies means that shareholders and consumers have struggled to influence decisions. This, combined with a weak civil society in Lao PDR (Matthews, 2012), means that major dam construction has been initiated without sufficient consideration of sustainability issues.

There are an increasing number of tools that can help dam developers identify and manage risks. These include risk assessment tools, such as WWF's Water Risk Filter, designed to assess risks linked to the river's catchment – such as low flows – that can potentially affect the performance of dams. They also point companies to safeguards (see next section) which are used to assess and manage adverse impacts resulting from dam projects.

Emergence of environmental, social and governance safeguards

Environmental, Social and Governance (ESG) safeguards cover standards, guidelines and assessment tools which aim to improve performance and promote transparency, integrity and accountability. These safeguards help identify risks of environmental and social impact, hold developers to account in reducing these risks, and introduce an element of competition between them with respect to social and environmental performance.

All dam projects are subject to national statutory safeguards with regards to ESG issues. These include regulations for conducting Environmental Impact Assessments (EIAs), and environmental/social conditions in project agreements linked to national law (e.g. power purchase agreements (PPAs)[9], project development agreements (PDAs) and project concession agreements (CAs)).

In addition, a number of international ESG safeguards exist. These raise the bar higher than national statutory regulations. Some are regional guidelines often underpinned by international agreements (for example, the ICPDR Guiding Principles on Sustainable Hydropower 2013 – see Figure 5) and may or may not be mandatory. Others are linked to the source of finance and are usually conditional:

- Development banks – such as the World Bank and the Asian Development Bank (ADB) – use their own safeguards to try to reduce adverse impacts from the projects that they finance. These safeguards are legally binding on all parties that receive or provide financing for projects. They are generally monitored and independently verified.
- Some private banks have chosen to follow guidelines such as the Equator Principles (Box 2). Outside the development bank safeguards, the Equator Principles are the main framework used to assess and manage ESG risks in dam finance transactions. However, much private financing does not require adherence to safeguards beyond national standards (Skinner & Haas, 2014).

9 A power purchase agreement (PPA) is a contract between two parties, one which generates electricity (the seller) and one which purchases electricity (the buyer). The PPA defines all of the commercial terms for the sale of electricity, including when the project will begin commercial operation, the schedule for delivery of electricity, penalties for under delivery, payment terms, and termination.

Overall, a number of ESG safeguards exist which may apply to a particular project. These are illustrated in Figure 5, which includes examples of specific safeguards.

Figure 5. ESG safeguard landscape

MANDATORY

NATIONAL REGULATIONS – applicable to all projects and dependent on host country

- SEAs, EIAs
- Environmental & social conditions in project agreements (e.g. project development agreements (PDAs), project purchase agreements (PPAs) and concession agreements (CAs))
- Compensation, benefit sharing and resettlement standards

STANDARDS LINKED TO FUNDING SOURCE

- World Bank and other development bank safeguard policies
- Equator Principles
- OECD Export Credit Group Renewable Energy Agreement Guidelines

VOLUNTARY

REGIONAL GUIDELINES

- Mekong Preliminary Design Guidance
- ICPDR Guiding Principles on Sustainable Hydropower

INTERNATIONAL GUIDELINES AND TOOLS

- EU Linking Directive
- WCD Principles
- HSAP/The Protocol
- IEA Technology Collaboration Programme on Hydropower
- ICOLD technical guidelines

Notes:

EU Linking Directive (EU, 2004). states that CERs (Certified Emission Reductions) from large hydropower projects (>20 MW) can only be used in the EU ETS (Emissions Trading Scheme), when relevant international criteria and guidelines, including those contained in the WCD (2000), will be respected during the development of such project activities Available at: eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32004L0101:EN:HTML

Equator Principles (2013). Adopted by some private banks. Further information in Box 2. Available at: www.equator-principles.com/resources/equator_principles_III.pdf

HSAP/The Protocol (IHA, 2011). Hydropower Sustainability Assessment Protocol. A monitoring tool used to assess hydropower project performance against a range of sustainability topics and indicators. Available at: www.hydrosustainability.org/Protocol/The-Protocol-Documents.aspx

ICPDR Guiding Principles on Sustainable Hydropower in the Danube Basin (ICPDR, 2013). Developed through dialogue with representatives from the hydropower sector following a request by the Danube Ministerial Conference 2010. Available at: www.icpdr.org/main/activities-projects/hydropower

ICOLD technical guidelines. A series of bulletins of different technical aspects. Available at: www.icold-cigb.net/GB/publications/bulletins.asp

IEA Technology Collaboration Programme on Hydropower. A working group of International Energy Agency member countries and others that have a common interest in advancing hydropower worldwide. Available at: www.ieahydro.org/about

Mekong Preliminary Design Guidance (MRC, 2009). Provides developers of proposed dams on the Lower Mekong mainstream with an overview of the issues that the Mekong River Commission (MRC) will be considering during the process of prior consultation under the 1995 Mekong Agreement. Available at: www.mrcmekong.org/assets/Publications/Consultations/SEA-Hydropower/Preliminary-DG-of-LMB-Mainstream-dams-FinalVersion-Sept09.pdf

OECD Export Credit Group Renewable Energy Agreement Guidelines (OECD, 2005). Agreement on special financial terms and conditions for renewable energy and water projects. Available at: search.oecd.org/officialdocuments/displaydocumentpdf/?doclanguage=en&cote=td/pg(2005)19/final/corr

WCD Principles (WCD, 2000). Principles for decision-making on large dams. More information in Box 3. Available at: www.internationalrivers.org/sites/default/files/attached-files/world_commission_on_dams_final_report.pdf

World Bank safeguard policies (World Bank, 2017). These policies require borrowing governments to address certain environmental and social risks in order to receive Bank support for investment projects. The current policies will be replaced during 2018 with the Environmental and Social Framework (ESF). Available at: www.worldbank.org/en/programs/environmental-and-social-policies-for-projects/brief/environmental-and-social-safeguards-policies

Box 2. Equator Principles

The Equator Principles were first established in 2003 in collaboration with the International Finance Cooperation (IFC). The latest review and update was in 2013. The principles comprise a set of minimum standards for due diligence when assessing and managing ESG risks for projects with capital costs of more than US$10 million. They are based on the World Bank's Environmental, Health and Safety Guidelines, and require compliance with IFC's Performance Standards on Social and Environmental Sustainability (considered the leading benchmark for corporate ESG risk management (West, 2013)). The Equator Principles have been adopted by almost 80 banks and cover more than 70% of international project finance debt in emerging markets.[1] However, few Asian banks have adopted them and so 75% of private infrastructure funding in Asia escapes them.

Sources: Equator Principles (2013); Skinner & Haas (2014).

A particularly important milestone in the improvement of ESG standards was the publication of the World Commission on Dams (WCD) guidelines in 2000 (Box 3). Over time, the WCD has seen many of its recommendations taken up by financers, developers and regulators. Multilateral donors, for example, have incorporated its concepts into their ESG policies, and the EU and the OECD have used it to improve national standards. Indeed, the WCD's framework is considered by many as the most comprehensive and useful guidance for dam decision-makers (Foran, 2010), and it still serves as an important reference point for the debate on sustainable water infrastructure (Skinner & Haas, 2014).

Box 3. World Commission on Dams – seven strategic priorities

The report Dams and Development (WCD, 2000), outlined seven strategic priorities and 26 guidelines as a framework for decision-making on large dams. It comprehensively framed the development opportunities and risks, and advocated for the assessment of costs and benefits and consultation with stakeholders. However, it was not prescriptive or intended as a blueprint: WCD argued for negotiated outcomes appropriate to each national and local context.

The WCD seven strategic priorities:

1. Gaining public acceptance;
2. A comprehensive options assessment;
3. Making best use of existing dams;
4. Sustaining rivers and livelihoods;
5. Recognising entitlements and sharing benefits;
6. Ensuring compliance;
7. Sharing rivers for peace, development and security.

The Hydropower Sustainability Assessment Protocol, 'the Protocol' hereafter, has operationalised many of the principles of the WCD (HSAP, 2011). The Protocol was developed by a multi-stakeholder forum, composed of developing and developed countries governmental agencies, industry, development banks and commercial banks of the Equator Principles group, and WWF, The Nature Conservancy (TNC), Oxfam and Transparency International.

The Protocol is a tool to measure and guide performance of hydropower projects and plans. It measures project performance against defined sustainability topics and indicators. It can be applied at the four project stages: early, preparation, implementation and operation. Most applications focus on single projects, but the early stage component can also be applied at a river basin, country, or system scale. Projects are assessed and scored against up to 23 topics of best practice under four categories: environmental, social, technical, and economic/financial. These are based on definitions of good practice agreed by multiple stakeholders. The official assessments are led by a certified assessor and engage government, civil society, private sector actors and local communities. In 2017, 24 assessments had been undertaken, covering all continents and project stages and sizes, single and multi-purpose projects.

The Protocol is not a standard so it doesn't replace bank safeguards or regulatory requirements such as the European Water Framework Directive (WFD). Rather it is a standardised tool for measuring sustainability and can be used to inform other requirements – for example, the World Bank promotes the use of the Protocol to guide the application of its Safeguards.

While it has yet to show widespread uptake and impact, a review of ESG safeguards (Skinner & Haas, 2014) found the Protocol to be the best tool for operationalising the principles of the WCD. New initiatives such as green and climate bonds are increasingly recognising the Protocol, and this is promoting the development of more focused, lower cost derivatives of the Protocol to attract finance and mainstream sustainability standards in the hydropower industry (IHA, 2017).

There are documented examples of where the application of good standards has resulted in reduced, and better managed, social and environmental impacts. For example, the Gulpur Hydropower Project in Pakistan (Box 4) is an example of how stringent ESG standards of development banks can play a critical role in reducing the ecological impacts of dams. The IHA has recently published a compendium of case studies on projects that have undergone a Protocol assessment, each one showcasing one of the Protocol's topics in which they scored highly (IHA, World Bank & HSAP, 2017). For example, the Chaglla project in Peru is an example of how independent third-party reviews of the EIA helped boost performance and innovation; and strong engagement with local communities and partners improved pre-project conditions.

In addition to project-specific ESG approaches, strategic tools are emerging that address more fundamental issues such as project siting, based on comprehensive system-level planning and analysis of cumulative impacts. These are discussed in Section C1.

Box 4. Gulpur Hydropower Project, Pakistan

The Gulpur hydropower project is being developed on the Poonch River, originating in the Western Himalayas. The planning and initial EIA occurred in the absence of an environmental flow assessment. However, the international agencies funding the project (ADB and IFC) have very strict ESG standards and required an environmental flow assessment to be completed due to the presence of two globally threatened fish species in the National Park.

Through extensive stakeholder engagement; review of the assessment by government environmental departments and environmental NGOs; alterations to the project design; and the development of a Biodiversity Action Plan; the project was approved. The project has set the precedent for future hydropower projects in the region. This case demonstrates the importance of stringent ESG standards, but also the importance of a strong legal framework to uphold the environmental conditions set on projects.

Source: Harwood et al. (2017)

Financing trends for large dams

New infrastructure projects are highly capital-intensive so sourcing finance is a major consideration. Often financers exert significant influence over project choice and design as well as ESG standards.

Finance for – and development of – water infrastructure is progressively shifting from the public to the private sector. This is particularly the case for hydropower where investors are motivated by the stable revenue streams expected from power generation (IHA, 2016) and electricity supplier markets have begun to deregulate (Skinner & Haas, 2014). A number of state-owned hydropower assets and concessions have recently been privatised: for example, Brazil sold its operating rights for 29 hydropower plants for US$4.51bn; Turkey announced tenders for the privatisation of 10 hydropower plants with a combined installed capacity of 538MW (IHA, 2016); Mexico's Federal Commission for Electricity went from state-owned to private. A new class of commercial hydropower developers is therefore emerging, looking for sources of finance.

There are several sources of finance for dams and hydropower, as highlighted in Box 5. Often the finance for a single large dam is provided by a number of sources and new blended finance models are emerging which are making investment more attractive (IHA, 2016) – for example, development funding is often leveraged with private capital, and vice versa. Profundo (2008) describes three archetypal finance models (Table 1) for large dam projects, while recognising that the financing for each individual dam can be quite different and no dam fits exactly into a certain type of model. Table 1 sets out for each of these 'models': typical funding sources, associated ESG safeguards and relevant trends.

