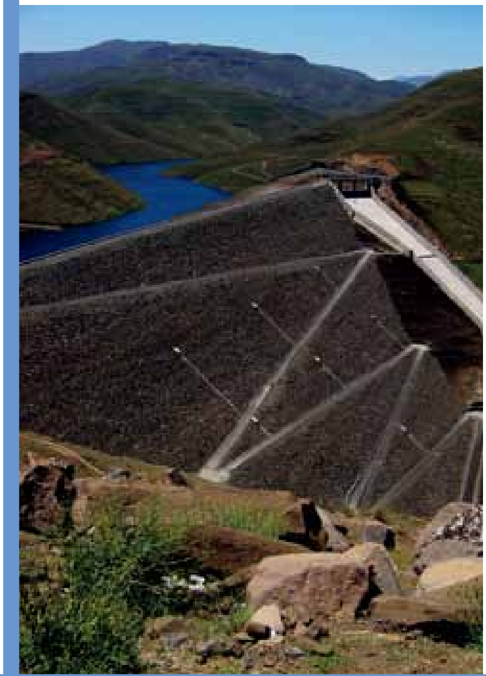
SIWI



LARGE-SCALE WATER STORAGE IN THE WATER, ENERGY AND FOOD NEXUS

PERSPECTIVES ON BENEFITS, RISKS AND BEST PRACTICES

Andreas Lindström, Jakob Granit

Edited by Josh Weinberg

PAPER 21

STOCKHOLM, AUGUST 2012

List of Abbreviations

ADB	Asian Development Bank
AfDB	African Development Bank
EIRR	Economic Internal Rate of Return
ENSAP	Eastern Nile Subsidary Action Programme
EU	European Union
FIRR	Financial Internal Rate of Return
HEP	Hydro Electric Power
HSAF	Hydropower Sustainability Assessment Forum
ICOLD	International Commission on Large Dams
IEA	International Energy Agency
IFI	International Financial Institution
IHA	International Hydropower Association
IWRM	Integrated Water Resources Management
kV	Kilovolt
LEPA	Low Energy Precision Application
MW	Mega Watt
NBI	Nile Basin Initiative
NELSAP	Nile Equatorial Lakes Subsidiary Action Programme
OECD	Organisation for Economic Co-operation and Development
RE	Renewable Energy
RRFP	Regional Rusumo Falls Hydroelectric Power Project
SEA	Strategic Environmental Assessment
SSEA	Strategic/Sectoral Social and Environmental Assessment
TWh	Terawatt hour
UN	United Nations
UNDP	United Nation Development Programme
UNEP	United Nations Environment Programme
US	United States
USD	US dollars
WB	World Bank
WCD	World Commission on Dams

How to site:
Lindström, A., Granit, J., Weinberg, J. (2012). Large-scale water storage in the water, energy and food nexus: Perspectives on benefits, risks and best practices. SIWI Paper 21. SIWI, Stockholm.

Acknowledgments
The authors would like to thank peer review input from Klas Cederwall, Anton Earle, Anders Jägerskog, Karin Lexén, Rickard Liden and Bernt Rydgren.

Disclaimer
The analysis and policy recommendations in this report do not necessarily reflect the official view of SIWI. The authors take full responsibility for the content and findings in the report.

SIWI Paper 21
Published August 2012
by Stockholm International Water Institute (SIWI)

Design by Elin Ingblom, SIWI.
Cover photos by Jakob Granit, SIWI.

For electronic versions of this and other SIWI publications, visit www.siwi.org.

Table of Contents

Key Findings

This report provides an overview of the current status of large scale artificial water storage development and its functions in the water, energy and food security nexus. The objectives of this analysis are three-fold. It presents a typology of water storage structures in order to give an overview of the different storage options, the benefits they provide and how they can contribute to development. This is followed by an analysis of the risks and trade-offs posed by different storage options that must be evaluated in the planning and operational stages. The study then highlights best practices and lessons learned from past experiences that can help guide efficient and sustainable implementation of storage projects. To conclude, it explores emerging opportunities for water storage schemes to enhance water, energy and food security in the future. The following five key findings provide perspectives on benefits, risks and best practices of water storage in the water, energy and food nexus.

1. Large-scale water storage supports economic development, builds water security and buffers against increasing rainfall variability. Several examples from around the world demonstrate how water storage has supported rapid socio-economic development in many regions and countries. Increases in irrigated agriculture land areas have fostered greater food security and electricity generated from hydropower have contributed to large scale grid-based electrification to boost industrial outputs and contributed to economic growth and human development. Hydropower plays an expanding role in integrated power systems and can enable increased use of intermittent renewable energy sources such as wind and solar power. Hydraulic infrastructure and water storage also play an important part in protecting people from the impacts of unpredictable hydrological variability, floods and droughts.

2. Well-designed water storage and hydropower systems can enhance both climate change adaptation and mitigation, but such systems must also plan for a more extreme and variable climate. Integrated regional system planning for water and energy use can support a transition to decarbonise the energy supply chain and provide solutions to meet growing energy demand. While water storage sites do produce some greenhouse gases, their emissions are much lower than conventional fossil fuel. More research is needed on greenhouse gas emissions from reservoirs and possible solutions to reduce them. Hydropower can be developed to mitigate climate change through wider use of renewable energy sources. Existing and future dam and storage assets need to consider the impacts of climate change induced extreme weather conditions and changes in run-off variability. Efficient modelling and planning, including reliable forecasting of different scenarios, will play a vital part in present and future project development. In many places, well designed large scale water storage development is a strategic management response to establish water security and adapt to long-term climate change. This requires, however, thorough options and impact analysis to determine if a storage project is a viable choice.

3. Environmental and social consequences at the local and regional levels need to be addressed up-front when developing water storage. Issues of resettlement, compensation and environmental degradation are critical factors to consider in all water storage projects. In many cases, projects will affect people and ecosystems, often significantly. Consequences can include livelihood losses, impacts on traditional and cultural values, and degradation of public health. Compensation for individuals and communities has been inadequate in some cases. Successful strategies to engage local populations can provide guidance when planning new projects and help create new and meaningful livelihood opportunities for people that are affected by storage construction.

4. There are several ways to mitigate negative impacts from water storage in the project design, implementation and initial planning stages. Environmental and social impacts should be addressed through proven governance and technical solutions at the early planning and design stages. Strategic Environmental Assessments (SEA) are, for example, gaining increasing attention globally as an instrument to identify environmental and social issues in major development programmes and incorporate strategies to address them into the planning, project development and investment finance process. This includes engaging representatives of populations that will be affected by storage construction early in the planning process, and maintaining their involvement throughout the detailed project design (pre- and full feasibility) and implementation stages. Methods and techniques to ensure good project planning and stakeholder engagement tools have been developed actively since the World Commission on Dams produced its industry benchmark report in 2000.

5. Expected benefits from initial stages of storage projects plannings may at times promise too much, but there are also cases where outcomes exceed expectations. Many water storage structures do not reach their expected potential predicted at pre-commissioning stages. Social and environmental trade-offs may overtake the economic benefits. Hydropower dams, however, exceed the target set for economic returns and development outcomes more than any type of other water storage. Existing hydropower electricity generation capacity can also be improved through technical upgrades during the project's life-cycle. Reasons for lower than expected outputs for other storage types are often consequences of gaps between the initial planning assessments and actual carrying out capabilities in subsequent project stages of water storage projects. This can ultimately lead to chronic operational problems. Increasing the efficiency of existing storage schemes provides a major opportunity for increasing output through improvements in water storage technology.

1. Introduction

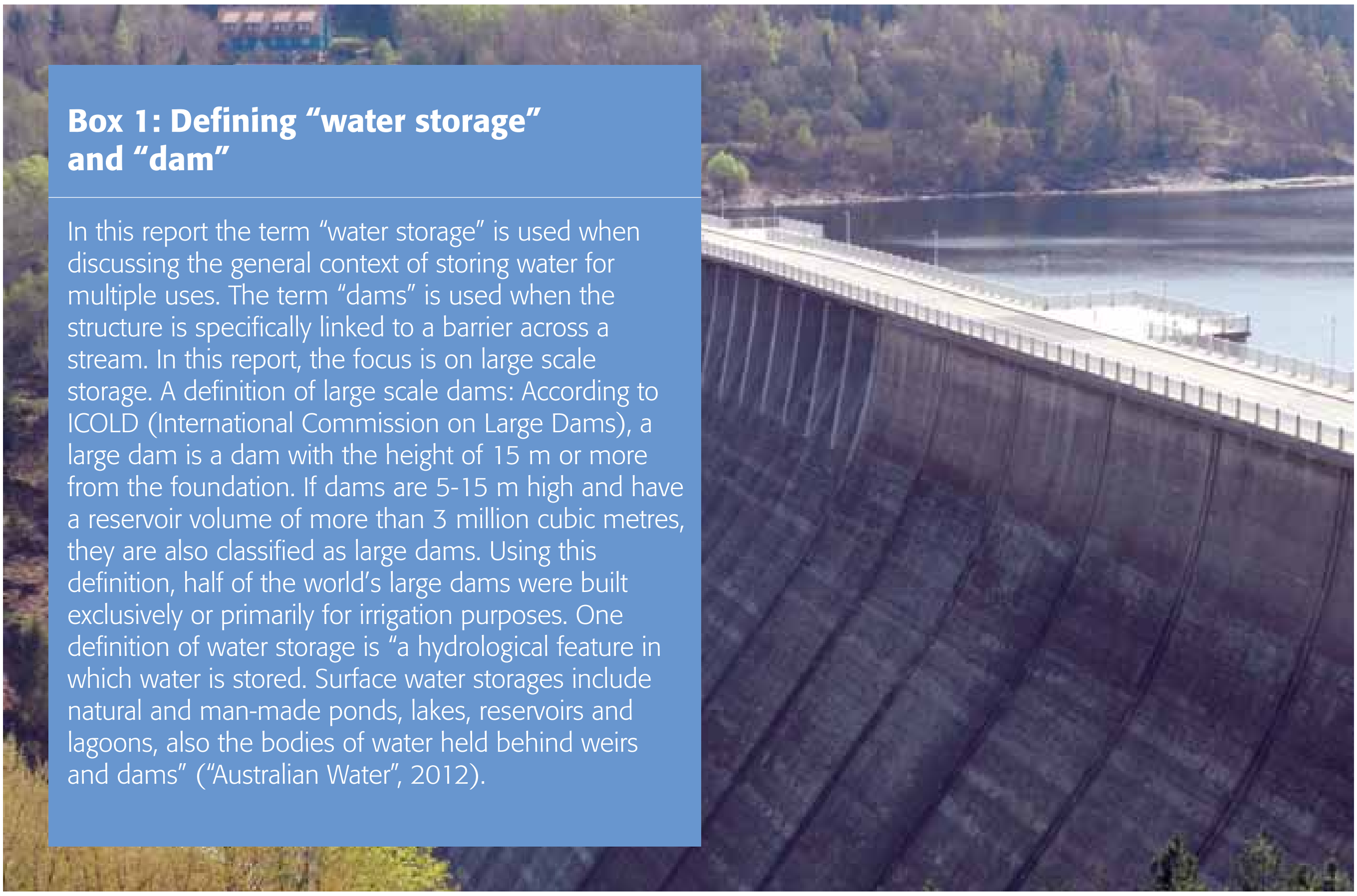
Artificial water storage has, and will continue to have, a large role to play in both emerging and mature economies. The ability to treat, store and manage water is pivotal to meet demand for goods and services and to maintain ecosystem functions. Controlling water flows to deliver the preferred amount of water at the right time is essential in order to support efficient food and energy production and to provide development opportunities for many nations. Increasing climate variability and greater demand for water from growing populations and economies make it even more important.