Box 5. Sources of finance for dams and hydropower (adapted from Profundo, 2008)

1. Debt finance

- Multilateral development bank loans – e.g. from the World Bank, ADB, EIB.
- National development banks loans from government-owned development banks in the host country - e.g. Brazilian Development Bank (BNDES), China Development Bank.
- Private sector bank loans from foreign and domestic commercial banks.
- Bilateral Export Credit Agency (ECA) loans – loans from an overseas government ECA to the project, to enable the project to buy goods and equipment from that country. This could be for hydropower technology, which can account for around 30% of the investment cost of a hydropower scheme. They facilitate bilateral business.
- Bonds issued by project developers to institutional and private investors such as pension funds, insurance firms, and asset managers. Green bonds finance projects that reduce environmental and/or climate risks. They are a new and rapidly growing source of finance for clean energy, including hydropower, which is currently the largest sector within climate-aligned bonds. However, a number of green bond issuances exclude large hydropower investment due to concerns about environmental impact; as a result, the Climate Bonds Initiative (CBI)[2] is developing new science-based criteria for screening hydropower projects.

2. Equity finance

- Provided by equity holders in the project, including governments, development banks, and project developers.

3. Grants/subsidies

- National subsidies – e.g. small hydropower in the EU can benefit from feed-in tariffs or green certificates.
- Development bank grants to fund projects in developing countries.

Table 1. Typical finance models and associated ESG safeguards and trends

Dam finance model (Profundo, 2008)	Typical sources of finance	Associated ESG safeguards	Trends
Development Dams: established to develop water and hydropower resources in low-income countries that do not have sufficient means to finance dams with domestic capital	Development banks (e.g. World Bank, ADB) often used to finance feasibility studies and attract other forms of lending	Development bank safeguard policies – e.g. World Bank Safeguards, IFC Performance Standards	Since the 1990s, multilateral and bilateral development banks are playing an increasingly smaller role in terms of their direct financial commitment to 'Development Dams'. However, their support with planning and assessments can help attract funding from other sources (Profundo, 2008). Chinese corporations have instead become the single largest financer of hydropower in developing countries (Skinner & Haas, 2014).
	Bilateral/regional carbon funds – e.g. EU Emissions Trading Scheme (ETS), OECD export credits for renewable energy	EU Linking Directive which regulates carbon credits in the EU ETS – asks for WCD standards to be met. OECD's Export Credit Group Renewable Energy Agreement Guidelines (OECD, 2005)	The use of carbon markets to finance hydropower is becoming increasingly important. Large hydropower projects have received the highest carbon offsets through the CDM. European States dominate investment in hydropower via the EU ETS, but China plans a nationwide emissions trading system by 2017, expected to be the world's second largest (Soanes et al., 2016).
National Interest Dam: part of a strategy (usually of an expanding economy) to develop major hydropower and/or irrigation schemes	Funded through domestic sources of expanding economies that have financial means Principle source: state-owned electricity companies or national development banks Supplemented by: loans from domestic (private or state-owned) banks and the issuance of bonds on the domestic capital market	Possibly Equator Principles	Chinese state-owned development banks and power utilities fund significant dam development in China (but also overseas). National capital markets (pension funds, insurance companies, asset managers, private investors) of the host country will increasingly finance projects (Profundo, 2008).
Commercial Dams: developed for profit by a private company (financial loans are paid back with proceeds from the dam's operation). Financial feasibility likely to be more secure than with National Interest Dams or Development Dams (where political feasibility more important).	Principle source: domestic and foreign private banks Supplemented by: multilateral development banks and/or export credit guarantees (to limit financial risk). Electricity distribution companies can also play a significant role as financiers: either by direct investment in the hydropower company, or indirectly through signing long-term Power Purchase Agreements (PPAs).	Possibly Equator Principles	Chinese corporations have become the single largest financer of hydropower in developing countries (Skinner & Haas, 2014). Global capital markets will be tapped intensively by the emerging class of private hydropower developing companies (Profundo, 2008).

Overall, the reduction in importance of dams funded by the development banks, and the rise in 'national interest' and 'commercial' dams, means that fewer dams are covered by dam-specific international ESG safeguards such as World Bank and OECD policies. The review of ESG safeguards by Skinner and Haas (2014) indicates that only around 10–15% of new hydropower dams are covered by such policies, although Equator Principle finance may apply to rather more. However, given that only a handful of Asian banks adhere to the Equator Principles, the review concludes that the majority of hydropower dams today are constructed solely under the provisions of national legislation. China has become the single largest financer of hydropower in developing countries and has no explicit safeguard policy (Skinner & Haas, 2014), although some developers do now have their own policies.

The Tehri dam on the Ganges River, in the state of Uttarakhand, India. The dam became operational in 2005, and is one of the largest in the world. It is part of a project in which the Indian government plans to link 37 major rivers through a series of dams and canals to provide drinking water and generate electricity. In WWF's report 'World's Top 10 Rivers at Risk', the Ganges River has been identified as one of the 10 at risk, due to water withdrawal.

PART B
THE REALITIES OF DAM DECISION-MAKING

Despite the widespread availability of tools and guidance, dams around the world still generally underperform in terms of social, environmental and economic sustainability (Scudder, 2005). Many river basins are full of inappropriate dams.

There is evidence to suggest that dam development has been driven by a 'bias to build' mentality, prevalent across all infrastructure sectors (Flyvbjerg, 2005). Water resources management has long been a branch of engineering, undertaken with a can-do mindset that has prompted infrastructure solutions rather than seeking alternatives such as demand management and green infrastructure. This approach has been bolstered by research and policy messaging that promotes the importance of storage dams in increasing economic resilience to hydro-climatic variability (Grey & Sadoff, 2007; Garrick & Hall, 2014). In addition, the political economy in many contexts has resulted in power dynamics, special interests and optimistic economics that favour new infrastructure.

This part of the primer explores the governance issues and decision-making processes that have led to this 'bias to build' and the proliferation of inappropriate dams. Many of the issues draw on the common mistakes highlighted and exemplified in WWF's Seven Sins of Dam Building (WWF, 2013).

B.1 PIECEMEAL PLANNING

Infrastructure such as dams has often been developed in a piecemeal fashion, built on a first-come, first-served basis and without an underpinning master plan that provides a comprehensive evaluation of all project options. Due to this lack of system thinking, each new piece of infrastructure potentially competes with – or even interferes with – previous infrastructure investments.

The issue is particularly profound in the energy sector: many countries have deregulated their energy sectors, reducing government oversight of hydropower planning. Hydropower developers identify their preferred project sites according to criteria such as lowest risk, lowest cost per kWh, and installed generation capacity. Governments maintain some regulatory powers by requiring environmental impact assessments (EIAs) on proposed projects or, in some countries, issuing time-bound licenses to developers.

There are a number of issues that arise with developers cherry-picking dam projects in this way:

- Different project options, as well as no-go areas for development, are not properly defined and developers draw on incomplete information.
- Poor site selection can lead to impacts that cannot be effectively mitigated. Developers often assume that mitigation solutions can be found for any site, and that environmental and social risks can be evaluated much later, even during operation. However, this means that by the time such risks become apparent, developers and politicians may have already made significant commitments, leaving no easy way out.
- Developers are generally only responsible for one site and treat projects as if they were standalone. However, where there are multiple planned projects, economic, environmental and social effects can only be properly evaluated by looking at the cumulative effects of all projects in a basin or area.
- The objectives of the developer are not necessarily aligned with those of the host government and public interest. For example, a developer may only be able to obtain finance for a small project at a given site, while the best development option for that site would actually be a far larger project.
- The time horizon of developers is often relatively short due to the high cost of capital and/or the limited duration of licences and concessions. Many governments also have to operate within political windows of opportunity and short election cycles. This can lead to projects that do not perform well under a range of future conditions and insufficient attention being given to impacts – such as sediment – which only manifest themselves after decades.

Growing awareness of these problems has led a number of countries to re-consider their project selection. In some cases such a move has been triggered by major conflicts over projects, financial costs of delays and cancellations. Some countries have kept the selection of projects in the public domain, and only invite developers to bid on projects once these have been cleared through a systematic planning process. For example, Iceland regularly updates its energy master plan, and divides the remaining hydropower and geothermal potential into three categories (open for development, protected from development, and left for future consideration). Every four years, the new parliament appoints a stakeholder and expert committee, and at the end of the term, votes on the committee's proposals for development.

B.2 WEAK ENVIRONMENTAL-SOCIAL-GOVERNANCE SAFEGUARDS

Weak EIAs and other safeguards have constrained some countries' ability to balance development risks with opportunities for dam projects (IIED, 2015). Where safeguards are weak, or weakly enforced, dam developers may seek cheaper mitigation and compensation options to reduce impacts, rather than avoiding impacts in the first place. In some cases, short cuts may be pursued to achieve project completion and other considerations, including affected people's livelihoods and food security, are ignored (Box 6).

The specific issues associated with applying EIAs and international ESG safeguards are discussed below. In general, weak safeguards lead to uncertainty about the management of critical ESG risks, which reduces investor confidence (IIED, 2015). An ambiguous process for addressing ESG risks also makes it more difficult for local communities to engage constructively with dam projects to manage their risks.

Box 6. The design of the Manantali Dam, Senegal River Basin

Construction had already commenced on the Manantali dam before environmental and social safeguards had been properly assessed. The dam had been rushed through planning and design in order to take advantage of the increase in investment in commercial farming in the river basin and secure access to land. Major issues that were highlighted within the environmental assessments were left unresolved, most notably the lack of attention given to environmental flows.

Dam releases of 2,000 m^3/s were required to support downstream riparian agricultural production and maintain floodplain and estuarine ecosystems, but the installed flow capacity was only 480 m^3/s. Fish production in the river and estuary dropped by 90% within 15 years of dam completion.

Sources: DeGeorges and Reilly (2006); Krchnak et al. (2009)

Challenges with EIAs

Whatever the specifics of national standards, almost all countries require by law an Environmental Impact Assessment (EIA) which reviews the environmental, and often social, impacts of a project or various alternatives to a project. EIAs are most widely applied at the scale of individual projects, but this presents a number of weaknesses (Brismar, 2004; Opperman et al., 2015; Seliger et al., 2015):

- Project-level impact assessments cannot adequately address the complex issues and cumulative effects over time caused by multiple infrastructure projects within a basin.
- EIAs happen after technical and financial feasibility studies and after key decisions about the project have been made – this includes the project's site, which has been found to be the main factor affecting environmental and social risks.
- Because the EIA often comes late in the decision-making process, significant investments in the project have already occurred, and momentum and support for the project are well developed.

Strategic Environmental Assessments (SEAs) are sometimes stipulated by national regulations and address the effects of programmes, plans and policies, rather than individual projects. They can be conducted at various spatial scales and have the potential to improve how projects are selected and developed (Hussey & Pittock, 2012; Song et al., 2010). In some cases, such as Vietnam, SEAs have been used to assess cumulative effects against multiple criteria. However, many SEAs happen only after feasibility studies and after key decisions have been made.

In many situations, the EIA/SEA consultants are hired and paid for by the investors and consequently are motivated to produce an assessment that supports the project. In some instances EIAs of large dams are drafted to ensure approval by environmental authorities no matter how severe the impacts (Fearnside, 2015). Authorities are sometimes insufficiently equipped to be able to critically evaluate EIA studies, and the EIAs are not in the public domain.

As a result, too many EIAs are still cosmetic exercises that rarely result in the rejection of a project (Sadler et al., 2000) and generally result in only minor modifications and mitigation strategies (Opperman et al., 2015). The WCD advocated "cutting the direct link between feasibility study and project approval" in favour of an assessment process that occurred early enough that it could realistically reject or relocate inappropriate projects.

Box 7. Political economy and EIAs in the Mekong and Brazil

A recent analysis of hydropower actors in the Mekong region suggests that EIAs are limited by numerous political economy constraints. In particular, there is a paucity of public participation, so power rests disproportionately with the project approval agencies. As a result, EIAs are manipulated by investors, consultants and governance agencies that have vested interests in the projects; they have become a box-ticking exercise. Long-term changes in power relations are needed, and might only come about through building public activism.