This report focuses on large scale artificial water storage structures used for various purposes (see definition in box 1). These structures constitute large man-made incursions in natural environments and interplay in delicate ways with hydrological cycles and natural water storage functions. Different kinds of water storage occur naturally as a crucial part of functioning ecosystems. This report does not cover natural storage, but recognises its value for functioning ecosystems (see box 2).

The importance of smart planning, sound implementation and dedicated maintenance of large storage facilities cannot be overstated. Well planned large scale constructions provide intended services while avoiding disrupting natural water flows needed for natural storage systems. Poorly planned projects not only risk falling short of expected outputs but can also have adverse effects on natural systems and local populations.

According to Lehner *et al*, 2011, there are approximately 40,000 registered large dams in the world. Large scale water storage schemes regulate and deliver water in a timely manner for multiple uses. But they can also disrupt ecological and social systems. Change in a water flow regime may have negative impacts on the generation of aquatic ecosystem goods and services and can upset socio-economic systems. To prevent negative externalities, many lessons learned have been collected by different institutions over a long period of time. Presently these experiences are not documented in a systemised manner. They can be found in various strategies, road maps and engagement protocols of many institutions but there is no unified system that is commonly recognised by all stakeholders. In this report we have collected and synthesised key lessons from those experiences, which can help guide future storage planning to minimise risks and negative impacts.

The emerging theoretical framework for the water, energy and food security nexus demonstrates the clear need to improve our understanding of the linkages between water use in society and energy and food production. This knowledge is crucial to avoid future supply shortages that will impede development and to provide all people with access to water, energy and food, while maintaining ecosystem services. Food supply, energy production and different water delivery services all depend on sizable, reliable, continuous and efficient supply of water. Vast amounts of energy are also needed throughout the food supply chain. Water supply services likewise require significant sums of energy to move, heat, and treat water for human use. This report analyses the critical role of storing water in this nexus.



Box 1: Defining "water storage" and "dam"

In this report the term "water storage" is used when discussing the general context of storing water for multiple uses. The term "dams" is used when the structure is specifically linked to a barrier across a stream. In this report, the focus is on large scale storage. A definition of large scale dams: According to ICOLD (International Commission on Large Dams), a large dam is a dam with the height of 15 m or more from the foundation. If dams are 5-15 m high and have a reservoir volume of more than 3 million cubic metres, they are also classified as large dams. Using this definition, half of the world's large dams were built exclusively or primarily for irrigation purposes. One definition of water storage is "a hydrological feature in which water is stored. Surface water storages include natural and man-made ponds, lakes, reservoirs and lagoons, also the bodies of water held behind weirs and dams" ("Australian Water", 2012).

Photo: Jakob Granit, SIWI

Box 2: A brief overview of natural water storage

Natural water storage takes place in many different forms, including in lakes, aquifers, wetlands, glaciers and soil. Lakes, an area of contained surface water, can be fed through run-off water from glacial melt or as part of river systems. Lakes often allow outflow of water through connected rivers and streams but occasionally they are part of "closed" systems where water is drained, mainly through evaporation. Large amounts of freshwater are also stored in the glaciers around the world and they collectively form the largest freshwater reserve on the planet. Glaciers are formed when ice and snow are compounded over a long time period in specific zones and where the rate of accumulation is greater than the natural reduction rate. The increased melting of the world's glaciers poses immediate threats in certain areas and in the longer term it might affect the availability of global water resources in general ("As glaciers melt", 2011).

Groundwater (water located below the ground surface) can either be stored in soil pores, or in different cavities. Porous rock types and other underground material often form aquifers ("Aquifer", 2007). In soil, groundwater is located below the water table, where soil pores are completely saturated thus forming an aquifer. Groundwater is recharged through percolating run off water from the surface level and is discharged through the surface in different water systems (seepage areas, oasis, wetlands, springs etc.) or pumped mechanically for various purposes.

Water is also stored in wetlands that can be both natural, or in some cases constructed by humans. These areas are characterised by their ability to store water at times as groundwater, soil or surface water ("Wetlands", 2012). In general a wetland is a land area that is permanently or seasonally covered with water, whether fresh, salt or brackish water. In addition to being one type of water storage unit, wetlands often encapsulate unique ecological values due to the specific conditions offered by the aquatic soils found in these environments. Another important natural system of water storage is found in top soils and the root zones of plants. Water in this zone is dependent on precipitation and is the key component in rain fed agriculture.

The above mentioned natural systems of water storage co-exist with an increasing number of constructed water storage structures, both small and large, which are built to satisfy human needs. Small scale systems can often be used for purposes such as rain water harvesting to boost drinking water supplies, or to provide irrigation water. Small to medium scale water storage structures constructed from earth or cement (and sometimes tanks) are also used to support local agricultural units (on-farm reservoirs) with irrigation water during dry periods.

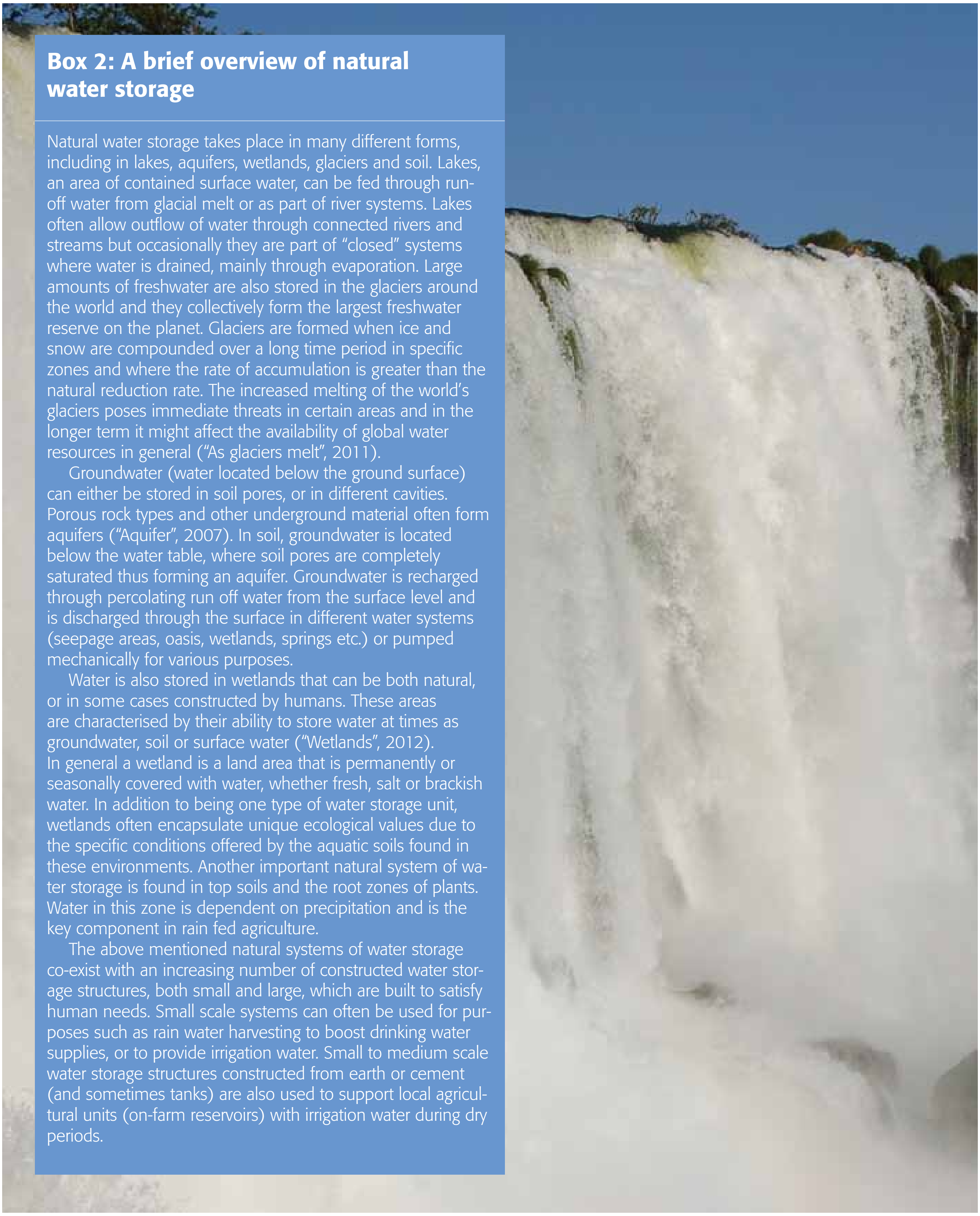


Photo: Jakob Granit, SIWI

The following section introduces a typology of key water storage functions in the water, food and energy nexus. The overview also assesses the performance of the structures based on literature reviews. We have used a functional typology and list these functions as follows: 1) irrigation, 2) hydropower, 3) water supply, 4) flood control, 5) multi-purpose use, which combine two or more functions, and 6) storage for tailings.

The International Commission on Large Dams (ICOLD) register has 37641 large scale dams (a dam that stands at 15 meters above the foundation). This is the most comprehensive data set that currently exists, but it is not complete. In the register a majority of the large dams are single-purpose. Figure 1 provides a map of the registered dams by location and function. Half of the single purpose dams are used for irrigation, followed by 18 per cent for hydropower, 12 per cent for water supply and 10 per cent for flood control and the remaining per cent represents other functions ("Purposes of dams", 2012).

2.1 Irrigation

The productivity and efficiency of water storage used for irrigation purposes is affected by many related socio-economic circumstances that extend beyond the formal area of water storage construction. Potential benefits from irrigation storage depend on a wide range of connected components where some examples can be the efficiency of existing agricultural systems and practices, as well as market availability. According to the World Commission on Dams (WCD) there are three typical indicators to measure the performance of large scale water storage projects for irrigation (WCD, 2000):
1) physical performance for water delivery, area irrigated and cropping intensity;
2) cropping patterns and yields, value of production;
3) net financial and economic benefits.

Of the 52 large water storage projects analysed in the WCD knowledge-base, almost half did not achieve planned physical performance targets and also failed to reach expectations on the total land area actually irrigated. Projects appear to be prone to poor performance in the initial phases but improve over time. General trends show that irrigated areas increase, on average, from 70 per cent of estimated area in year 5 to 100 per cent by year 30. Values reflecting crop intensity are more consistent with envisioned targets (Correa, 1999). Within the WCD sub-sample group of dams, close to half of the investigated projects achieved or exceeded expected targets from the first year of operation. The size of the dam seems to play a part in how well these structures meet targets relating to water delivery, actual cropping intensity and proportions of irrigated areas. According to WCD, dams of smaller size usually perform better. Dams corresponding to heights less than 30 metres and reservoir areas smaller than 10 km^2 generally show greater consistency in fulfilling required outcomes, while 90 per cent of projects that failed to meet their targets were of larger dimensions.