Source: Wells-Dang et al. (2016)

In Brazil, a coalition of conservative lawmakers is pushing for legislation to loosen the requirement for EIAs for agriculture and infrastructure projects, including dams. This seems to be a backlash against the previous government's curb on deforestation. The ongoing political corruption is likely to fuel efforts to stymie regulation and push development.

Source: Latrubesse et al. (2017)

Challenges in applying international ESG safeguards

On top of national statutory regulations and the requirement to do an EIA, there are sometimes additional international ESG safeguards that are applicable to particular projects, usually dependent on funding source. These are often more stringent than national guidelines, but a number of issues have arisen with their application (Foran, 2010; Le Clerc, 2012; Skinner & Haas, 2014; Soanes et al., 2016; Transparency International, 2008; West, 2013):

- Safeguards are not applicable to many projects. A review of ESG safeguards for large dam projects showed that many hydropower projects in developing countries financed by the private sector, particularly in Asia, are subject only to nominal national standards.
- Addressing ESG issues adds costs, particularly where site selection has been unfavourable and issues are addressed late in the planning process. For private investors, such costs affect the project's profitability and viability so they tend to be avoided unless they are a project-financing requirement.
- Often safeguards are not binding. There is a concern that in some cases signing up to a particular safeguard is merely a public relations exercise and there is little change in practice.
- Implementation of safeguards can be hampered by limited institutional capacity and guidance on some safeguards is weak. For example, there is no guidance on how banks are to implement the Equator Principles, leading to inconsistent application. Meanwhile, there is confusion in how to assess 'respect for WCD' guidelines required through the EU Linking Directive[10], which has created additional barriers.
- It is unclear how well safeguards are being implemented and enforced as many lack independent verification and re-assessments after a certain period of time. With the Equator Principles, for example, it is unclear whether financial institutions would take any action to enforce compliance if a particular project failed to meet performance standards.
- Some safeguards (e.g. the Equator Principles) have been criticised for not requiring project-level reporting; they tend to report on a bank or company's operations as a whole. In addition, reporting tends to be left to corporate communications departments who may have little understanding or knowledge of on-the-ground implementation.

10 This is a challenge given that the WCD was never seen as a blueprint. In their assessment of ESG safeguards, Skinner and Haas (2014) point out that the voluntary assessment tool for dam developers under the EU Linking Directive reflects a significantly watered-down version of the WCD, and its descriptive approach is not particularly normative or measurable. Respect for the WCD process under the EU Linking Directive is therefore unlikely to constitute a significant barrier to accessing EU carbon credits.

Power station and penstocks at Ribeirão das Lajes hydropower scheme, Paraiba do Sul River Basin, Brazil. The main reservoir (out of view) was filled in 1908 and also supplies water to Rio de Janeiro.

B.3 SHORT-TERM BENEFITS AND LONG-TERM UNCERTAINTIES

Many dams were built to achieve short- to medium-term benefits and were informed by minimal data and awareness about potential impacts. Even today, infrastructure is not always built with long-term interests in mind. Where infrastructure appears urgent (for example, if there has been a recent flood or drought, or power outage, or the next election approaches) there may be a temptation to skip steps in the planning process and to avoid comprehensive or strategic planning. However, this type of approach increases the risk that projects will confront obstacles and delays, and that societies are left with inappropriate dams in the wrong locations. A classic example is the Manantali dam in West Africa (Box 6).

Such short-termism can also arise with the build-operate-transfer (BOT) form of project financing whereby a private developer receives a concession to finance, design, construct and operate infrastructure, before returning it to the host country after the agreed period of time. It enables the project proponent to recover its investment, operating and maintenance costs in the project within the concession period. Upon transfer the project could have a theoretical lifespan of 20 years or more, but the builder/operator has been incentivised to run operations efficiently only until transfer. This can result in projects in poor condition and requiring significant renovation, which the government (often the receiving party) may be unable or unwilling to make.

Planning, designing or adapting dams for the long-term is a major challenge. There are uncertainties in societal preferences and future demand. Climate change will increase uncertainty about hydrological conditions. Flow data and hydro-climatic modelling are important in helping to identify trends and build more realistic scenarios of future flows. Planning for uncertainty is particularly difficult at the scale of individual dams because collecting data takes additional time and means immediate benefits have to be postponed. However, there are economies of scale if these issues are tackled as part of a wider effort to strategically plan infrastructure.

B.4 LOCAL VERSUS NATIONAL AND TRANSBOUNDARY INTERESTS

Responsibilities for water management are often divided between local, basin, national and transboundary levels.

Local decision-makers can favour local interests even if these result in sub-optimal outcomes for the country or river basin. For example, local officials might use national funds to secure a dam that benefits local construction firms or provides services only to a relatively small group of people.

Meanwhile, many decisions about large dam projects are made by national governments and are driven by high-level political and strategic interests. There is evidence to suggest that the spatial scale at which water is managed is becoming larger, and there has been a shift from local to national decision-making (Crow-Miller et al.,2017). While this means that benefits and their distribution can be considered from a broader perspective, it creates a tension because dams that would have brought significant benefits nationally can be strongly opposed by local groups who often bear the brunt of social and environmental impacts. For example, hydropower development can fuel a nation's economy and bring in export revenue, but results in significant local impacts such as resettlement.

Tensions between local and national interests can be compounded by the fact that decisions about national projects can be confined to a restricted circle and made behind closed doors, well in advance of any stakeholder consultation or EIA (for example, as reported by Newborne, 2014, in Brazil). In many cases, the shift in decision-making scale has been accompanied by increasing suppression of local oppositional voices (Crow-Miller et al., 2017), or of under-represented or under-privileged groups.

As discussed in Section C, strategic planning of infrastructure can help resolve such tensions, alongside best practices in avoiding, minimising and offsetting impacts, including benefit sharing. Government decision-makers also need to recognise how difficult it is for local communities to give up ecosystem services; accustomed or traditional rights; cultural assets; or to agree to being physically or economically displaced, even if appropriate compensation is offered.

Many rivers are transboundary and effective basin-wide governance is needed to develop, implement and enforce rules for managing water resources and associated infrastructure. However, in many basins this is hampered by a perceived threat of losing national sovereignty and weak capacity to negotiate and implement transboundary agreements. The UN Watercourses Convention (UN, 1997), which entered into force in 2014, was developed to try to address some of these challenges. It is a flexible legal framework that establishes basic standards and rules for cooperation between watercourse states on the use, management, and protection of international rivers.

B.5 PUBLIC VERSUS PRIVATE INTERESTS

It is the role of public agencies and policies to ensure that dams fulfil the broader objectives of society. However, public water resources agencies are often limited by mandate, funding and technical capacity, and are influenced by corruption and political interference.

In some instances the private sector is heavily relied upon to overcome chronic shortfalls in public finances and fund essential infrastructure. Investors and financers of dams necessarily have their own agendas: they are looking to make a profit and they protect themselves from regulatory changes and other risks through long-term licences and contracts, such as power purchase agreements (PPAs). Depending on contract design, the flexibility to respond to changing social expectations and to adapt to emerging impacts may be less than in projects that are fully in the public domain.

Where there are no suitable regulatory mechanisms in place, decision-making is vulnerable to manipulation and public agencies may not have the power to protect societal interests. Private investments often bring powerful actors with vested interests to the table, and they are sometimes able to capture the agenda to advance their own interests (Hepworth & Orr, 2013). Particular attention should therefore be given to the finance sector and how that shapes water infrastructure today (Crow-Miller et al., 2017).

Often the boundary between the government and private sector is blurred for national-level projects: power is concentrated into the hands of political elites, who act to deliver political and financial rewards to certain high-level actors. Powerful private sector and political interests can combine with certain enabling conditions to create an environment that promotes infrastructure development at all costs, as demonstrated in the Lower Mekong region (Box 8).

Box 8. Drivers of hydropower development in the Lower Mekong

Matthews (2012) conducted a political analysis of hydropower decision-making in the Lower Mekong. The analysis reveals that large-scale hydropower in Laos PDR has been driven by the interests of powerful actors in Thailand including EGAT (a Thai state energy company), Thai IPPs (Independent Power Producers) and the private sector, and facilitated by certain enabling conditions within Laos. Large investments have been discouraged in Thailand itself due to its strong civil society. Meanwhile, in Laos the government's openness to investment, a lack of capacity to regulate development, the existence of corruption, and a closed state that controls international NGOs and forbids grassroots civil society, has created an environment that enables powerful actors to capture the benefits of hydropower development while neglecting the social and environmental costs.

Source: Matthews (2012)

B.6 THE SOCIAL LICENCE TO OPERATE

Every dam project that goes ahead should have a social licence to operate – i.e. the acceptance as legitimate by the broadest possible range of stakeholders.

Many large infrastructure projects fail to obtain social acceptance because, as described above, decision-making is not transparent, is restricted to powerful elites, and overrides institutional frameworks. Mechanisms for public consultation and participation are often poor (WIGO, 2016) and many projects fail to properly address resettlement and downstream livelihood issues (WWF, 2013): promises of relocation and compensation are frequently broken and funds for relocation embezzled.

Failing to obtain a social licence risks further project delays, and manifests itself as a risk for private developers and investors. McAdam et al. (2010) comment that the greatest hurdles faced by large infrastructures today are almost always social and/or political, rather than technical. Meanwhile Plummer (2013) cites public protects and resettlement issues as the biggest causes of cost and schedule overruns for dam developers.

A strong, well-organised and critical civil society is important in providing independent oversight of private investments and helping to achieve social acceptance. However, even with substantial public opposition it can be very difficult to stop a dam because of the vested interests of the powerful individuals involved. For example, private actors may have sunk costs, expected profits and may be wary of corruption exposure; meanwhile, government actors may want to use the dam to demonstrate they are doing something to solve a water problem or reaffirm their sovereign decision-making powers.

Ultimately, governments need to be able to attract private investment while retaining control of their water resources, maintaining independent regulation of all actors, and ensuring decisions are transparent and take account of public interests. In many cases, governance reform will be required to achieve this.

B.7 FALSE ECONOMICS

Evidence suggests that across all infrastructure sectors developers tend to overplay the benefits and opportunities and underplay the costs and risks, and decision-makers do not learn from past experience (Flyvbjerg, 2005). One study found "overwhelming evidence that budgets are systematically biased below actual costs of large hydropower dams" (Ansar et al., 2014), and suggested that over-optimism in terms of costs and risks is "often exacerbated by deception, i.e. strategic misrepresentation by project promoters". The reality is that cost overruns and schedule slippage mean that many large infrastructure projects fail to recover their costs within the planned timeframe.

This threatens the viability of projects and, if the developer becomes bankrupt, makes them a burden to the taxpayer.

Decision-making around dams should be based on a transparent and realistic assessment of the dam's financial, economic and social viability (Ansar et al., 2014; WWF, 2013). This should be done during the early stages of planning and take into account external influences, such as markets and climate change.

Box 9. Subansiri Dam, Lower Subansiri River, India

Construction of the Subansiri hydropower project in the Himalayan highlands was initiated in 2005 but has yet to be completed due to failure to obtain a social licence. Despite developers re-designing and reducing the capacity of the project, and the central government agreeing to allocate a greater portion of the power generated to the local region, the local authority and protest groups can't accept the lack of assurance on the project's safety. If completed, the Subansiri Dam will be among the largest hydropower projects in India.

The project is sited in inaccessible mountains prone to heavy sediment erosion and landslides, earthquakes and flooding in the monsoon season. Failure by the government and developers to produce publically available safety assessments and downstream impact studies for the dam has fuelled years of fierce debates and local protests over the safety and relocation of populations downstream. Construction was halted in 2011 and, whilst there have been attempts to resume, the dam remains incomplete.

Source: Sharma (2012)

PART C
TOWARDS BETTER DAMS

Part B demonstrated that past approaches and decisions around dams are a poor guide for meeting societal needs. Part C describes mechanisms for improving the planning, financing and management of dams.

The Mitigation Hierarchy (Kiesecker et al., 2009; WWF, 2014a) is a useful framework for dam planning. It suggests working through a hierarchy of four steps to deal with environmental and social risks and impacts: avoid, minimise, restore and offset. The boundaries between the different levels of the hierarchy are blurred, but different levels tend to be more relevant at different points in the dam planning and design process, and at different scales.