The main reasons for poor performance of large scale water storage project for irrigation are generally found at the administrative or institutional levels. Common issues include: insufficient distribution networks, inefficiencies resulting from centralised administrative systems to regulate financing for canal developments, unclear divisions of responsibilities between institutions, poor coordination between planning agencies and a lack of incentives to engage local stakeholders in agricultural communities. A second performance criterion put forward in the WCD is actual

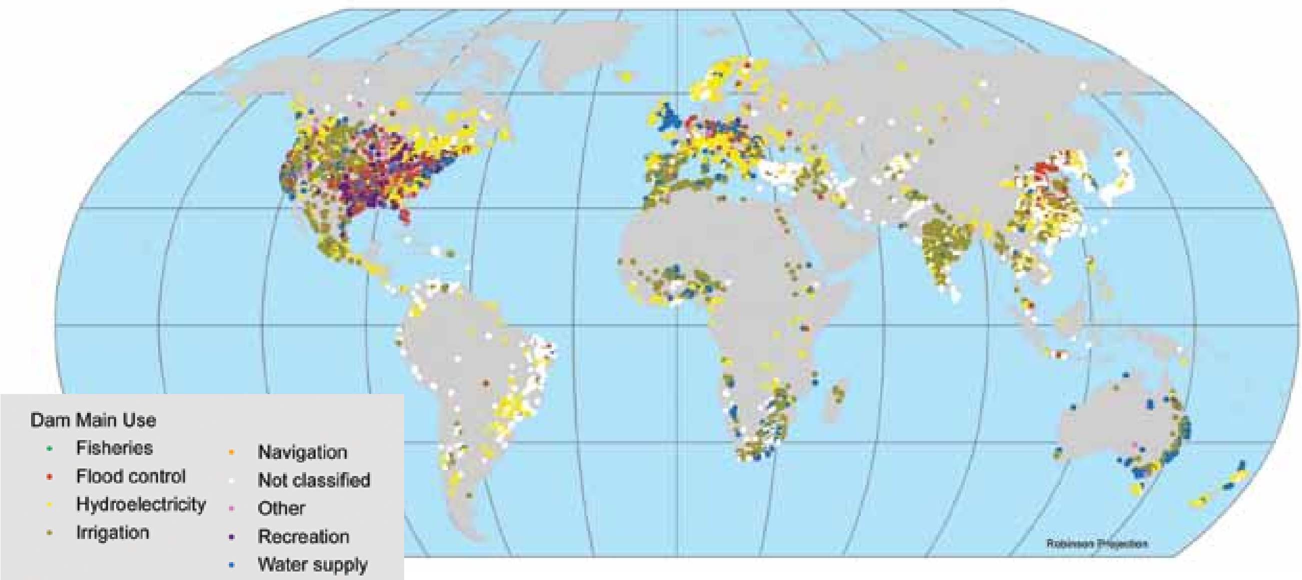


Figure 1. Location of large dams by function (Center for International Earth Science Information Network (CIESIN) ("Dams", 2012).

crop yields and the value of agricultural goods produced. There tends to be a rather substantial variability in actual outcomes compared to planned outcomes in terms of agriculture outputs. The primary factor that causes this variation is the difference in the capacity of local stakeholders to effectively manage, maintain, and utilise the storage system. Lower crop yields are observed when agricultural activities and crops are pre-determined in planning stages of the projects. Higher yields or gross values of production are more frequently observed when farmers are free to react to changing market behaviours and have greater flexibility to adapt their planting to produce more high-value crop types. Other reasons for variations in outputs relate to inefficient farming methods, usage of sub-standard quality crop types and usage of farmland of uneven standards. Inadequate storage facilities, underdeveloped drainage systems, unfit irrigation, pest infestations, and severe weather conditions are other commonly referred to reasons for poor performance.

Conventional assessments, such as the Financial Internal Rate of Return (FIRR) and Economic Internal Rate of Return (EIRR), are applied by the WCD to measure net profitability of irrigation water storage projects. The EIRR is a better indicator for human development, as it assesses overall economic output from a societal perspective. It is suggested that in developing economies, EIRR values over 10 per cent are considered satisfactory (Mander & Nagraj, 1999). Of examined projects, the average EIRR value was about 10,5 per cent, though a considerable amount of evaluated projects rated as low as 5 per cent. It should be noted, however, that all results were evaluated within a relatively short time period after projects were commissioned. In most cases, irrigation water storage first reach optimised functionality after several years of operation, which means these values may increase over time.

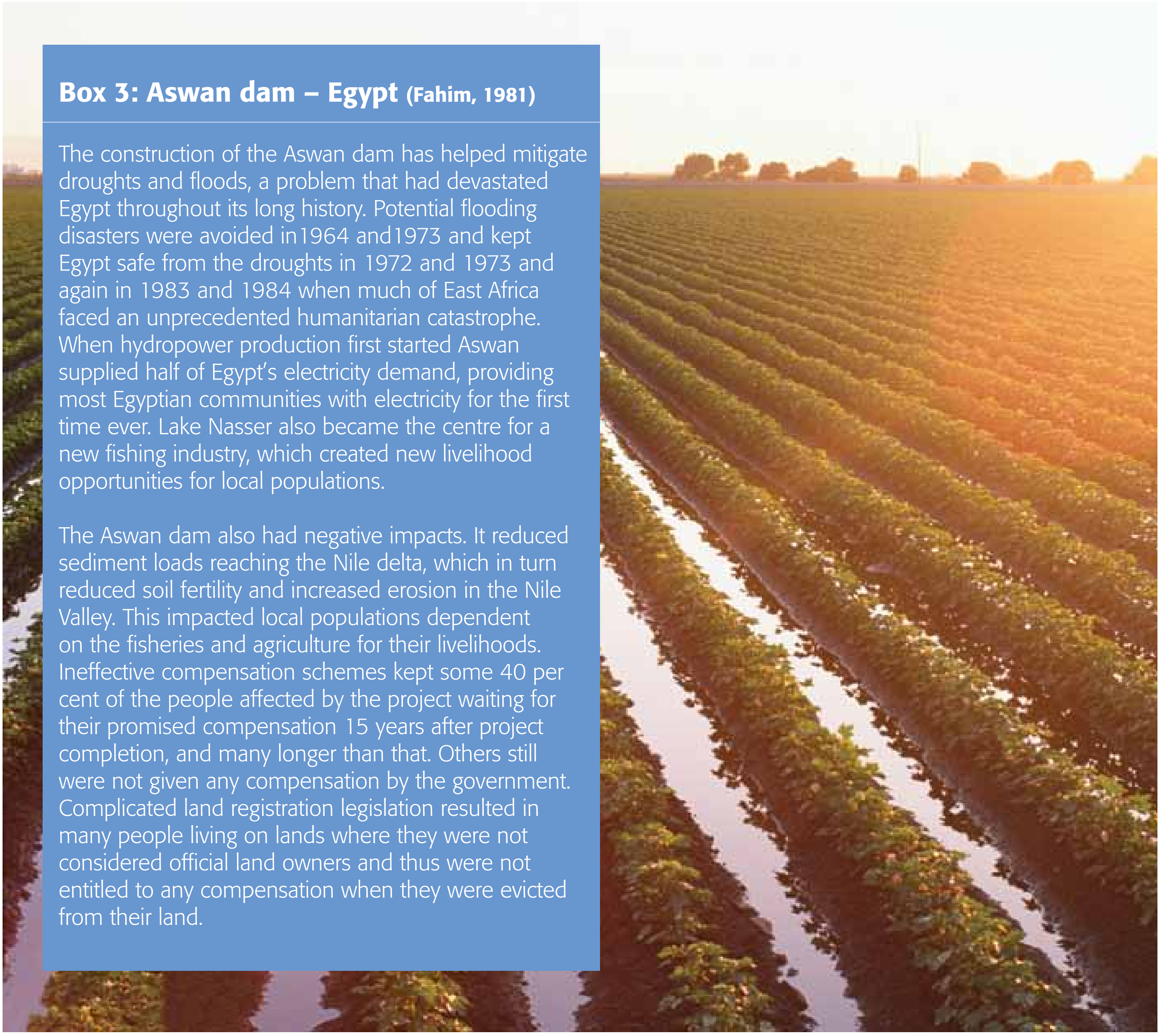


Photo: Getty Images

Box 3: Aswan dam – Egypt (Fahim, 1981)

The construction of the Aswan dam has helped mitigate droughts and floods, a problem that had devastated Egypt throughout its long history. Potential flooding disasters were avoided in 1964 and 1973 and kept Egypt safe from the droughts in 1972 and 1973 and again in 1983 and 1984 when much of East Africa faced an unprecedented humanitarian catastrophe. When hydropower production first started Aswan supplied half of Egypt's electricity demand, providing most Egyptian communities with electricity for the first time ever. Lake Nasser also became the centre for a new fishing industry, which created new livelihood opportunities for local populations.

The Aswan dam also had negative impacts. It reduced sediment loads reaching the Nile delta, which in turn reduced soil fertility and increased erosion in the Nile Valley. This impacted local populations dependent on the fisheries and agriculture for their livelihoods. Ineffective compensation schemes kept some 40 per cent of the people affected by the project waiting for their promised compensation 15 years after project completion, and many longer than that. Others still were not given any compensation by the government. Complicated land registration legislation resulted in many people living on lands where they were not considered official land owners and thus were not entitled to any compensation when they were evicted from their land.

2.2 Hydropower

Hydropower – the method of harnessing kinetic energy from moving water and transforming it for other useful purposes - has a long history. The early forms of utilising the mechanical power of moving water included powering mills to produce flour from grains ("What is hydropower's history?", 2012). Modern hydropower generation dates back to the late 19th century. In 1920, hydropower provided 40 per cent of the electricity produced in the United States ("Hydropower usage", 2010). Most hydropower produced today utilises the same methods, and the technology is considered mature (see box 4). Hydropower facilities are usually classified as schemes with storage reservoirs, run-of-river or pumped storage.

Environmental problems associated with hydropower generation are often linked to the storage functions. Some of these problems include flooding that can occur when reservoirs are established and change the aquatic environment, which shift from a lotic (rivers, springs, streams) to a lentic (lakes, swamps, ponds) system and cause sedimentation in the reservoir. Hydropower plants utilising water storage are the best way to generate large amounts of power at more stable levels. It is also possible to generate power using little to no storage by creating run-of-the-river hydropower schemes. Some of the largest major hydropower schemes in the world with major storage are found in China and South America, such as the Three Gorges Dam in China (which has an estimated capacity of 22 500 MW), Itaipu in Brazil (14 000 MW) and Guri in Venezuela (10 200 MW capacity)

The benefits of large scale water storage designed for hydropower purposes are evaluated by WCD primarily upon their ability to meet power delivery targets. According to the WCD knowledge base, hydropower dams appear to meet pre-determined targets more than irrigation dams. Close to 50 per cent of the projects within the knowledge-base exceeded targets.

Most of the hydropower plants that provided benefits beyond expectations had installed extra generation capacity after commissioning. Roughly one-fourth of examined dams with higher outputs than expected had installed more than 100 per cent of the capacity they had planned for in respective feasibility studies. This demonstrates that it is possible to make the projects more effective over time.

There are also cases where outputs are lower than expected, with 5 per cent of examined hydropower dams in the WCD knowledge base falling well below expected outcomes. The reasons for lower than expected results differ. In general, the time spans for hydropower dams to reach expected outcomes are shorter than with irrigation dams, averaging 80 per cent of the expected capacity reached within the first year of operation. This subsequently increases in years two-to-five to come close to 100 per cent realisation of expected targets. Similar to irrigation dams many problems related to poor performance can be traced to the planning phases of hydropower projects. Errors or changes at early development stages show clear linkages to greater delays in reaching expected power generation targets in early years of operation. This might include delays in filling up reservoirs, postponements of components in construction phases, design changes or an inability to get turbines up and running according to the initial planning.

There are also natural circumstances that can cause power delivery of large hydropower dams to be more variable and less reliable once operational. Changes in weather conditions, precipitation and hydrological patterns might yield considerable differences in annual energy outputs due to weakened river flows. In many cases, huge variations in power production can be traced to drought seasons in specific regions. Land use changes in catchments upstream can increase erosion, leading to siltation that reduces storage capacity and the storage potential of the reservoir.

Photo: Jakob Granit, SIWI

Regarding profitability of hydropower dams, conclusions can be drawn from a variety of case studies performed by the WCD. Even if a number of projects fall short of predicted targets very few projects can be considered economically unprofitable. The number of projects falling slightly short of planned profitability is matched by a number of projects that outperform their original estimates of profitability, with specific projects reaching respectable EIRR values even after decades in operations. The Kariba dam located on the border between Zambia and Zimbabwe in the Zambezi river basin, which boasts an EIRR value of 14,5 per cent, is a prime example.

2.2.1 Storage hydropower

Hydropower schemes that have a reservoir which is capable of storing water for power generation at any given time is called storage hydropower. The reservoir provides the opportunity to release water when it is most advantageous and provides a constant flow of water via penstocks through turbines. Storage hydropower can therefore be used for both base and peak power load. The storage creates flexibility in generation and is therefore often a preferred method of hydropower generation. Large reservoirs can also provide additional multi-purpose benefits such as flood control, water supply and drought mitigation water supply. The reservoirs can retain several months of water flow or have multi-year storage capacity, as can be found in the Kariba Dam, or in the Aswan Dam on the Nile River in Egypt.

2.2.2 Run-of-the-river hydropower

Run-of-river hydropower plants use little to no water storage (in some cases there is small storage in ponds, called "pondage") and do not alter the normal flow of the river to a substantial degree. Definitions of what can be considered a run-of-river scheme differ. Some claim that only schemes with no water storage can be labelled as run-of-river, while others argue that schemes storing small volumes can still be considered as such.

Run-of-river schemes are generally considered to have a lower environmental impact than hydropower types that utilise major water reservoirs. However it should be recognised that the extent of environmental impacts are site specific and can vary for different projects. The principle of run-of-river is to rely on the natural downward flow of a fast moving river and divert a pressurised portion of it through a conveyer pipe (a small "headpond" upstream often ensures that the intake end of the pipe/penstock is kept under water), either on ground or (more commonly) below, to powerhouse/ turbines in order to generate electricity ("Run of the River", 2012). Water is then channelled back to the main river. The run-of-river technology is applicable for both small scale and larger scale projects, but the absence of reservoirs might make it most suitable for projects of lesser scale.

Still, some outstanding issues related to run-of-river and the environment persist. Reduced flows in the main river that result from the diversion of water are one concern. Substantial volumes of a river's main stem will be temporarily abstracted, which can impact existing flora and fauna. Due to small or non-existent storage functions, run-of-river plants are much more vulnerable to changes of flow regimes than plant types with substantial water reservoirs. This means that power production rates, however continuous, can vary along with fluctuating river flows. When some pondage is used, run-of-river schemes can be utilised to provide base load requirements and can also respond to meet peaks in demand.

2.2.3 Pumped storage hydropower

Pumped storage is a form of hydropower that can serve as a regulator to meet the varying demands for power over different time scales. The technology has been available since the late 1800's but is of increasing importance as it can balance load differences on power grids as an alternative to more typical base load providing technologies, such as conventional thermal energy or nuclear power (Levine, 2003).

Pumped storage provides a "battery" to back up other forms of energy. It entails the usage of off-peak power to store energy in the form of water, which is then released during peak demand. Water is pumped from its source to a natural or artificial reservoir (in rare cases both reservoirs are artificial) at a higher elevation by using less expensive (surplus generation capacity) electricity in times of lower demand. The water is then released through turbines at times of high electricity demand using the energy stored from off-peak hours. Though a net consumer of energy, pumped storage plants make economic profit on the value of the power they produce in times of high demand.

Hydropower in general and possibly pumped storage in particular, has a large role to play to expand the deployment of renewable energy (RE) technologies. Both provide a feasible option to regulate and store power due to their quick response time. Hydropower can therefore facilitate intermittent energy generation technologies such as wind and solar energy. To further add to the sustainability of pumped storage, experiments using wind or sun power to fuel water pumps have been conducted (Bueno, 2006).

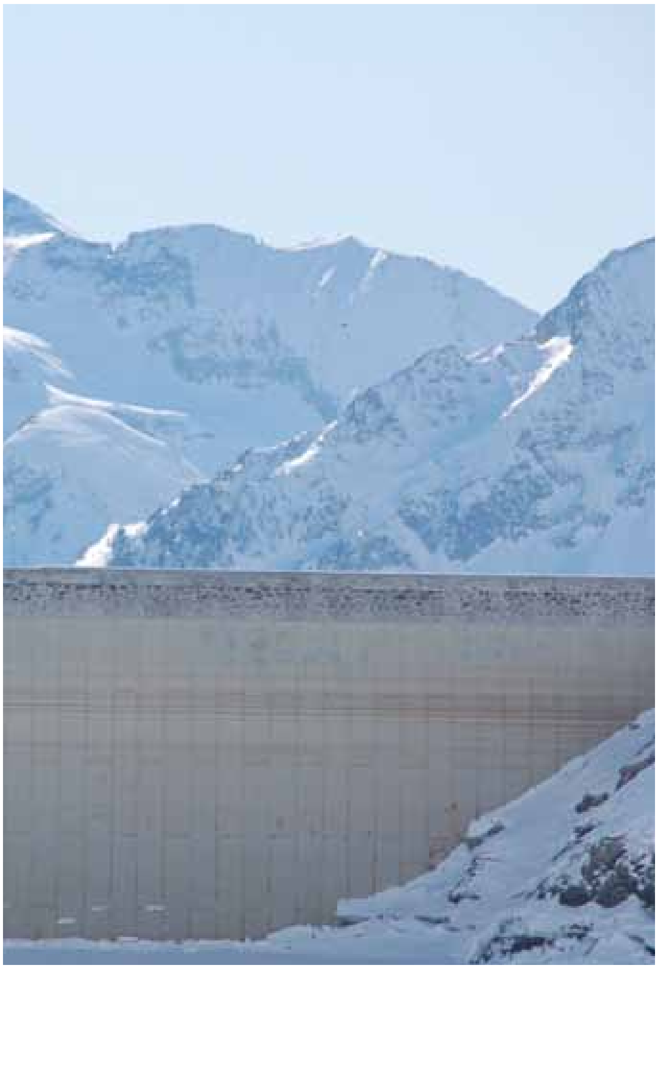


Photo: Jakob Granit, SIWI

Box 4: Scandinavia: Hydro-powered development ("Vattenkraften i Sverige", 2002; "Uppsala Mitt i Sapmi", 2011; "Ett Samtal", 2011)

The ability to store and regulate water has been instrumental for economic development in Scandinavia, especially in Sweden and Norway. With few natural energy resources besides hydropower, water storage has played an integral part in Swedish industrial development. Large scale storage solutions began at the end of the 19th century and start of the 20th century. In northern Sweden, dams were constructed in scarcely populated areas and provided power for growing financial hubs in the south. Within a few decades, reliable and adequate power supplies fuelled the economy enabling Sweden to transform from a poverty stricken country to join the richer nations in the world. In addition, the need to transfer power long distances stimulated innovation. The Swedish engineer/inventor Jonas Wennström developed the three-phase transformer (in parallel with the Russian inventor Michail Dolivo-Dobrovolskij) and the first 400 kV transmission line was constructed to connect the Harsprånget power station to southern Sweden. Hydropower had similar importance in Norway's development.

As hydropower assets were exploited on a larger scale in northern Sweden, several implications emerged at the local level. The indigenous Sami population suffered as they lost ownership of their land. As the land was nationalised by the government, they only received right to "land usage". Some even argue that the Swedish national government committed "land- theft" in this process. Critics claim that ambiguous laws were created in the Nordic countries, especially Sweden and Norway, which enabled the government to drive the Sami people from their lands in order to exploit natural resources. This process has been described as a colonisation much like what have been experienced in other parts of the world, such as the imperialism in 19th century Africa. As a result of land loss, the Sami people also lost opportunities for livelihood generation, access to traditional cultural areas and many accounts of abuse have been documented. Land ownership and compensation issues are still a contested topic in these areas. Consequences of storage and hydropower development, such as altered water quality and loss of local fauna, are still felt in northern parts of Sweden.

2.3 Water supply

Water storage systems designed with the primary purpose of providing bulk water supply can be assessed and evaluated according to their ability to meet pre-determined targets of water delivery. According to the WCD knowledge base samples, roughly one in four of dams had reached less than half of initially planned supply targets. While other discussed dam types have shown a somewhat solid ability to catch up and sometimes exceed intended targets over time, water supply dams on the other hand do not show similar features, with some 70 per cent of sample subjects not reaching their intended targets even over considerable time periods.

Contrary to other single purpose water storage types that usually meet their targets, water supply dams fall short more often both regarding of water delivery and timing as well as cost recovery and economic return. In all investigated cases where bulk water supply exceeded expected outcomes, supply functions were part of multi-purpose dam schemes. According to WCD, demand for water supply tends to grow even in connection to dams not specifically built for that purpose because they often foster population growth and economic expansion.

The general economic profitability of single purpose water supply storage can be considered to be rather unsatisfactory. Poor performances (with EIRR values well below 10 per cent) seem to be the norm of examined subjects within the WCD knowledge-base. These results are also echoed somewhat in general findings regarding water supply and sanitation projects of different organisations. The Asian Development Bank (ADB) has reported a large number of projects failing to meet both FIRR and EIRR targets (WCD, 2000). A World Bank analysis of 129 supply and sewerage projects reported that practically all delivered EIRR values were below 10 per cent (WCD, 2000). Insufficient tariff systems and pricing mechanisms are common reasons for poor economic returns. Of examined projects in the knowledge base, 35 of 50 utilities carried their operation and maintenance costs through tariffs (ibid). However, several studies show that there is a general willingness, even in developing nations, to pay for satisfactory water supply and sanitation services. In many cases, people already pay water vendors considerably more than they would for the operation and maintenance costs of a piped supply system. The EIRR and FIRR values for water supply dams may be misleading since water is not traded at its full market value due to political and social considerations.

2.4 Flood control

Ambitions to control river flows for improved agriculture and industry and to protect populations and property from flooding are a fundamental aspect of water resources management and storage. Traditionally, water storage that regulates river flows operate by storing varied volumes of flood waters in constructed reservoirs and then controlling the timing of water discharge over time. By doing this, it is possible to regulate peaks in tributary river flows and mitigate flooding. Indicators to assess performance of flood control dams thus relate to the actual reduction of flood peaks and the subsequent reduction in negative impacts on the economy, property, society and human health (WCD, 2000). According to WCD, flood control dams generally achieve their purpose to reduce levels of peak floods and lower risks to downstream activities during extreme hydrological events. Even when maximum storage capacities are breached in extreme cases, the delays in floods create an opportunity to issue warnings and begin evacuation and rescue operations (Robinson, 1999).

Problems related to the functions of flood control dams are often confined to physical or technical aspects of construction. Documented risks include faulty operational procedures of reservoirs in times of quick changes in external conditions or mechanical malfunctions of dam components, such as flood gates and flood control structures. As peak-flow regulation may only be needed a few times each year, flood control dams are often combined with other purposes. Consequently there may be risks for competing and conflicting utilisation where empty reservoirs must be maintained for flood control, while irrigation and hydropower requires reservoirs to be as full as possible at all times.

Another significant issue faced is the emerging challenges presented by climate change. Existing water storage structures were designed according to the conditions that existed at the time then were built. There is, therefore, a need to re-evaluate the safe discharge capacity of dam structures if the hydrology changes. Re-optimisation and reassessment of operational rules are also needed as quality information accumulates over years of operation and can offer opportunities for better and safer operations.

Consequently, overall reassessments of water storage functions are increasingly recommended by water resources managers as a tool to safely and effectively control and manage floods. As identified by the WCD, some structural issues to consider when adopting an integrated flood managing system include the high costs of developing fully reliable control systems, and the capacity reductions that occur over time due to sedimentation. Further steps are needed to take advantage of the potential positive impacts that floods can generate for many ecosystem services.