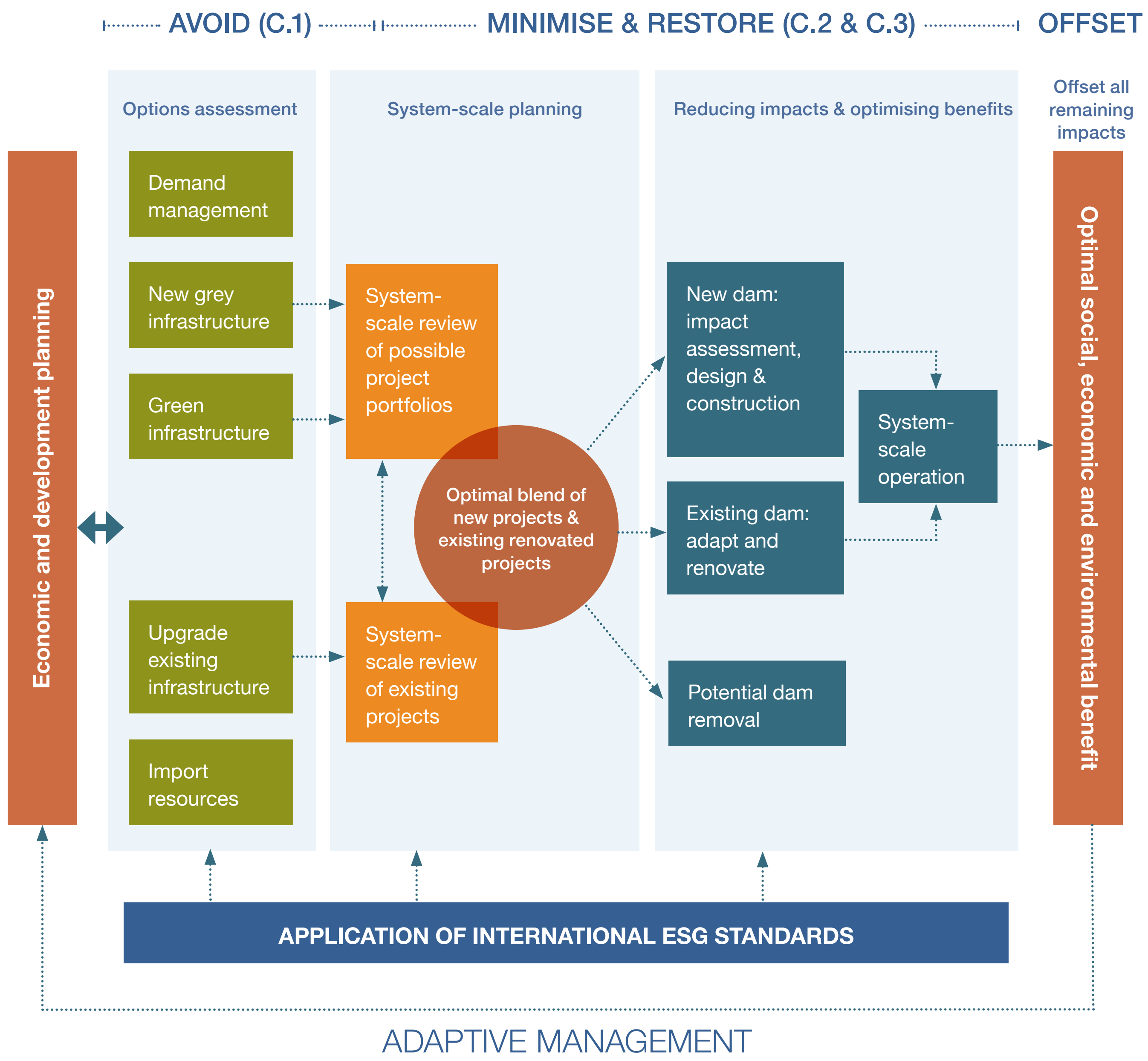
1. **Avoid** building unsuitable dams, and look to alternatives to infrastructure. If a new dam is necessary then avoid the most damaging sites (e.g. areas with high social or environmental value) and direct development towards those sites that result in fewer environmental and social impacts. Section C.1 focuses on infrastructure planning at the national and basin scale to help avoid the wrong dams in the wrong places.
2. **Minimise** the direct and indirect impacts of dams by appropriate choice of project scale and type (such as RoR or storage), and design. There should be a focus on minimising social impacts such as resettlement and impacts to key ecosystem services and biodiversity. Section C.2 focuses on how to minimise potential impacts once individual dam projects have been approved by planners.
3. **Restore**[11] river functions through better operation and management of dams and reservoirs. Operation should strive to restore or maintain river ecosystem processes and services to people downstream. Upstream areas should be managed to reduce erosion and reservoir siltation. Section C.3 focuses on the reoperation and renovation of existing dams to restore river functions and optimise benefits.
4. **Offset**[12] those impacts remaining. For most dams there is likely to be some residual impact after avoiding, minimising and restoring. These residual impacts should be offset through measures that maintain or enhance environmental or social values. These measures may include – but are not limited to – financial compensation to communities for losses such as land. They can also include re-creation or restoration of habitats, the provision of substitute ecosystem services, and measures to tackle the drivers of biodiversity loss in the wider landscape. Measures for offsetting should be defined proactively before negative impacts are experienced and should fully counter any damage suffered. When offsetting is specifically for adverse impacts on biodiversity, is designed proactively, fully counterbalances these impacts, and is 'in kind', it constitutes a 'biodiversity offset' (WWF, 2012). A detailed discussion of offsetting is beyond the scope of this primer, but it is worth noting that it can be usefully linked with the 'avoid' stage: offsetting could include improved management and protection of no-go areas – otherwise those areas, even if avoided in one decision, remain more vulnerable from future dam proposals.

11 Sometimes this step is referred to as mitigate – for example, in WWF's Position on Dams (WWF, 2014a). In this primer, 'mitigate' is considered a broader term to describe the alleviation of impacts – through avoiding, minimising and restoring.

12 Sometimes 'environmental compensation' or simply "compensation" is used instead of the term 'offsetting'. In this primer, 'compensate' is used to specifically refer to monetary payments for losses incurred, whereas 'offsetting' covers a broader range of measures.

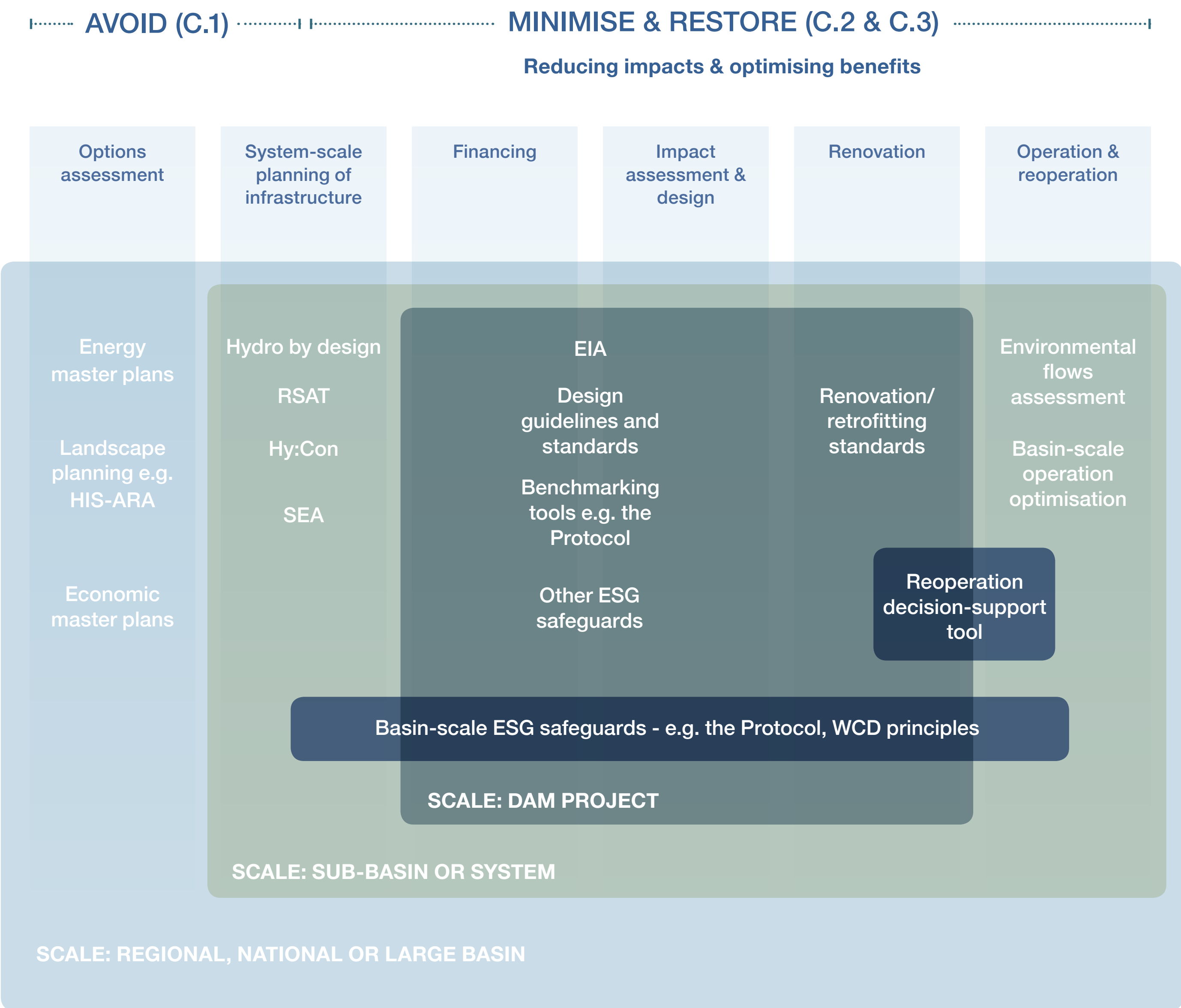
Figure 6 illustrates how these concepts, and the sections of Part C, link to each other to form a strategic approach for achieving better dams.

Figure 6. A strategic approach for better dams



There are a number of available tools and approaches that are introduced in the following sections and which are applicable at different stages in the strategic approach shown in Figure 6, and which are applicable at different scales. Figure 7 provides an illustrative – and non-exhaustive – guide to which tools are relevant and when.

Figure 7. Available tools to support a strategic approach to dams



Notes (further explanations given throughout Section C):

EIA: Environmental Impact Assessment

HIS-ARA: Hydrological Information System and Amazon River Assessment

Hy:Con: used to assess 'economic attractiveness' and 'conservation needs' for hydropower projects in Austria.

Hydro by Design: tool developed by TNC to assess numerous geographical configurations of hydropower dams with numerous criteria simultaneously.

Reoperation decision-support tool: tool for existing dams developed by the Natural Heritage Institute.

RSAT: Rapid Basin-wide Hydropower Sustainability Assessment Tool

SEA: Strategic Environmental Assessment

C.1 BEFORE THE DAM: RIGHT DAMS, RIGHT PLACES

This Part C.1 focuses on the series of steps that should be taken to assess whether new dams are the best option for meeting societal needs.

Strategic economic planning

Infrastructure is not necessarily built to address local needs; it is often part of national economic development planning – for example, to provide power for export-oriented industries, to export power directly to neighbouring countries, or to provide water for exported-oriented agriculture. Therefore a strategic perspective is needed for infrastructure planning which considers export and import opportunities. A proper economic planning process, which makes a full assessment of the different options can take years, particularly if data are limited.

Once medium and long-term trends in demand and supply of water, food and energy have been established, options then need to be considered for how they might be met. Civil society organisations have an important role to play in supporting and influencing economic planning processes, particularly in questioning demand projections and advocating for less conventional options. However, many countries lack strong infrastructure planning capabilities and, as described in Part B, do not support open public debate about water, food and energy resources.

Considering alternatives

The 'bias to build' infrastructure such as dams means that alternative options are not always considered.