There are several ways in which societies have traditionally managed floods. Constructing barriers, or levees, along the course of the river is a common method. Levees prevent surplus water volumes from deviating from the main channel and reach surrounding areas. Levees can also have negative consequences as they can induce water to move at a higher velocity, which can carry larger sediment loads downstream instead of being deposited at the river bank. They can also provide a false sense of security. There are many ways in which levees can be breached, if run-off increases beyond their capacity and flows over their edges. Long retention times of excess water also pose a risk to saturate the levee, cause it to seep and, ultimately, become less stable. Erosion of the levee is also a risk which can cause them to collapse. Poor maintenance can lead to new or worsen existing weaknesses in the levee, specifically at various connection points in the structure.

Dam-reservoirs are constructed with the purpose of holding significant volumes of water, which can also prevent floods (see box 5). This requires careful oversight and back-up strategies, as the absolute storage volume offered by dam-reservoirs can only contain a certain amount of water flow, and may not always be sufficient to contain rapid influxes of water entering the reservoir. Another method to mitigate floods is called "eco-flooding". This system relies on using existing, less sensitive, storage space in the landscape. By diverting part of the excess river flow to other areas in the terrain it is possible to temporarily reduce water flow further downstream. This system usually needs support functions, including the construction of levees, to contain water flows to assigned areas (Wikström, 2007).

2.5 Multi-purpose use

Several water storage schemes serve many of the typical water management functions described in the previous sections of this chapter: irrigation, hydropower, water supply and flood control. These are known as multi-purpose water storage schemes. Regions served by different water storing facilities often must meet more user needs and provide more benefits than single purpose water storage structures. It can also be a strategic decision to try to incorporate as many features as possible when deciding on large scale investments due to the high capital costs involved.

Single purpose dams are expected to perform better when compared to multi-purpose storage because it is usually less complicated to improve performance in one area than it is to manage trade-offs from several user needs. With regard to achieving physical targets, the performance of multi-purpose dams is therefore

Photo: Jakob Granit, SIWI

Box 5. Flood control in Oklahoma, USA
("Programmes in Oklahoma", 2011; "Oklahoma Flood Control", 2011)

Oklahoma is a state that is severely affected by floods due to periods of intensive rain fall. Historically this has meant the loss of life, property and economic opportunity. A vast network of over 2000 upstream dams, including some large scale structures, has proven to be critical in mitigating impacts of severe floods. According to some estimates the state of Oklahoma saves approximately 70 million USD in damages annually by having the protective dams in place.

difficult to evaluate. They also show a slightly larger scale of variation in achieving expected returns on investment. A WCD study conducted on 12 projects demonstrated that all generated slightly lower (roughly around 4 per cent) EIRR values than projected in pre-operational phases.

Multi-purpose structures, arrangements and layouts are, by definition, more complex than single use designs. Combining different uses, such as hydropower and flood control, requires that alternative reservoir functions are balanced and maintained in an optimal way to maximise benefits from multi-purpose schemes (see box 6). The WCD concludes that the impacts of conflicting water use arising between different operational uses of multi-purpose dams are underestimated. Ecosystem services and socio-economic development schemes will usually be considered during project design even in a single purpose scheme.

2.6 Tailings storage

The extraction of minerals in the mining industry produces large volumes of by-products. In Sweden, mined iron- ore can contain as little as one part metal per thousand or as much as to 20-30 per cent (Isaksson & Lundström, 2005). The rest of the left over material (called "tailings") is often crushed to finer grain sizes. As the refinement process of metal extraction is water intensive, the by-product (slurry) often has high water content. The most common way to store tailings is to use impoundment systems, called "tailings dams". There are an estimated 3500 tailings dams in the world (Zardari, 2011). If considering the physical structure alone, these dam types are often among the biggest in the world. Tailings dams are designed to safely store water and rest products that potentially contain harmful chemicals produced in the mining process. The viscosity of the slurry makes it suitable for transport to the deposit site by pumping through pipes where the sedimentation process can take place.

Surface tailings dams can be built in different ways. In general, dams consist of a constructed embankment, and dikes are often built from waste material from the mining process or soils from the surrounding area. Construction usually follows a step-by-step method, where new dikes are added as the deposit grows during the duration of mining operations. Dam types built using raised embankments are normally constructed in one of three different ways: the downstream method, the upstream method, or the centreline method (Chambers & Higman, 2011).

The downstream method begins with a "starter dike", and new dikes are added facing away from the deposit area. This structure is considered very stable because it allows for greater control and more substantial "packing" of embankment material. This means that it can allow more direct contact with water surfaces. It also enables the embankment to be divided in different zones with impermeable cores and internal drains, which resembles conventional dams in terms of solidity (Isaksson & Lundström, 2005). On the other hand, in many places the area that can be covered by tailings dams is restricted, which limits the amount of outward expansion at times making this method unviable.

The upstream method also begins with a starter dike, but then adds filling material on top of the original dike and forms an inwards leaning embankment towards the water surface. This method allows sediments to form a sloping surface area (commonly referred to as "beach") from the embankment towards the water surface. These structures are usually not divided in zones and thus considered less stable. This puts greater emphasis on the properties of the tailing sediments providing the embankment foundation and the ability to drain the dam.

Centreline dam types expand their embankment structure in a vertical manner from the starting dike. Consequently, the added material will also be located on both upstream and downstream sides of the embankment. This construction method embodies properties of both the upstream and the downstream types.

The storage of tailings can come with considerable risk. Tailings dam accidents represent a significant portion of dam failures

Box 6: Three Gorges Dam, China
(Wines, 2011)

The Three Gorges Dam is a multi-purpose scheme intended to provide a major lever in Chinas rapid development. Plans to construct the dam had been in place throughout the 20th century with actual construction taking place from 1994-2008. The main objectives of the dam are to provide flood control of the Yangtze River, electricity to the industrial sector and to improve navigational conditions. Presently the dam protects people in the middle and lower reaches of the river from flooding, which previously led to massive losses of lives and property throughout China's history. Access for transport by boat to the interior parts of China has been greatly improved. The dam helps fuel China's economic boom by producing an annual output of approximately 80-100 TWh/year. That is more than the entire hydroelectric production of Sweden, another top producer in terms of hydropower.

There are, however, major social impacts from this multi-purpose storage scheme. The construction of the reservoir displaced an estimated one million people from more than 1000 villages. There have been problems related to compensation for resettlement and generation of livelihood opportunities. Corruption is listed as one reason for this. The creation of the reservoir submerged several facilities that contain dangerous residues, which now contaminate local water resources. Some speculate that the shifting water levels of the reservoir are eroding the surrounding slopes and contributing to several landslides that have severe impacts on humans and property. Chinese officials have stated that there have been adverse environmental hazards related to the construction of the dam.

recorded in the modern era ("Chronology", 2011). As tailings dams not only store water but also potentially toxic or harmful residues from mining operations, they are more complicated to decommission. Dams must, essentially, be designed to last indefinitely. A breach in security of a tailings dam not only risks harm to life and property in a single catastrophic occurrence, but it also risks long-term environmental damage if the content of the reservoirs reach beyond designed boundaries.

Differences of purpose also bring differences in perceptions. A conventional dam is seen as an investment that requires sufficient maintenance to turn profit. A tailings dam is more frequently viewed as an unwanted necessity and a costly side-effect of the mining process and consequently might not receive the proper attention (Chambers & Higman, 2011). The design of tailings dams, as previously explained, might also be one reason for the seemingly high frequency of failures. The fact that most dams are constructed in sequences can be one factor affecting their stability. The cheaper "upstream" dam type might be a favoured design among project developers, but they offer less stability than other types. The integrity of the upstream type dam can be compromised by its lower drainage capacity and the composition of the tailing itself as it makes up part of the actual dam structure.

Over the past decade, several major accidents with tailings dams have been recorded. Common reasons for failures are related to changes of external circumstances, and structural weaknesses in both the embankment and its supportive functions. Heavy rainfall and mud slides are known to increase pressure on dam structures and ultimately cause them to break. The sensitive process of raising the embankment and other maintenance work are also moments when dams have been known to fail. Beyond the immediate dangers caused by these failures, polluted slurry can infiltrate drinking water reserves. The properties of the slurry make it difficult and costly to sanitise and it can inflict substantial long term damage on human and environmental health (see box 7).

Box 7. Tailings dam accidents
("Chronology", 2011)

On October 4 2010, the embankment of a basin near the village Kolontár in Hungary broke down. Approximately 1 million cubic metres of alkaline sludge stored from a nearby aluminium industry flooded surrounding areas. Ten people were reported killed in the incident and some 150 injured. About 800 hectares were polluted by red sludge that reached seven different municipalities in the area. The exact cause of the dam break has not fully been established but it is thought that increased pore pressures in the structure caused a break at a seepage point.

On April 25 in 1998 a significant failure occurred in The Los Frailes tailings dam located in Aznalcóllar, Spain. The dam supported a lead and zink mining industry. A slab of underlying material beneath the embankment structure started to move, which eventually caused an entire part of the structure to collapse and breach the dam. Some 5 million cubic metres of slurry flowed out and covered several thousand hectares of agricultural lands. The slurry contained heavy metals and reached important water ways, such as the Guadiamar River. The parent company, Boliden ltd. (also responsible in the case above) admitted a year after the accident that the dam was poorly constructed. The three year clean-up effort cost an estimated 300 million USD.

Photo: Getty Images

The benefits of developing water storage were summarised in the previous section, including its ability to buffer against climate variability, increase outputs from agricultural and energy production, stabilise water supply and stimulate economic development. The lack of strategic multi-sector programme planning has, however, sometimes led to significant environmental and social impacts from water storage projects. Understanding the potential negative social and environmental consequences from water storage projects and how to mitigate them is essential to optimise the outcomes of and returns on such investments. The following section will analyse the role of water storage in economic development and potential trade-offs to be considered.

3.1 Environmental impacts

3.1.1 Flow regimes

Flow regimes are crucial to aquatic ecosystems. Flora and fauna both depend on the regularity and timing of floods in order to survive. Effects of water storage on ecosystems depend on their storage capacity combined with the chosen operational method. Consequently flow regulation normally decreases flood peaks and increases low flows , normally leading to reductions of overbank flooding. Water temperatures and chemistry compositions are also affected by alternate flows induced by storage facilities. As a result, water released from water storage often has a different chemical composition from the inflowing river water. Surges of organic material and nutrients into reservoirs, often as consequence of human activities in the catchment area, can cause eutrophication, worsened water quality, water hyacinth growth and environmental degradation. How water is released from the reservoir might play a part in the overall water quality. Water released from surface levels are nutrient depleted while water released from the bottom of the reservoir often is oxygen depleted but nutrient rich and has potentially high levels of iron, hydrogen sulphide and manganese. Indicators from the Yangtze River suggest that the Three Gorges Dam has altered river flows and made the river more stagnant, affecting its chemical balance and ability to clean itself.

3.1.2 Sedimentation

Water storage in reservoirs tends to reduce water flows and velocity. The reduced speed of flowing water leads to greater sedimentation. The degree of sedimentation is often dependant on several factors, such as specific dam operational methods and surrounding land use practises in the catchment area. Downstream areas are potentially exposed to erosion as result of lower sediment loads. Other downstream effects of sedimentation alterations include nutrient loss and the destruction of natural habitats for different species of flora and fauna (particularly fish). Some Australian dams face severe problems with the siltation of reservoirs and fertile lands have been lost downstream (Chanson & James, 1998). Sedimentation can also be more rapid than initially predicted, as has been detected in some African reservoirs. This is usually a result of an underestimation of sediment inflows in planning stages (Shahin, 1993).

3.1.3 Aquatic ecosystems and fisheries

Storage functions can lead to changes in the flow, chemistry or temperature of water and this can often impact the natural pro-

Photo: Jakob Granit, SIWI

duction systems in aquatic ecosystems. Aquatic plants reduce light penetration into the reservoir and as they decay they deplete oxygen levels in the water. This might hinder or alter production of types of plankton, algae or other aquatic microorganisms at the base of the food chain, and thus create severe consequences throughout the ecosystem.