- **Demand management** should be considered ahead of other options as it is often more efficient than increasing supply (McKinsey, 2009). Energy demand can be curbed through improving consumer energy efficiency, and reduction in water demand can be achieved through cutting post-harvest food waste and the application of efficient technologies for domestic, agricultural and industrial use. Water efficiency measures are best implemented within an effective and fair water allocation regime.
- **Alternative sources of supply** include changing crops, importing food, improving agricultural productivity on rain-fed lands, or other renewable sources of energy.
- **Green infrastructure** such as floodplain wetlands and forested watersheds can, depending on context, supply similar services as dams – for example, water storage and flood attenuation.
- **Retro-fitting and reoperating existing infrastructure** can enhance water supply or power generation while simultaneously restoring ecosystems (Watts et al., 2011) and avoiding further impacts.

In terms of energy planning, there is much scope for countries to diversify their energy sources. A number of countries (e.g. Brazil and China) rely heavily on hydropower without considering the full costs involved.

Cost-benefit and trade-off analyses should be conducted to ascertain the relative merits of different alternatives to meeting resource needs. Where infrastructure is a viable option, it is important to be clear about its primary purpose and carefully analyse the trade-offs that arise from bringing in additional purposes.

System-scale planning

Where new water infrastructure has been identified as the best option for meeting societal objectives in a basin or region then a planning process should be pursued at the scale of the river basin (or another appropriate scale for the system) which considers different infrastructure options.

System-scale infrastructure planning shifts planning away from focusing on single projects. It strives to design a portfolio of projects that collectively produce greater benefits to society than could be achieved by making uncoordinated decisions about individual projects (Opperman et al., 2015). Such a system can reduce impacts, while maximising benefits such as power generation and flood storage. System-scale planning yields the best results when it is embarked upon at large spatial scales and early in infrastructure development, before sites are 'locked in' and when the best opportunities for reducing impacts – and optimising benefits – remain.

All infrastructure planning should be embedded within existing river basin and landscape planning, with due consideration for the policies and priorities of other sectors such as agriculture, urban planning, industry, forestry, tourism, fisheries and conservation. Ultimately, strategic basin planning is needed, which includes a process to understand society's vision for the entire river basin and how it should it be used.

This should then inform objectives within a series of thematic plans, including on water infrastructure (Pegram et al., 2013). The European Water Framework Directive (EU, 2000) sets a good precedent for strategic basin planning; mandating the preparation of River Basin Management Plans, which then must go through a Strategic Environmental Assessment (SEA). These serve as a good basis for system-scale planning of infrastructure, as well as other development.

A basic objective of a system-scale infrastructure planning is identifying locations where infrastructure might be developed with relatively low environmental, social or economic impacts. Prominence can be given to protecting certain rivers stretches (no-go areas for infrastructure) that provide particularly important values such as maintaining connectivity for biodiversity, key species or cultural benefits. Tools exist for helping to identify no-go areas, for example WWF's Free Flowing River methodology (Box 10). Identifying good sites and no-go areas for infrastructure has advantages for both nature conservation and infrastructure development: highly vulnerable river sections receive protection, high costs of mitigation and compensation are avoided, and the risks of delays or stranded assets are reduced.

System-scale planning has three key characteristics:

1

It assesses river reaches/projects according to **multiple criteria**, reflecting different interests such as economic development, social well-being and the environment. Example criteria include hydropower generation; displaced people; forest loss; sediment load; fish productivity[13]; degree of flow regulation (DoR); and degree of river fragmentation (DoF) (Box 10).

2

It **integrates economic, social and environmental criteria.** Most assessments of environmental or social issues associated with infrastructure (e.g. EIA or SEA) happen after technical and economic feasibility studies. Integrated assessments enable trade-offs between economic criteria and environment/social criteria to be more easily identified and deliberated. Trade-offs should be discussed with a diversity of stakeholders to inform decision-making. This helps to achieve the integration of different interests and areas of public policy, such as conservation with national energy planning (Opperman et al., 2015; ICPDR, 2013).

3

It simultaneously assesses **multiple portfolios** of potential infrastructure projects against the criteria in order to try to optimise the benefits from the whole system (TNC, WWF & University of Manchester, 2016). Consideration of multiple projects is important because impacts and benefits of individual projects take effect at scale, upstream and downstream, and overlap with impacts of other projects.

A number of tools are emerging which facilitate system-scale infrastructure planning. Brief descriptions of these tools are shown in Table 2. The most recent of these, and which meets all three characteristics, is the 'Hydropower by Design' approach piloted in Myanmar (see Box 12).

13 Reductions in fish productivity have been used to estimate the additional land and water needs that would be required to replace lost fish protein (Orr et al., 2012).

Box 10. Indices for measuring cumulative environmental impact: Degree of Fragmentation (DoF), Degree of Regulation (DoR) and identifying Free Flowing Rivers

The indices of DoF, DoR and FFR can be used alongside other criteria to compare the impact of alternative portfolios of dam projects.

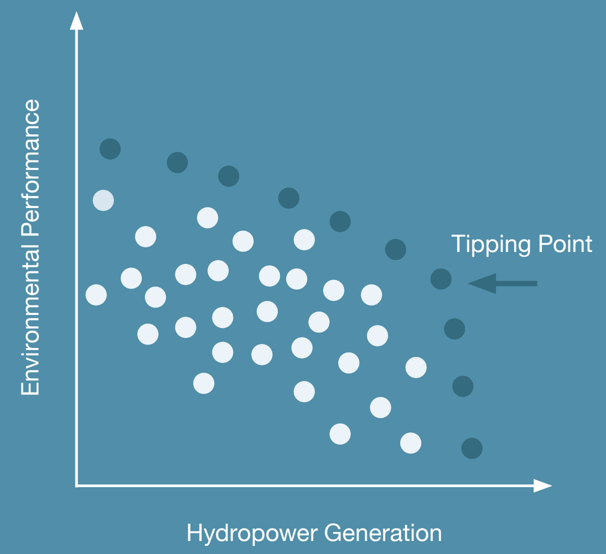
DoF measures the extent of river fragmentation caused by dams; DoR measures how strongly a river can be regulated by dams. Together, DoF and DoR give an indication of the larger scale, cumulative impacts of dams on the hydrological network, measured by the number of river kilometres that are affected. These indices are relatively easy to calculate, even for a large number of dams.

The DoF and DoR have been used as a basis for the Connectivity Status Index (CSI). The CSI index has been recently developed by WWF and McGill University. The index gives each river reach a value on a sliding scale from 0 to 100%. Those rivers that are made up of river reaches that score over 95% are defined as Free Flowing. The CSI index combines DoF and DoR to convey the longitudinal effects of dams, but also gives an indication of latitudinal dis-connectivity and flow depletion by including other pressures such as road density, urban areas and abstraction for irrigation. The index can be used to help identify those rivers that remain relatively pristine and free-flowing, and therefore potential no-go areas for dams.

Sources: WWF (2016b); WWF (2016c)

Box 11. Analysing trade-offs

The trade-off plot shows environmental performance versus hydropower generation for groups of dams (from TNC, WWF & University of Manchester, 2016). As might be anticipated, environmental performance of a group of dams tends to decrease as their hydropower generation capacity increases. However, all the light blue dots have unnecessary environmental impacts, while the dark blue dots represent the optimal 'surface' where environmental performance is maximised for a given level of power generation. Such a plot is useful in making decisions about trade-offs between two criteria/objectives. Often it is possible to identify a tipping point: here, expanding power generation beyond the tipping point would rapidly diminish environmental performance, with only a minor gain in generation.



If there are numerous infrastructure configurations/portfolios, and several criteria against which to analyse them, then sophisticated methods can be used to analyse trade-offs. For example, Hurford et al. (2014) produce a series of 'trade-off surfaces', which allow decision-makers to better visualise their options and balance performance across many criteria. This type of approach was used as part of a framework put forward for hydropower decision-making in Myanmar (see Box 12).

Table 2: Decision support tools for system-scale planning

		Characteristics of system-scale planning		
Tool: name and objective	**Example of use**	**Uses multiple criteria?**	**Integrates economic, social and environmental criteria?**	**Considers multiple portfolios of potential projects?**
HIS-ARA Hydrological Information System and Amazon River Assessment. This spatial approach seeks to integrate hydrological and ecological data to assess different river reaches in terms of ecological value, risk and opportunity. It helps identify stretches where river connectivity should be maintained and dam development should be avoided. It is not specifically directed at infrastructure planning, rather it supports the development of regional conservation strategies.	First developed and applied by WWF's Living Amazon across the Amazon (unpublished, 2010). Then applied to Tapajós (WWF, 2016c)	✓	Considers ecosystem/ biodiversity criteria but these are not assessed with economic criteria	Looks at stretches of river rather than project portfolios
Hy:Con. Used to assess 'economic attractiveness' against 'conservation needs' for hydropower projects. Numerous conservation criteria included in 'conservation needs' assessment – including those linked to ecological status, hydro-morphological status, key habitats, key species, floodplains, legally binding protection, river continuity.	Used to inform the Austrian government's Energy Strategy. WWF used the tool to assess over 100 planned hydropower projects in Austria (Seliger et al., 2015).	✓	✓	Considers hydropower projects individually, but plots them as a group
ICPDR Decision support matrix – from the ICPDR's Guiding Principles on Sustainable Hydropower. Classifies the suitability of river stretches for sustainable hydropower development according to hydroelectric potential and environmental/ landscape criteria.	**International Commission for the Protection of the Danube River** (ICPDR, 2013) promotes its use across the Danube basin.	✓	✓	Looks at stretches of river rather than project portfolios
'Hydropower by Design'. Used to assess numerous geographical configurations of hydropower dams with numerous criteria simultaneously.	It is being used to make the business case for sustainable hydropower to governments, developers and funders around the world – including in Columbia, Kenya and the US (Opperman et al., 2017a). In 2016 it was used by WWF and TNC to explore hydropower options on the Irrawaddy in Myanmar (Box 12).	✓	✓	✓

Box 12. System-scale planning in Myanmar to strengthen the development impact of hydropower investments

Myanmar has a large deficit in power supply. There are numerous potential sites for hydropower and different combinations of these projects would produce different cumulative effects – benefits and impacts.

WWF worked in partnership with TNC, the University of Manchester and DFID to illustrate a system-scale planning framework for hydropower development. The framework compared portfolios of potential hydropower projects across multiple criteria. Each portfolio represented a distinct combination of dam locations and management options. Key elements of the framework are:

- Optimising the system such that it cost-effectively meets regional power demands and that it is consistent with a sustainable approach to energy development.
- Quantifying, deliberating and balancing the trade-offs between hydropower production and other economic, environmental and social objectives (as defined by stakeholders).
- Assessing whether the planned portfolio of hydropower assets achieves robust and resilient performance under a wide range of plausible climate and institutional futures.

The framework was applied as an illustration to the Myitnge River, a tributary of the Irrawaddy River. A river simulation model of the main river channel was built. The simulation model, capable of generating hundreds of thousands of possible portfolios, was coupled with a search algorithm to select a sub-set of high-performing portfolios whose performance across a set of metrics could then be compared through trade-off curves. The metrics were selected to correspond to a range of objectives and stakeholder interests/topics (e.g. power generation, investment costs, fish productivity, forest loss, flood control, navigation, sediment load). The trade-off curves allow decision-makers to visualise the different portfolios and identify those that perform well – and not so well – across various metrics.

The results were generated with publicly available basic data in a very short timeframe. They clearly showed that some portfolios are better than others, that some interests are compatible with each other, and that there are quantifiable trade-offs between others. One key insight was that there are several portfolios that produce almost the same amount of energy, but with very different impacts on fish productivity.

Source: TNC, WWF & University of Manchester (2016).

System-scale planning makes transparent the likely costs and benefits to different stakeholders of different options, and therefore provides a good basis from which better projects can be identified. Opperman et al. (2017a) found that, beyond environmental and social benefits, system-scale planning can produce economic and financial benefits – which may be more compelling for some decision-makers. Economic benefits arise because system planning can produce a set of investments that work together to deliver water and energy benefits more effectively than a set of unplanned projects. Financial benefits arise because system planning can:

- Reduce project-level uncertainty and delay. Although the process of bringing together diverse objectives demands a greater initial investment of time and resources and sufficient political and stakeholder engagement, it should streamline the subsequent authorisation process for individual infrastructure projects. This reduces project-level uncertainty and delay and leads to greater predictability for developers.
- Achieve financial viability for investors – by guiding site selection towards projects with lower environmental and social risk and therefore with less likelihood of cost over-runs and delays. This helps to improve the acquisition and terms of financing for infrastructure projects.

Stakeholder participation

A system-scale planning approach offers the opportunity to actively engage different stakeholders in planning processes to achieve the best possible option with the broadest support. In particular, involving representatives from different groups in the selection of criteria and analysis of trade-offs between different options helps bring different perspectives to bear.

The planning process should be transparent, include data acquisition and analysis, and allow for the involvement of all interested and potentially affected parties – following frameworks for participation set out in relevant conventions, laws and guidance notes[14]. Engaging stakeholders at an early stage is critical for ensuring their views are taken on board in processes for decision-making. It's also important that stakeholders are given a real opportunity to challenge decisions. Many vulnerable social groups have limited experience or capacity to engage, such as indigenous peoples[15]. Engagement and consultation must therefore be tailored to different groups, and ensure an informed civil society.

All of this requires a strong institutional framework that can represent and balance various stakeholder interests. It requires maintaining independent regulation of all actors, and guarding against capture of decision-making by any narrow or vested interest. In many cases, governance reform will be required.

Ultimately, effective stakeholder participation increases the legitimacy of the decisions made, and should ensure significant improvements in terms of costs, timing and acceptance by different interest groups (ICPDR, 2013). A good example of collaborative multi-stakeholder planning of water infrastructure is recent advances in British Columbia's hydropower sector (Box 13). In the Mekong region a powerful multi-stakeholder dialogue and assessment tool has been developed to guide a basin-wide, participative approach to hydropower development: the Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT, Box 14).

Box 13. Participatory Hydropower planning in British Columbia, Canada

British Columbia is a hydroelectricity powerhouse, with a long history of dam building extending well before initiatives such as EIAs or public hearings. In 1996 a water use planning process was initiated, prompted by a number of socio-environmental legal challenges and a recognition that dams needed to be better operated for ecosystem needs. This process sought to find a better balance between competing uses of water and resulted in the implementation of flow releases from dams which have led to improvements in fish productivity and habitat.

The success of the water use planning process is due in part to its collaborative approach, which involved a wide spectrum of groups. The process exemplified a number of success factors of collaborative water governance, namely a partially delegated structure; decision-making at the scale of the river basin affected; extensive participation beyond the proponent and the regulator; a collaborative process; and science-based decision-making (Nowlan & Bakker, 2010). The process was also successful in engaging and bringing benefits to First Nations, who have been negatively impacted by hydropower dams.

Source: Mattison et al. (2014)

14 For example, the Aarhus Convention (UNECE, 1998) is applicable in Europe; the UN Watercourses Convention is relevant for states with transboundary rivers (UN, 1997).

15 Indigenous peoples require special protection and have special rights over projects that affect their lands and waters (UNDRIP, 2008). For example, Article 19 of the UN Declaration on the Rights of Indigenous Peoples: "States shall consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free, prior and informed consent before adopting and implementing legislative or administrative measures that may affect them"; the International Labour Organisation´s (ILO) Indigenous and Tribal Peoples Convention No. 169 (ILO, 1987): "The peoples concerned shall have the right to decide their own priorities for the process of development as it affects their lives, beliefs, institutions and spiritual well-being and the lands they occupy or otherwise use, and to exercise control, to the extent possible, over their own economic, social and cultural development."

Proposed dam site near Pak Ou caves on the Mekong River not far from Luang Prabang. After much protest, the government relocated construction elsewhere. Laos or Lao People's Democratic Republic

Box 14. A multi-stakeholder dialogue tool – RSAT in the Mekong

The Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT) has been co-developed by WWF, the Asian Development Bank and the Mekong River Commission. Its primary intent is to bring key stakeholder groups together and provide a common basis for dialogue and collaboration, forcing stakeholders to look beyond individual projects and take a basin-wide, integrated approach to hydropower planning and management. More specifically, RSAT assists in identifying development strategies, institutional responses and management measures that can be deployed to optimise the benefits of hydropower and reduce risks.

RSAT includes a range of assessment methods to enable a flexible approach depending on the assessment objectives and the needs and capacity of the institutions involved. The assessment methods are designed primarily for group work and are suitable for participants with both technical and non-technical backgrounds. They include multi-criteria gap analysis; issue prioritisation; action planning; and institutional mapping. Outputs may include identification of risks and opportunities, a series of recommended actions, a ranking of sustainability performance or gap analysis report.

C.2 BUILDING BETTER DAMS: FINANCING, ASSESSMENT AND DESIGN OF INDIVIDUAL PROJECTS

This Part C.2 focuses on the planning stage once the purpose, site and type of infrastructure have been agreed. It is at this stage that the private sector – including developers, financiers and engineers – are often the key decision-makers. Better financing models, impact assessments and design can all help minimise environmental and social impacts.

Financing infrastructure

Private financiers of dams want well-defined, low risk projects in a safe investment environment. Financial risk is linked to environmental and social risk: financial risks often arise through delays and liabilities caused by adverse impacts on communities and the environment. Environmental issues can also impact on the performance and lifetime of the project and hence revenue streams and depreciation costs.

These risks act as a barrier to attracting private sector finance for dam projects, particularly in countries with lower credit ratings. Much risk is associated with the planning phase, prior to there being certainty that the project will proceed (due to complex approval processes, community negotiations and land acquisition). A good system-scale planning process ensures only lower risk projects move forward, but further measures are likely to be needed to manage project risks and attract private finance:

(1) New finance models that share risk between different project partners

For large hydropower, there is a trend towards government and private developers taking responsibility for different stages in project development, depending on which party is most able to address which risks (IIED, 2015). For example, many projects are financed through public funds during the risky construction stage and then refinanced on successful completion. This enables public funds to be released and creates opportunities for private financers in the operation phase.

Public sector financiers (such as the IFC) are increasingly taking equity in, as well as providing debt finance for, infrastructure projects. This means they take on more of the financial risk, increasing the confidence of private financiers (on insolvency, equity holders are only repaid once all debt finance has been repaid). This enables the development objectives of the project to be met and the private sector to focus on profit generation (IIED, 2015).

Project preparation facilities are being used to prepare and de-risk projects and create a pipeline of 'bankable' projects. These include those initiated by public sector finance institutions (for example, ADB's Asia Pacific Project Preparation Facility[16]), and the recently initiated Hydropower Preparation Support Facility (HPSF) (IHA, 2017). HPSF will manage a fund to select and prepare the most appropriate type and location of hydropower projects. Approved projects will be auctioned for development; as a result the developer pays for project preparation, but without the risk of the project not being approved. Such facilities are potentially powerful instruments to promote basin-wide planning approaches that consider cumulative impacts of dam projects.

(2) Applying ESG safeguards

Development banks and private financiers, through initiatives such as the Equator Principles, have shown that improving ESG safeguards is synonymous with reducing financial risk and enhancing returns (IIED, 2015). Development banks that provide financial support for the implementation of ESG safeguards in the public interest can help to de-risk investment and lever private capital (IIED 2015). Meanwhile, green bonds, with their ESG commitments, help lower the risk profiles of projects and help attract private finance.

To effectively reduce financial risk, international ESG safeguards should be applied from the very beginning and throughout infrastructure planning, design and construction. This ensures that ESG costs are identified early and can be factored into long-term project financing and revenue streams – for example, ESG costs for hydropower developments should be reflected in power purchase and concession agreements so the costs can be internalised in electricity tariffs. In turn, this reduces risk to private developers' returns by managing potential implementation delays that trigger contractual penalties and large interest payments.

Strengthening Environmental Impact Assessments

The purpose of an EIA is to (1) make an assessment of a potential project's social and environmental impacts, and therefore inform the decision about whether to go ahead with a project; (2) describe how, if the project does proceed, impacts should be avoided and reduced. An EIA should not be a cosmetic or 'rubber stamping' exercise for projects that have essentially been given the go ahead. EIAs should be carried out before project sites are 'locked-in', ideally during a system-scale infrastructure planning process (as described in Section C.1).

Characteristics of a good EIA include:

- It fully considers and reflects the river basin's context, including socio-economic, cultural and biophysical aspects.
- It includes an assessment of the project's effect on cumulative impacts from other infrastructure, and how this relates to any thresholds limiting the river basin's carrying capacity.
- It takes an iterative approach involving all project proponents, actors and affected groups and experts (including engineers, economic planners and environmental and social specialists).
- It sets out measures for project improvement, including reduction of impacts as well as enhancement of social and environmental status (e.g. the Guiding Principles on Sustainable Hydropower Development in the Danube Basin (ICPDR, 2013) ask that hydropower development be accompanied by ecosystem restoration).
- It follows the 'mitigation hierarchy' to describe how the project will first avoid and then minimise impacts.
- It is underpinned by best-practice ESG safeguards.

16 www.adb.org/documents/asia-pacific-project-preparation-facility, www.iadb.org/en/about-us/project-preparation-facilities,6010.html, www.ebrd.com/news/2014/ebrd-launches-infrastructure-project-preparation-facility.html

Approaches to avoid EIAs becoming 'rubber stamping' exercises include:

- Ensure EIAs occur early enough so that they can realistically reject or relocate inappropriate projects.
- Separate the project proponents from the EIA process, for example by excluding them from the selection of EIA consultants, and/or by securing independent funding for EIAs (Fearnside, 2015).
- Establish an open online platform for the peer review of EIAs.
- Raise the standard of terms of reference for EIAs so that only an interdisciplinary expert team could deliver them.
- Increase the capacity of government regulators to enforce high-standard EIAs and objectively assess them.

Improving project design and adaptability

Dam design should be guided by a quality EIA, as well as other applicable ESG standards. It should consider all available design measures to minimise impacts and maximise benefits. Many of these measures have been developed relatively recently and so more evidence of their effectiveness is needed. The implementation of some measures can cause losses for hydropower generation; in some countries legislation exists to compensate these losses.

Design measures for dams include (Krchnak et al., 2009; Noonan et al., 2012; Olden & Naiman, 2009; Opperman et al., 2015; Pittock & Hartmann, 2011;):

- **Fish passages** such as by-passes, ramps, ladders, flumes and lifts that enable fish and other mobile aquatic organisms to move upstream and downstream. They tend to only be effective in some locations and for some targeted species, and even then still block a significant portion. The higher the dam, the more difficult and expensive it is to build effective fish passages. Fish lifts and 'catch and truck' operations are deemed to be less effective than rock ramps that mimic natural waterways. A systematic review by Noonan et al. (2012) of studies of fish passage efficiency indicates that efficiency decreases significantly with fish passage slope and is highly dependent on the type of fish passage. Strong swimmers such as salmonoids were found to be significantly more effective at passing upstream than non-salmonoids; but the review highlighted that there have been few studies carried out for non-salmonoids and in tropical regions or the southern hemisphere.
- **Fish friendly and aerating turbines** reduce harm to fish that pass through them and improve water quality. Their effectiveness is limited by the size of infrastructure, type of fish, and may only contribute to preserving a small number of fish.
- **Thermal pollution mitigation devices** such as towers reduce the effect of thermal stratification in reservoirs and can release flow at a more natural temperature for biodiversity.
- **A wide range of outlet and turbine-generator capacities** enable an array of dam operating objectives to be accommodated. Many existing hydropower dams lack adequate turbine-generator flexibility to allow dynamic environmental flow releases.
- **Multi-level, selective withdrawal outlet structures** facilitate a wide range of reservoir operating modes.
- **Sediment flushing devices** such as bypass tunnels and bottom outlets reduce the build-up of sediment behind a dam, increasing its life expectancy and releasing more sediment downstream to aid natural river processes. They are not as effective for dams with long reservoirs, as the inflowing sediment settles at the stagnation point rather than close to the dam outlets, which would allow flushing.
- **Re-regulation dams** positioned downstream of the hydropower dam can be operated to smooth out unnatural fluctuations in flow caused by power generation for peak demands.

The operating objectives for dams will change in response to changing social priorities and climate change. Investment in adaptive management is therefore critical to avoid the environmental and economic risks of future uncertainty. Good adaptive management includes (Krchnak et al., 2009):

- incorporating design features that facilitate a wide range of operating modes – as listed opposite;
- documentation of baseline conditions;
- a programme of monitoring and evaluation to test the assumed response of the river ecosystem;
- adjustment of the operating mode to improve performance, and continued monitoring as new dam operations are implemented;
- power purchase agreements that allow for the required flexibility.