Different species of fish are normally only adjusted to living in either lotic or lentic ecosystems. Water storage installations transform the two systems. They might also act as barriers, disconnecting rivers floodplains and migration routes, which impact living organisms in different aquatic ecosystems. Losses in downstream fishing outputs due to water storage constructions have been registered for several river basins. Less freshwater flows to deltas and estuaries increases salinity levels, affects nursery habitats for many fresh water species, and enables predatory species to enter these ecosystems. The Grand Coulee Dam in the US, for example, was built without any consideration of its impact on the local fish population. As a result of loss of natural habitats for salmon, a quarter of a million dollars each year in terms of fishery yield is lost ("Dams and Migratory Fish", 2011). Terrestrial fauna can also be exposed to new threats as a consequence of dam constructions as some animals might be affected by subsequent changes in their habitat.

Studies indicate that the availability of silica, a macro-mineral nutrient that supports several primary production functions, may be declining. Dissolved Silica (DSi) stems from weathered silicate-rich minerals transported by rivers to the sea. These minerals are vital to certain plankton- algae (diatom) that often act as base for other life-forms and thus provide a fundament for a functioning aquatic system ("Diatoms", 2011). Dams for various purposes change river characteristics and increase silica retention times in freshwater systems, causing DSi levels to decrease dramatically in estuaries and oceans ("Global Patterns", 2012).

In the case of the Baltic Sea, recent studies show that DSi might become a limiting nutrient to algae growth and add even greater pressure to an already strained aquatic environment (Papush, 2011). In this case, the construction of reservoirs primarily for hydropower production is speculated to be one contributing factor.

3.1.4 Evaporation and greenhouse gas emissions
Capturing water in large reservoirs especially in hotter climate zones will lead to evaporative losses of water. The amount of lost water will differ depending on several factors. The climate in which the reservoir is situated is the key factor determining evaporation levels, but they are also influenced by the size, shape and depth of the reservoir. Determining the amount of water lost to evaporation for a specific water storage function can be difficult if it is connected to more than one reservoir or if the reservoir has a multi-purpose design. The range of estimates for evaporative losses from reservoirs is broad and values vary for e.g. hydropower production from nil to 100 m3/MWh (Granit & Lindström, 2011).

Several gases are clustered under the term "greenhouse gas", the common denominator being their ability to absorb and hold heat in the atmosphere. Among well-known greenhouse gasses are carbon dioxide, nitrous oxide and methane ("Greenhouse Gas Emissions", 2012). Carbon dioxide and methane are produced and emitted in a varying degree from water storage schemes. Reservoirs slow the flow of water and organic matter is deposited in the reservoir. As organic matter is decomposing, greenhouse gases are produced and transmitted to the atmosphere ("Reservoir Emissions", 2012).

The science regarding both evaporative losses from reservoirs and the accumulative effects of produced greenhouse gases are not conclusive. Both areas need further exploration in order to determine the extent to which these factors impact on ecosystems and climate change.

3.2 Social impacts
Large scale projects pose many challenges from a spatial, geographical, financial and social point of view. It is important to make a proper stakeholder analysis and identify how projects affect people. Stakeholders that gain will usually be those that benefit from commercial agricultural production or in urban settings, while negatively affected stakeholders are those that are forced to undergo substantial changes to their existing lifestyles.

Water storage projects are often planned as components of national development programs or regional growth catalysts. They can carry elements of nationalistic pride as well. In this context it is critical to safeguard vulnerable populations including resettled people (people forced to move as consequence of water storage projects), hosts (people inhabiting lands that receive resettled people) and people living downstream. Downstream communities can have their livelihoods, such as cultivation systems and grazing areas for cattle, disrupted as a consequence of altered river flow regimes. Specific mitigation and compensation schemes need to be part of project design as well as strategies for efficient stakeholder involvement (Wet de, 2000).

3.2.1 Health
Dams can impact human health in several ways. Human health impacts are generally greater for dams located in tropical climate zones and less prevalent for dams in temperate climate zones. The creation of large reservoirs, (turning lotic systems to lentic systems) to provide for power generation and other water related uses also means the creation of habitats where potentially disease spreading vectors can thrive. Malaria by mosquitoes and bilharzia by aquatic snails are some of the more well-known conditions that can be attributed to large scale storage facilities, but many more exist (William, 1999). There is also a correlation to the size and stability of the reservoir and the quantity of disease bearers where the larger and more stable reservoirs naturally provide a better foundation for these to gain foothold and multiply.

The supportive networks that enable various storage functions can add further complications. Extended water conveying systems, such as watered fields, open canals and ditches, can transport disease bearing elements directly to populated areas (Ibid). Improved storage capacities enable more frequent intervals of irrigation water for agricultural purposes. If water is contaminated, this can result in an increased number of people exposed to risk as they will come in contact with contagious elements more frequently. There can also be health risks associated with the construction phase of a project as large numbers of people are relocated to a specific area and risk increased exposure to infectious disease.

It is essential that responsible project development take health implications into account when providing compensation and enacting mitigation measures to affected population groups. One way to do this is to ensure that adequate steps are taken to actively reduce risks that potential diseases are spread around reservoirs. This can be done by making sure that health care facilities are installed in affected areas and that trained personnel can conduct routine check-ups to help minimise health impacts from dam construction.

3.3 Dam safety and flood risk management

Dam structures come with obvious safety concerns. Many dams around the world face challenges on two fronts; aging structures must be maintained and future pressures from changing hydrological conditions must be assessed as well. Storage facilities are structures designed to last a long time, and many existing structures have been in operation for a century or more. Should storage structures fail they pose potentially large risks to surrounding areas. There are several reasons to why dams can fail, including the following typical causes outlined by FEMA ("Why Dams Fail", 2010):

- Overtopping caused by floods that exceed dam capacity.
- Structural failure of materials used in dam construction.
- Movement and/or failure of the foundation supporting the dam.
- Settlement and cracking of concrete or embankment dams.
- Piping and internal erosion of soil in embankment dams.
- Inadequate maintenance and upkeep.

Dam projects are traditionally designed to optimise flow rates based on historical data. This data may be less reliable to predict future conditions due to increased run-off. If existing and future structures are not designed to accommodate changing conditions, the outputs from the dams can be affected and the risk of dam failure can increase.

In the last two decades alone, there have been dozens of dam failures. The reasons for these failures have often been a mix of poor maintenance and an inability to handle increased pressures from exceptionally high levels of rainfall or snowmelt. Natural disasters, such as earthquakes, have also been cause for dam failures. The risk of failure is greater in older constructions that might not comply with more recent standards for dam safety and they are costly to upgrade.

Managing risks related to dams consists of several possible components. The most important stage is the planning, which needs to incorporate qualified water resources modelling to assess potential outcomes under varying climatic- and hydrological conditions. Other crucial aspects to risk management include strong monitoring systems, performance protocols and training for operators to respond to critical situations (Cederwall, 2006).

Flooding is a primary consequence of dam failures. Floods are created when volumes of water exceed the reservoirs capacity to contain them. When storage structures give way, substantial quantities of water can reach previously protected areas and harm ecosystems and societies. As several rivers are blocked by a sequence of multiple dams, the breach of one such structure can induce a domino effect with potentially devastating consequences for an entire catchment area. Consequently, managing floods and excess run-off water is important in order to prevent disasters related to dam failures and the failures themselves.

Photo: Jakob Granit, SIWI

The following section will provide an overview of lessons learned on best practices in water storage development based on work by IFIs and other international bodies (see table 1). Considerable experience from various water storage projects around the world over several decades have been gathered and assessed by many stakeholders. Key principles for successful implementation and existing frameworks for good practises are presented here for consideration by interested stakeholders in water storage projects, including regulators, developers, financiers, and communities affected by storage projects.

Table 1. Examples of existing international guidelines, frameworks and assessment systems for sustainable water resources and storage development

Guideline/Framework	Organisation	Year	Description
World Bank Safeguard Policies	World Bank	1980-	The World Banks Safe Guard policies have been developed to guide decisions in all aspects of the Bank's operational work including at the stage of identification, preparation and implementation of projects and programs in order to minimise harm on humans and the environment.
World Commission on Dams- Dams and Development, a New Framework for Decision Making	World Commission on Dams (WCD)	2000	The World Commission on Dams was established in 1998 with the purpose of conducting a broad evaluation on various outcomes related to large dams. The commission was made up by a wide range of stakeholders and final results were published in a report in 2000.
Equator Principles	International Finance Corporation	2003	The Equator Principles is a risk assessing and managing framework originating from elements of the International Finance Corporation Performance Standards as well as elements from different World Bank guidelines. The system is used to evaluate credit risk to infrastructure and industrial projects and is used by commercial Banks.
Water Resources Strategy – Strategic Directions for World Bank Engagement	World Bank	2004	The Water Resources Strategy builds on World Bank operational experience. It spans a broad range of water management issues such as legal and regulatory components including development, operation and maintenance of water storage infrastructure.
Dams and Development – Relevant Practices for Improved Decision Making	UNEP/DDP	2007	The report covers a range of essential issues related to social and environmental sustainability connected to water storage in foremost developing countries. The report is a collaborative effort between UNEP and the Dams and Development Project (DDP).
Hydropower Sustainability Assessment Protocol	International Hydropower Association (IHA)	2010	The protocol was developed by IHA and a wider network of stakeholders. It functions as a tool to evaluate hydropower projects through four identified stages of development (early stage, preparation, implementation and operation). The protocol assesses relevant social and environmental themes connected to hydropower projects and includes ranking functions.

(Sources: About the Equator Principles 2011; International Hydropower Association 2010; UNEP/DDP. 2007; WCD, 2000; World Bank, 2004 a; World Bank, 2004 b)

4.1 Assessing opportunities, options and risks in the initial planning stages

Water storage projects have several development stages, where economic, financial, technical, social and environmental considerations need to be taken into account. It is essential to identify available options as early on in the overall process of water storage development as possible. Evidence shows that early identification of project options tends to reduce project costs, increase stakeholder involvement and minimise overall risk associated with project development. Ideally, option identification should not be a one-time occurrence but rather be a continual process where project components and options are analysed in an iterative manner in order for decisions to be based on the most updated findings in technology and science. Stakeholder participation should be considered an integral part of this process in order to legitimise the development decision taken and to gain broad-based input and acceptance. When identifying options, one should take into account the existing legal regulatory frameworks on energy and water utilisation. External financing (donor organisations, IFI) and project due diligence frameworks can, when applicable, be linked to initial planning processes. This can provide guidance for best practise in the comprehensive planning stage supporting national frameworks (UNEP/DDP, 2007).

According to a recent framework prepared by the Hydropower Sustainability Assessment Forum (HSAF), hydropower development strategic assessments can be divided into six sub-themes; (International Hydropower Association, 2010):

1) Demonstrated need/demand

The scale of investments in water and energy infrastructure must be motivated by an underlying need and demand analysis, as services provided by these affects several sectors. The assessment protocol points to the existence of "viable markets of water and energy services" as indicators to the existence of demand.

2) Options assessment

Strategic option identification is essential to successfully implement energy development projects. Options assessment should take a sustainability perspective where a wide range of alternatives should be investigated using multiple social, economic, environmental and technical criteria. This ensures that the project can be considered as a viable prioritised option. By comparing different sources of fuel (in the case of a hydropower project) and different sizes and scopes of project choices, the best viable options can be identified for subsequent detailed project analysis. The SEA approach (see 4.1.2) can be a useful tool in upstream project identification and option assessment (Granit, 2011).