Successful adaptive management requires active governance and adequate funding, including upfront costs to design and construct flexible infrastructure. However, such investment is likely to incur less costs overall than modifying or removing a dam later on, when it is discovered not to provide the desired services anymore. Adaptive management should also consider the costs of decommissioning, and how provisions can be made to keep a dam as economically, as well as environmentally, viable for the longest period of time (Krchnak et al., 2009).

C.3 EXISTING DAMS: OPTIMISING BENEFITS

Dams have a finite operational life, as their reservoirs will eventually silt up and physical components, such as the dam wall or spillway, can physically degrade requiring either major repair or decommissioning (WCD, 2000). In many countries, numerous dams exist that no longer serve their original purpose or have become unsafe. Out of the 84,000 dams in the US, 4,000 are deficient and 14,000 are highly hazardous (ASCE, 2013). The Oroville Dam (California) is a case in point: in February 2017 its spillways were damaged after heavy rain, prompting the evacuation of more than 180,000 people.

As stocks of dams increase in size and age, it will become more challenging and costly to deal with them (WCD, 2000; Postel & Richter, 2003). The financial costs will vary immensely depending on the location and size. It is estimated that US$21bn will be needed to repair the aging dams in the US (ASCE, 2013). Many obsolete dams remain as they are because of the high costs of repairing or decommissioning them. They continue to cause major damage to river ecosystems, without delivering the benefits they were designed for.

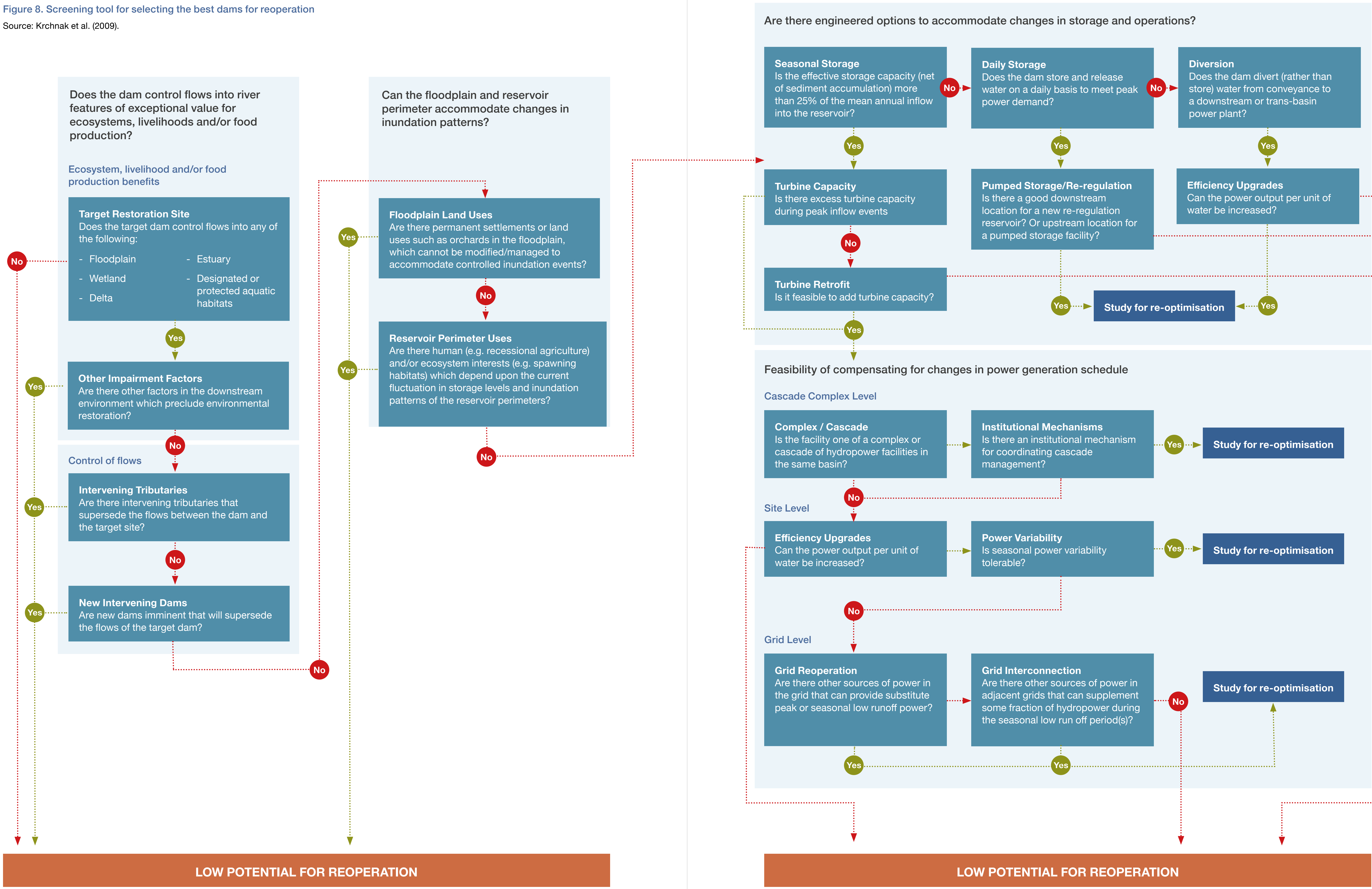
Despite the costs involved, the renovation and reoperation of existing dams offers opportunities. By improving performance, increasing safety and/or adjusting purpose, reoperation/renovation can help respond to changing climate and societal needs and remove the need for new infrastructure (WCD, 2000; World Bank, 2004; Ho et al., 2017). It can also help increase wider socio-economic benefits and reduce social and environmental impacts (Krchnak et al, 2009).

Often, the modification of existing dams is prompted by safety reviews, relicensing, changes in ownership, or the establishment of protected areas; or by incidents such as floods, droughts and accidents. Sometimes it may be catalysed by a change in government or legislation. For example, in the EU, the Water Framework Directive has triggered a review of each river basin's infrastructure. Ideally, the modification of dams should follow a strategic assessment of existing stocks to ascertain the best blend of renovation, reoperation and removal at a system or river basin scale. Many countries do not have this kind of approach in place, and a review by Pittock and Hartmann (2011) covering Australia, China, France and US revealed that there were many unrealised opportunities to improve the environmental, social and economic benefits of dams.

The strategic assessment of existing dams can be facilitated through a systematic, periodic relicensing system. The relicensing process is often most effective when led by an independent regulatory agency, when it includes public participation and when decision-making is based on transparent criteria of interest to society. In some instances, institutional reform may also be required, including a shift towards more integration across sectors (Pittock & Hartmann, 2011). Finally, existing infrastructure built prior to any system-scale plan should be integrated into river basin management plans.

Figure 8. Screening tool for selecting the best dams for reoperation

Source: Krchnak et al. (2009).



Reoperation and renovation

Reoperating existing dams – and effectively operating new dams – provides a huge opportunity to reduce impacts and achieve a wider range of benefits such as the release of environmental flows[17] to restore downstream ecosystem functions and services; the flushing of sediment to maintain storage capacity in the reservoir and maintain downstream geomorphological processes; or the supply of extra water during low flow seasons to supply irrigation systems, dilute wastewater or facilitate navigation. Sections (i) to (iv) below describe some of the purposes of reoperation/renovation in more detail.

Reoperation is achieved by implementing various water or power management techniques that increase the flexibility of reservoir storage and releases. For environmental flow restoration it involves shifting the dam's storage and release regime to reduce daily and seasonal distortions in natural flows. Where fundamental restoration of natural flow regimes is required at a hydropower dam, a shift to run-of-river operation may be necessary, generating more electricity during high flow periods and less during low-flow periods (Krchnak et al., 2009).

Reoperation requires the right hardware, such as spillways designed to handle large flow releases and bottom outlets for sediment flushing, as well as the right 'software' to manage operation, such as the rule curve of a reservoir (see Box 15). Opportunities for reoperation require a thorough assessment of this 'software': day-to-day operating rules, as well as the entire water management system for which the dam forms the water storage and/or power generation component.

The design of existing dams is likely to pose physical constraints to reoperation. For example, the size of the outlets and turbine-generator capacity may limit the rate at which water can be released from a dam, precluding the release of controlled flood flows or making it infeasible to release water at low levels comparable to natural droughts. Renovation may be able to solve some of these problems, but not all and at considerable expense. Meanwhile, the river basin context might also constrain some reoperation: for example, floodplain encroachment by development and high value agriculture may limit the feasibility of controlled flooding; or reoperation could increase channel instability downstream.

Krchnak et al. (2009) present a decision-making tool for the reoperation of existing dams (Figure 8). It is a simple screening flow chart designed to identify the most feasible dams for beneficial reoperation, based on physical/technical requisites. It does not deal with important economic or legal/institutional/political constraints, which are deemed to be most efficiently applied to those dams selected through the screening. It also does not attempt to determine whether ecosystem restoration objectives can be met through reoperation; that is left to a further stage of analysis.

Reoperation and restoring environmental should form part of wider efforts to restore river health. The dynamic and complex nature of river ecosystems requires a strategic approach to river restoration which understands and works with catchment and river processes; restores ecosystem structure and function; builds resilience and works towards sustainable outcomes. A framework for such an approach is set out in Speed et al. (2016).

Box 15. Rule Curves

Rule Curves define desired water levels and guide the use of reservoir storage through the year. They can also show certain operating rights and limitations for a reservoir. A reservoir in the European Alps that combines flood control with hydropower generation and recreation, for example, would have a rule curve that directs the operator as follows:

- February-March: increase releases and lower the water level before the spring snow melt
- April-June: rebuild water levels during snow melt
- June-September: reduce water level fluctuations during the recreation period
- Rest of the year: operate the reservoir for hydropower, at close to full supply level.

The operator may have a strict rule curve to follow, or may be allowed to operate within a certain range, depending on short-term weather and power demand developments.

17 Environmental flows describe the "quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems" – as defined by the Brisbane Declaration on Environmental Flows (Brisbane Declaration, 2007). This declaration presents summary findings and a global action agenda that addresses the urgent need to protect rivers globally, as proclaimed at the 10th International River Symposium and International Environmental Flows Conference, held in Brisbane, Australia, on 3-6 September 2007.

(i) Environmental flows

Release of environmental flows from dams can alleviate downstream hydrological alteration caused by the dam. An environmental flow assessment can be used to determine the characteristics of the flow release regime, such as volume and timing, which are necessary to maintain or restore certain components of the river ecosystem (Opperman et al., 2015). The site specific assessment of environmental flows should be carried out as part of the EIA[18].

The release of environmental flows from dams can have positive impacts on ecosystems downstream without significantly impacting on the original dam purpose (Box 16). However, the extent to which environmental flow releases can alleviate impacts downstream is often constrained by demands for water storage and hydropower generation. For example, controlled flood discharges may be important for maintaining downstream ecosystem health, but these must be released through the dam's spillway, sacrificing power generation. In addition, releasing environmental flows might be ineffective if other infrastructure upstream or downstream is not operated in a similar way (Opperman et al., 2015).

Environmental flow restoration via dam reoperation has been implemented in over 850 river basins in over 50 countries (Krchnak et al., 2009) but there is a paucity of monitoring data from these initiatives. For those reoperation initiatives underway, continuous monitoring should be carried out to evaluate the response and impacts of flow releases on river ecosystems. It's important this monitoring informs adaptive management: to date, the success of dam release experiments globally in actually informing operation decisions has been mixed (Olden et al., 2014).

(ii) Sediment management

Sedimentation poses a significant threat to the longevity and sustainable operation of dams. Over time sediment builds up in reservoirs and displaces storage capacity. This reduces power generation, reduces the reliability of water supply and flood management, and affects the downstream geomorphological regime. Simulations suggest that sedimentation is causing a decline in global net reservoir capacity of 5% compared with installed capacity (Wisser et al., 2013). Sediment also damages turbines and leads to inefficiencies in power generation and to costly repairs (Annandale et al., 2016).

Managing sediment accumulation can maintain reservoir storage capacity and in some cases extend the ability to generate dry season hydropower and extend the project's operating lifetime. There are several approaches to this (Kondolf et al., 2014; Krchnak et al., 2009), and many require specific design features which may or may not be possible to retrofit.

- Reducing sediment inflow: by catchment management to control erosion upstream, and by trapping sediment in headwater or channel structures above the reservoir.
- Minimising sediment deposition in reservoirs either by (1) using bypasses to route sediment around the dam, discharging it downstream; or (2) passing sediment through the reservoir via sluicing or turbidity currents. Sluicing involves discharging high flows through the dam during periods of high inflows. Turbidity currents are currents of dense, sediment-laden water that occur in many reservoirs: it is often possible to allow these currents to pass through outlets in the dam. This can be applied successfully to large reservoirs.
- Recovering or increasing storage volume through mechanical excavation or hydraulic excavation – through periodic drawdown or pressure flushing. This involves opening low-level outlets or special sediment sluice gates and considerably lowering reservoir levels to induce flow of sufficient velocity to flush sediments. The lowering of reservoir levels compromises power generation and reduces the potential for environmental flow releases during re-filling. Flushing sediment through sluice gates may not be practical for large reservoirs, where the sediments tend to be deposited at the inflow end of the reservoir.

The sediment management strategy is driven by a wide range of factors including reservoir size, geometry and operating rules; configuration of dam outlets; downstream environment and users that may be impacted by sediment release; and upstream catchment land use and sediment yield (IHA, 2017).

Where sediment management happens infrequently, it reloads the river downstream with sediment leading to sediment management issues. However, frequent, controlled sediment flushing can help alleviate some of the impacts the dam has on downstream geomorphology. Bypassing or routing strategies are considered less impactful because they maintain the natural rate and timing of sediment transport along the river (IHA, 2017).

18 Many different methods exist for environmental flows assessment; theses are discussed in WWF's Primer *Keeping Rivers Alive* (O'Keeffe & Le Quesne, 2009).

Box 16. Reoperating the Three Gorges Dam to help restore the Yangtze River

The Three Gorges Dam (TGD) on the Yangtze River in China is the largest hydropower plant in the world: capable of generating as much electricity as 18 nuclear power stations. Since it was completed in 2003 the TDG has fundamentally altered the flows and sediment regime of the Yangtze downstream, causing major impacts to geomorphology and ecology with knock-on impacts to biodiversity, water security and livelihoods. The numbers of the iconic Chinese carp and sturgeon have plummeted; channel incision has broken connections between the river and its floodplain lakes; and the delta is diminishing, prompting saline intrusion.

WWF raised the profile of environmental flows with the Chinese Three Gorges Corporation (CTG), the agency responsible for the dam, and other influential agencies. Research was undertaken with leading scientists to determine the water requirements for carp, an important source of food for the Chinese people. The research showed that an extra release of water during the spawning season could have a very positive effect on carp numbers. These findings formed the basis of reoperation guidelines for the TGD, presented to the Ministry of Water Resources in early 2011. In June 2011 the TGD released extra water over several days. Monitoring showed very positive results for carp. The TGD continued to conduct these pilot releases over 5 years. The flow releases have been associated with significant increases in fish, with monitoring suggesting that numbers are now 10 times their lowest level in 2008. In 2015, provisions relating to environmental flows were incorporated into the standard operating rules for the TGD.

The Three Gorges Dam, Hubei Province, China

(iii) Adaptation to climate change

Increasing hydro-climatological variability will require increased flexibility in the operation of infrastructure. This may render some existing infrastructure obsolete, but there may be opportunities to reoperate and renovate other infrastructure to increase its adaptive capacity. The World Bank (2011) suggests the following adaption measures for hydropower schemes:

- Structural: building de-silting gates, increasing flow release capabilities; increasing storage through increasing dam height and/or constructing small dams in the upper basin.
- Technology and design: modifying reservoir management rules and water reserves.
- Operation and maintenance: adapting operations to respond to river flow patterns; considering hybrid projects to complement other energy sources

The World Bank and IHA are finalising a set of guidelines on how to achieve climate resilience for new and existing hydropower and dam projects (IHA, 2017). It will include a reporting framework for climate resilience: this is important because the eligibility criteria for finance through the Climate Bonds Initiative will include a measure of climate resilience.

(iv) Operation for multiple benefits

There are opportunities to operate systems of dams in a way that balances multiple objectives. Hydropower cascades, for example, can be operated to restore environmental flows in the most ecologically significant reaches, while releasing water to maximise power generation in other reaches. This can be achieved with little reduction in the total power production of the cascade. In other hydropower cascades, upstream dams can be operated to optimise peaking power generation, while downstream dams can be converted to re-regulating reservoirs and operated for environmental flows (Krchnak et al., 2009).

Meanwhile, some systems can be operated to better achieve flood storage alongside hydropower generation by making greater use of downstream floodplain areas for flood storage (see Box 17).

Basin-level optimisation tools exist that help coordinate dam operation for improved efficiency. For example (Jeuland et al., 2014) used a framework to compare the economics of coordinated versus non-coordinated operation of river infrastructure in the Nam Ngum Basin, a sub-catchment of the Mekong. Results suggested that coordination can improve combined benefits from irrigation and hydropower by approximately 3–12% (or US$12-53m/yr).

Box 17. Optimising benefits in the Yangtze River, China

A system-wide feasibility study was carried to assess the benefits that could be created by coordinating flood management between reservoirs and floodplains in the Yangtze. The study showed that by reducing flood storage volumes in an upstream dam cascade and shifting greater flood-risk management onto the downstream floodplain, the Yangtze system could generate more hydropower, reduce flood risk across a wider area and improve the flow regime for fisheries. The study found that removing the flood storage volume in a planned hydropower cascade could increase annual revenue from hydropower 'by approximately US$400 million per year'. The increased revenue could be invested in floodplain management downstream, providing an equivalent or greater flood risk reduction than by operating the dam cascade for flood management, and generating additional environmental and social benefits.

Source: Opperman et al. (2013)

Dam removal

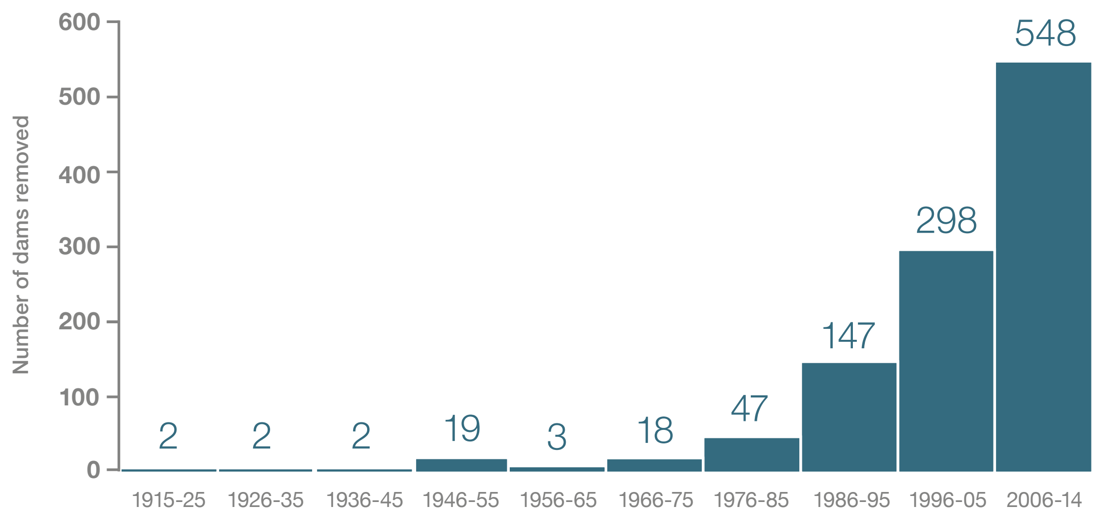
Much experience with dam removal comes from the US where the number of dam removals has increased significantly over the last few decades (EPA, 2016) (Figure 9).

Significant basin-scale increases in connectivity can sometimes be achieved through removing only a small number of dams. Kuby et al. (2005) conducted modelling in Oregon's Willamette River basin to compare the effect of different removal options from 150 dams. The study found that removing just 12 of the dams would reduce hydropower and water-storage capacity by 1.6%, but reconnect 52% of the basin (Kuby et al., 2005).

There are a number of reasons for why a dam might be removed (American Rivers, 2002; Born et al., 1998; Evans et al., 2000; Heinz Centre 2000; Lejon et al., 2009; Palmer et al., 2008):

- **Obsolescence.** The dam is no longer able to deliver its intended purpose or its intended purpose is no longer required by society.
- **Safety.** Older dams need particular attention because they have generally not been designed for flows outside a certain range based on historical records, and therefore are at risk of failing during high flow events. In addition, older dams retain higher volumes of sediment, which if flushed downstream could cause structural damage.
- **Economics.** Dam removal can be more cost efficient than continued repair, renovation and maintenance, as well as mitigating the potential damage caused by dam failure.
- **Public demand** for riverfront revitalisation and river aesthetics, sometimes with improved recreational opportunities such as boating and fishing. Conversely the existing reservoir may hold aesthetic and recreational value.
- **Environmental drivers/legislation**. Dam removal restores connectivity, natural river functions and habitat, leading to improved water quality and biodiversity. Dam removal for environmental purposes may be driven by legislative requirements.

Figure 9: Dam removal in the USA



Source: O'Connor et al. (2015) - based on "US dam removals by decade" data by American Rivers.

Glines Canyon Dam removal,16th March 2012, Olympic National Park, Washington State. This was the largest dam removal project in US history and part of the Elwha River Restoration.

There is no prescriptive method for determining if a dam should be removed, but the decision should be underpinned by an analysis of the costs and benefits of all the different options available: removal, renovation and reoperation. The decision should also be made with the basin context in mind, and therefore based on an analysis of how the removal - or not - affects other infrastructure in the basin and the cumulative impacts and benefits brought by infrastructure (American Rivers, 2002). Typically, evaluations of dam removal have considered environmental flows, dam age and especially failure risk, but more needs to be done to consider the socio-economic and ecological impacts, within the context of climate change (Ho et al., 2017). System-scale planning (as described in previous sections) is a powerful tool in this context.

A key challenge is the uncertain physical, ecological and social responses of removal (Tullos at al., 2016). As far as possible the feasibility of actually removing the dam should consider:

- Engineering feasibility: is removal practically possible?
- Social feasibility: are there local concerns about the removal (such as safety, access, noise, pollution) that need to be taken account of?
- Environmental implications: dam removal causes an ecological disturbance that needs to be carefully managed. It may be that the local ecology has successfully adapted to the modified hydrological regime. Sediment trapped behind the dam can have unpredictable impacts on fluvial morphology, turbidity and ecosystems downstream, and might hold significant concentrations of contaminants.

How rivers and their ecosystems respond to dam removal is only beginning to be explored. A recent review (Bellmore et al., 2017) of the status and trends of dam removal science in the US found that most dam removal studies only have one or two years of pre- and post-removal data and that they have tended to focus on the physical and chemical impacts of dam removal (i.e. flow and sediment) rather than on biological, water quality and socio-economic impacts. The studies carried out into physical responses of dam removals in the US suggest that (Major et al., 2017):

- Rivers are resilient and respond quickly to dam removals: rivers (particularly during high flow periods) can swiftly evacuate large fractions of reservoir sediment; and downstream channels typically take months to years, rather than decades, to stabilise.
- Dam height, sediment volume, and sediment calibre strongly influence downstream response to dam removal. Removals of large dams (≥10m tall) have had longer-lasting and more widespread downstream effects than removals of small dams.
- Downstream valley morphology influences the downstream fate of released sediment.

To date, there is very little experience with the removal of large, multipurpose dams. With their higher costs of removal and the dependence on their multiple functions, a proper assessment of their value is needed, along with strategic planning to ascertain how their services would be replaced (Ho et al., 2017).

As experience with dam removal increases, so should the ability of scientists, resource managers and engineers to predict the feasibility and cost of a decision to keep or remove a dam and the associated social and environmental impacts.

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COVER IMAGE: The Cana Brava Dam, near Minacu.
Upper Tocantins Basin, Goias State, Brazil

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