3) Regional and national policies and plans

All planned projects need to be harmonised with existing policies in a national and regional context. This ensures that current guidelines regarding different values, not least humanitarian, are not disregarded in the project development process.

4) Institutional capacity

Water and energy projects are heavily dependent on the quality and regulatory functions of several government institutions, especially the ministries working with finance, the environment, and labour. Pre-assessment studies should therefore strive to determine the need for institutional or regulatory framework strengthening.

5) Risks

This theme relates to different early identifiable risks that need to be addressed in order to avoid systematic failures affecting a potential project development. These can be risks associated with social, environmental, technical or financial issues. Such analyses ensure that no major investments are undertaken without a full understanding of all project risks. Typical risks assessed in the context of for example a large scale hydropower projects include:

- Political risk: Is there a political commitment to the project? In the case of multi-country projects, are project development agreements in place?
- Water rights risk: Is there a water resources management framework in place?
- Hydrology and sedimentation risk: How will rainfall variability and climate change alter the generation potential? How are watersheds being managed?
- Environmental and social compliance: Is the necessary legal framework in place and is it being enforced?
- Technical and construction risk: Are there guarantees that technical designs meet established norms?
- Lack of a suitable enabling environment: Is the necessary legal framework in place for a long term investment? Is the institutional capacity adequate to operate the storage scheme?
- Payment scheme risk: Are prospective customers able to pay for electricity generated? Is a power purchase agreement in place or being negotiated?
- Exchange rates/devaluation risk: Can interest on loans be paid off?
- Reputational risk: Have all social and environmental issues been taken into consideration to avoid corporate reputational risk?
- Corruption risk: Large scale infrastructure projects are always at risk for corruption. Is an anti-corruption strategy in place and is it being reinforced?

6) Comprehensive environmental planning

Successful comprehensive environmental planning should feature the following traits as expressed by the UNDP (UNEP/DDP, 2007):

- Substantial commitments from all involved parties and stakeholders are needed for successful environmental planning. Institutions must be given the proper time and resources needed to build capacity in environmental management planning and incorporate it into their processes. This ensures that environmental management concerns run through the entire project including contracts, agreements and certificates.
- Environmental management should be evaluated in the wider scope of project planning, including environmental management costs in overall project budgets and Strategic Environmental Assessments (SEA).
- Environmental management plans should be subject of continuous monitoring and oversight schemes to determine their effectiveness. Possible changes and corrections should be outcomes of these monitoring schemes in order to improve environmental performance as project conditions change.

4.1.1 Addressing climate change and rainfall variability

Climate change increases uncertainty and variability that must be accounted for when planning water infrastructure. In general, dry areas of the world are predicted to become drier, and wet climates will be wetter ("Global Climate Change", 2012). This will produce changed run-off patterns in different regions and can possibly force changes in how present and future dam projects are maintained and developed. In section 3.1.4, the greenhouse gas emissions of water storage options were discussed briefly. Water storing functions can also provide protection against adverse impacts of climate change, such as floods and droughts. Previous chapters have explored some of these functions to improve local adaptation capacity to climate change.

Hydropower is a considerably less carbon intensive energy than traditional fossil fuel based ones. Meeting energy demand with hydropower instead of other alternatives that release more greenhouse gases is one feasible way to mitigate climate change and promote "green" development, especially in developing regions. Despite some greenhouse gas additions from hydropower, this option is cleaner than traditional energy types and it is far more accessible and often more cost efficient than many other renewable options.

Dams and storage plants have a long life-span. Many existing plants today have been in operation for numerous decades and were designed in an era where present day hydrological impacts were not a concern. Higher frequencies of extreme weather and rainfall will heighten the importance of flood-control measures. It is critical to safeguard that the design of present day structures can withstand added pressures to avoid future dam failures.

Future projects must also be able to assess and factor in variables related to changed conditions to a greater extent than they have in the past. This is necessary to ensure human safety, and to procure acceptable outputs and economic return rates. This is especially important for hydropower production. Some regions might face increased run-off that will yield surplus production during certain times of the year, while other risk declines in production capacity as run-off rates decline (Phinney & McCann, 2005). Conflicts between uses might also be an issue in multi-purpose schemes where functions such as hydropower production and flood control have different requirements in terms of storage volumes. More effective planning and creative modelling is needed to account for complicated more variable climate and increased competition between users. Multi-dimensional scenario planning for different types of water infrastructure can help projects better prepare for uncertainty.

4.1.2 Strategic multi-sector and environment programme assessment

Strategic, multi-sector, and environmental impact assessments for development projects have developed and expanded considerably over the past few years. Strategic Environmental Assessments (SEA) are used globally to analyse impacts of development programmes early in the planning process and encompass environmental, social and human health issues detailed in section 3. An SEA is defined as "the formalised, systematic, and comprehensive process of evaluating the environmental effects of a policy, plan, or programme and its alternatives, including the preparation of a written report on the findings of that evaluation, and using the findings in publicly accountable decision-making" (Kulsum, Mercier & Verheem, 2005). The 2003 World Bank Water Resources Sector Strategy requires that alternatives to water storage schemes be assessed before project implementation. The WCD considers conducting these assessments as a core value. An SEA does not replace the project specific feasibility study and environmental and social impact assessments, which are necessary for project implementation. (Granit, King & Noël, 2011).

Photo: Jakob Granit, SIWI

It can, however, be used to by a wide range of stakeholders to analyse the potential benefits gained from large scale development programmes and the cumulative impacts of multiple development interventions. This brings a strategic perspective to planning, instead of a project specific approach. The SEA raises environmental and social issues of major development programmes early on in the planning, project development, and investment finance process (see box 8).

According to Granit et.al (2011), a typical SEA approach for the development of power programme is done in six steps:
1) regional power needs assessment;
2) inventory of power options;
3) screening of power options;
4) comparative analysis and ranking of power options;
5) cumulative impact assessment for portfolios of options; and
6) the development of a power development strategy and indicative power generation plan.

Each of these steps should be undertaken together with a managed stakeholder engagement process throughout the SEA.

Box 8. The Nile Basin Initiative and the preparation of the Regional Rusumo Falls Hydroelectric and Multi-purpose Project (Granit, 2011)

The Nile river basin encompasses an area of about 3 million square kilometres. Eleven countries, with a total estimated population of 300 million people, share the Nile river basin: Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, Sudan, South Sudan, Tanzania, and Uganda. Human security is strongly linked to poverty reduction. The Nile riparian countries took a major step to establish the Nile Basin Initiative (NBI) in 1999, an initiative that includes all Nile countries and provides an agreed basin-wide framework to fight poverty and promote socio-economic development in the region. The initiative is guided by a shared vision "to achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources." The Nile riparian countries seek to realize their shared vision through a strategic action programme, comprising basin-wide projects and joint investment projects at the sub-basin level and activities designed to build trust and common knowledge.

The riparian countries are now collaborating in two Subsidiary Action Programmes that are exploring investment opportunities in multi-purpose water management to stimulate development.

The two programmes are the Eastern Nile Subsidiary Action Programme, which includes Egypt, Ethiopia, and Sudan and the Nile Equatorial Lakes Subsidiary Action Programme (NELSAP), which includes Burundi, Democratic Republic of Congo, Kenya, Rwanda, Tanzania, Uganda, Egypt and Sudan. Approaches taken to increase joint investments include pre-investment studies, such as Strategic/Sectoral Social and Environmental Assessments (SSEA), and the design of far reaching multi-purpose programmes in areas such as IWRM, flood management, power generation, irrigation and drainage. The decision-making process is strong with the Nile Council of Ministers for Water Affairs serving as the highest decision making body of the NBI.

Currently, detailed feasibility work on the Regional Rusumo Falls Hydroelectric Power Project (RRFP) (shared by Burundi, Rwanda, and Tanzania) as an outcome of the SSEA is ongoing in parallel with work to establish a sub-regional water management framework on the Kagera river basin in which the project sits.

Photo: Jakob Granit, SIWI

4.2 Stakeholder involvement and project preparation

Evidence point to the fact that the exclusion of concerned and affected parties has led to tension and conflicts. The inclusion of downstream communities at early stages generates a greater potential for water storage projects to be implemented more efficiently. Successful cases demonstrate that a key element in achieving this is to have proper project timeframes to allow for stakeholder analysis and dialogue. This enables surveys and evaluations to be thoroughly conducted and the outcomes of these to be included in the actual planning processes. Increased focus on the wider arena of responsibilities that governments have when relocating individuals and communities, which goes beyond providing new dwellings is a positive trend. Inclusive, integrated planning processes for long-term development are also needed to ensure that healthy local economies are maintained after resettlement has taken place. Other basic humanitarian issues, including the provision of safe housing, water supply and sanitation all need to be part of the long term planning process (World Bank, 1998).

Wide stakeholder involvement is essential to bring in relevant perspectives on ecological, social, economic or other areas for all large scale water storage schemes. It is important that all groups receive information of planned actions in forms suitable to them and are offered a genuine chance to influence the situation. According to UNEP; best practises of stakeholder involvement correspond to the following conditions (UNEP/DDP, 2007):

- Sustainable decisions can only be reached when the needs of all involved interest groups are attended to;
- Stakeholders should be able to affect decisions with potential to affect their way of life; consequently their involvement must be actively sought and promoted;
- Stakeholders should be provided with sufficient information in order for them to contribute to processes and they are also to be informed on how their views have been treated and how they influenced the decision outcomes.

Stakeholder analysis methodologies and plans for participation enable effective stakeholder involvement. These should be incorporated early on in any water storage project in order to map out and engage all potential stakeholder groups. This analysis should identify people or organisations located close to an intended project site and pay particular attention to the potential positive and negative impacts alternative schemes may have on local people's lifestyles, livelihood opportunities, cultural customs and working conditions. UNEP promotes the following five steps as the keys to effective stakeholder involvement (UNEP/DDP, 2007).

1) Communicate
Information about a project should be communicated to stakeholders. Information provided should be balanced and objective in order to help stakeholders fully understand the problems and potential solutions. Information can be distributed though web based tools, fact-sheets, newsletters or other community events.

2) Consult
Stakeholders should be consulted in an interactive manner to gain their reactions and feedback. Surveys, polls, interviews and public meetings are different ways to interact with stakeholders.

3) Involve
The public should be directly involved in different steps of the process. This prevents an information gap from forming between the public and decision-makers and ensures that public opinions can be quickly incorporated in alternative plan developments. Interactions can take place through workshops and seminars or other easily accessible common forums.

4) Collaborate
It is not enough for project proponents to only inform and involve the public: They must also engage stakeholders in an advisory role. Stakeholder input should always be considered seriously at any level in project design. Tools to achieve such engagement can be citizen based advisory councils or other knowledge sharing functions.

5) Empower
Empowering stakeholders might constitute the most critical

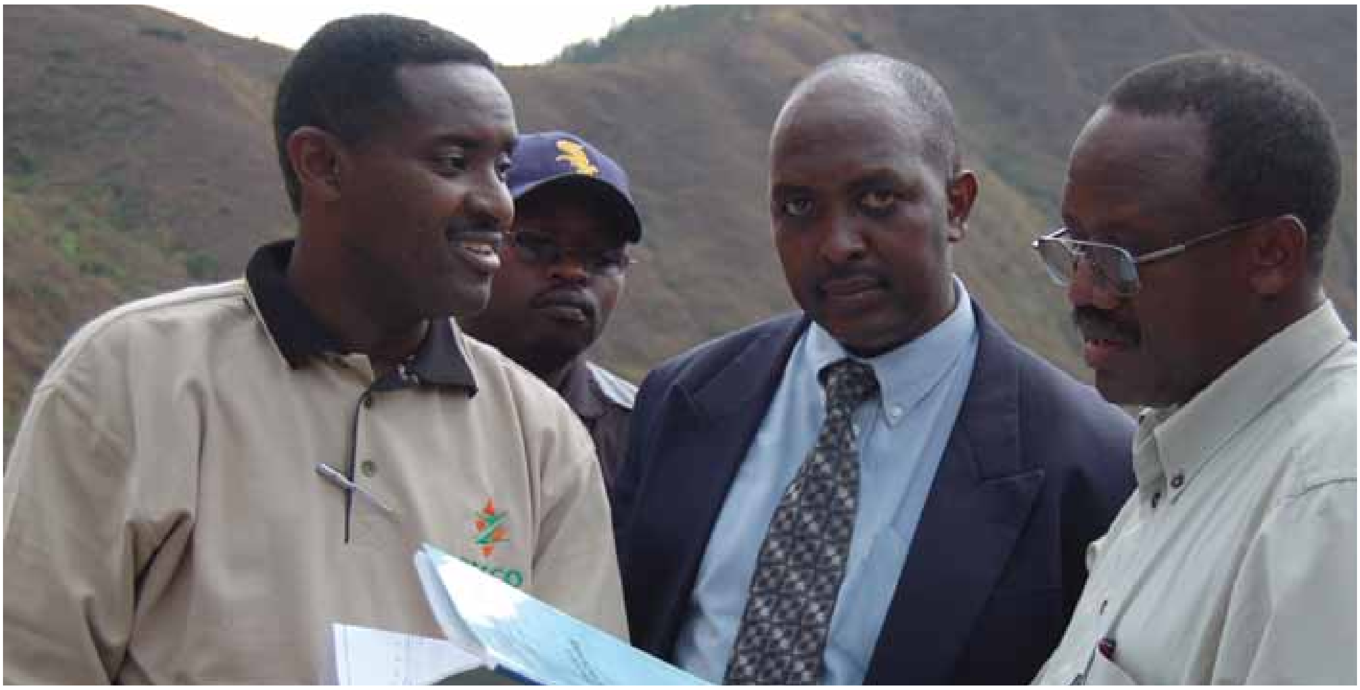


Photo: Jakob Granit, SIWI

Photo: Jakob Granit, SIWI

step as it places decision-making power in the hands of affected populations. This entails providing a public mandate in processes that could actually prevent certain actions that would otherwise be deemed unavoidable. Different democratic approaches, such as voting processes or citizen-based juries, may be the best way to realise this.

4.3 Resettlement and compensation

One of the most significant negative impacts of water storage construction can be involuntary resettlement (WCD, 2000). Resettlement involves a significant set of difficult issues to resolve. It can also present some opportunities as well as it provides a field for "soft" development interventions, which have the potential to generate benefits in the water storage construction process with relatively inexpensive and simple methods. The compensation of resettled populations is a critical topic that needs considerable attention in order to minimise negative social impacts of relocation. There are many aspects to consider. First, the form of compensation needs to be determined. Monetary compensation only between project developers and resettled groups is usually insufficient, as this tends to leave beneficiaries in a worse off situation once the last down payment has been spent (Grimm, 1991). Consequently, the allocation, division, and definition of compensation are important components to sort out in order to optimise resettlement processes.

Evidence demonstrates deficiencies and discrepancies in terms of how and when compensation has been dispersed. Official governmental relocation programmes include options for moving to pre-constructed official resettlement areas or plain cash compensations for individuals seeking alternatives outside relocation programs. In the latter case, tendencies seem to point towards protractions or unwillingness to disperse funds; where in some cases delays of up to five years have been documented (Hart, 1980). The compensation policy delays seem to be a common feature. In rare examples commercial farmers have been paid compensation to resettle at market price values for their farms, but have then not chosen to buy new farms and left farm workers uncompensated and without a source of income (World Bank, 1998). Also, issues regarding compensation for land have proven difficult due to registration logistics. In the case of the Aswan dam and other examples, large populations were not given any compensation because their land ownership was not official registered, which enabled the government to claim the land as state property without any obligation for them to provide compensation (Salem-Murdock, 1989). Host populations in lands where resettled populations are placed are generally not compensated to any extent for encroachments on their lands by resettling populations. Another constraint can be the availability of land where people can be relocated.

While project implementers normally will be involved in a project area for the duration of the project implementation phase, affected people will live with project outcomes for longer time periods. The gravity of the decisions made on people's lives must be taken into consideration. Compensation for people whose lives are profoundly affected by storage construction cannot be a delivered in the form of one-time payment. It is a continued process that requires the full commitment of project developers and owners. It is also important to realise that it might not be possible to find compensation measures that will fully accommodate all affected people. For example, the loss of cultural lands might always weigh heavier for some than any compensation that can be offered. Consequently it should be noted that even generally well thought out and executed compensation schemes will potentially leave some people discontent. Some key general principles according to Salignat and Guoqing (IHA Conference speeches 14-17 June 2011) should be considered when planning for any kind of compensation measures for those affected by development projects:

- The compensation measure must not lead to a lesser quality of life than what a specific target group enjoyed before the implementation of the project. The measure should at least lead to an equal quality of life than before and preferably to a better standard of living, as perceived by the affected population groups.
- The effect of a compensation measure must fully reflect negotiation and consultation outcomes. In order to achieve this, the compensation process must be iterative. This entails having sufficient and transparent monitoring and evaluation tools.

These tools should aim to establish that the rate of satisfaction among project affected people endures. If evidence points towards dissatisfaction, sufficient measures to adjust compensation schemes must be in place.

- Any compensation measure must provide components for diversification of various kinds, especially regarding livelihood opportunities. A resettled population must have the sufficient options to adjust to a new set of circumstances and find the most favourable way to regenerate income opportunities.
- Ensuring continuous and even support to exposed groups can effectively be done by forming partnerships between them and project developers. If project affected groups receive a share of potential profits or generated goods from a development project, equity and sustainability between parties can be guaranteed in a more straight forward manner.
- Strategies and measures of compensation must have been soundly evaluated before implementation and firmly approved and anchored within the targeted groups. Systems aimed at aiding effective implementation of compensation measures must be firmly in place well before actual implementation.

Installing the right mechanisms to find proper compensation, especially when resettling individuals and communities, requires strong institutional capacity. Compensation for resettlement demands comprehensive and long-term planning so that the measures are in place and resolved before actual construction begins. Project institutions should have the ability to create and manage resettlement programmes and be able to disburse direct compensation. This can include land preparation, providing job training, access to credit facilities, and output based aid that ensures sustainable human and economic development. As mentioned above, partnership/shareholder agreements between project implementing parties and affected groups can be one way of reaching sustainable outcomes.

4.4 Environmental mitigation measures

There are several ways to substantially mitigate negative environmental impacts of water storage construction. Measures that can be employed upstream and within the water storage reservoirs should be applying water resource managment strategies.

Alterations of flow regimes, water compositions and ecosystems are negative consequences of dam construction. However, changes to the water regime can also bring about new possibilities as one ecosystem transforms to another, enabling new life forms previously not adapted to a specific environment to thrive.

Water quantity concerns and substantial changes to existing flow regimes are possible consequences of constructing large water storage facilities. Considerable environmental degradation can follow if adequate water volumes to sustain ecosystems cannot be guaranteed. One way to prevent losses of environmental services on which people depend comes early in the project planning, where the minimum flows needed to safeguard ecosystem and social functions should be identified and agreed upon.

Maintaining thermal and chemical quantities of impounded water is also important to minimise effects on ecosystems. Methods to alter outlet functions are commonly used to prevent changes in temperature of water discharged into downstream waters. With multiple outlets from the reservoir, it is possible to release cooler or warmer water from different levels of the reservoir to downstream areas based upon the different needs of specific seasons. The chemical balance of stored water can be altered as a result of low dissolved oxygen levels, which is caused by decomposing organic matter and turbine functions (Bevelhimer and Coutant, 2006). This risk can be mitigated with improved turbine technology and alterations in how they are run. The incorporation of aeration weirs in the tailrace of the dam (tailrace weirs), aerating-reservoirs and turbine runners are examples of available technologies and methods to do this. Other approaches can entail removing vegetation before the filling of the reservoir; regular flushing to remove aquatic vegetation; and working proactively with behavioural change to promote less usage of nutrients upstream in agricultural activities (Bizer, 2001).

Sedimentation can also be a large problem in dams and reservoirs. Reservoirs are an obstacle to sediment transport downstream and functions of the reservoir itself are hampered by compounded sediment loads within the structure. There is clear potential to mitigate this in pre-construction phases by performing sediment control plans and risk assessments. Once the structure is erected, however, it can be a complicated task to ensure sufficient sediment loads reach areas downstream. Shore-line protection methods to prevent erosion from to natural causes, such as wind and wave movement, is critical. The erosion rate can be slowed by using vegetation. Specific plant types can be used to hinder run-off water from degrading shore lines. Protective walls can also be erected, such as "rock-rip raps", which include a mix of rocks, filtering materials and fabric. Both vegetation and constructed walls can be combined for extra protection against sedimentation. In some cases, flushing reservoirs clear from sediment loads has been proven as an effective way to increase flow downstream while reducing sediments in the reservoir. Other ways of removing sediments include dredging (usage of machinery to physically remove sediments) or building a debris dams upstream, which slows stream flows.

Another negative impact of dams is the potential effect on fauna, particularly fish stocks. The artificial blocks of various flows change the conditions of fish habitats and their movement between them. Building fish passes of various kinds can enable fish free movement. Creating new alternative spawning areas can also introducing new fish species that are adjusted to new conditions, although this impact on the greater ecosystem must be considered before choosing this option.

Water storage can be utilised as reservoirs for commercial fisheries by adapting to new conditions and introducing species capable of existing in the altered environment brought about by water storage construction. Reservoirs can also be used for recreation and tourism.

Artificial water storage has and will have a significant role to meet growing demand for water, energy and food. Three major global trends – expanding cities in need of reliable water supplies, rising requirements for dependable energy and growing pressure to produce more food with higher water efficiency – are likely to increase demand for water storage development in the near, mid- and long-term future.

Trend 1: Growing cities and global growth

Large-scale water storage structures have for many years served as a lever to promote development and economic growth in many parts of the world. Sweden, for example, is a country where hydropower has been one of several pillars that has historically fuelled growth and prosperity and continues to do so today (about 45 per cent of Sweden's electricity is generated from hydropower). The ability to sustain adequate quantities of water, regulate flows and buffer against variability in available run-off will be increasingly important as global demand for energy from growing populations and economies increases in the coming decades. Water storage structures can serve as guarantors for providing reliable water services to growing urban and industrial centres and water for agriculture. This is why they are a favoured option in many developing countries where energy costs are high and indigenous sources of power are needed. The ability of water storage to buffer against increased flood and droughts has led many IFIs and other development organisations to again prioritise water storage on their agendas in recent years.

Trend 2: Rising demand for renewable energy

The global demand for energy is projected to grow by close to 50 per cent in the coming 25 years (Energy Information Administration, 2010). Fossil fuels will continue to be the major source for various types of energy according the International Energy Agency (IEA). Power generation is projected to be the fastest growing component in energy production. Water is instrumental to produce energy: fuel extraction, processing and cooling all require significant volumes of water that is usually provided by fresh water systems.

The global pursuit of "green" economic development will further stimulate investments in carbon lean energy alternatives. Renewable Energy (RE) technologies constitute a very small part of the present energy mix. In order to reach stated targets to curb greenhouse gas emissions, major investments must be made. Despite extensive investment in research and development aimed to make the expansion of RE options more feasible on a larger scale, their growth in the energy mix has been steady but not rapid. The value of technologically mature alternatives cannot be underestimated. Hydropower is one of the more reliable options today and is projected to continue to be the dominant source in RE growth scenarios.

Hydropower can also be expanded in integrated power systems to enable increased use of intermittent renewable energy sources (i.e. energy sources that risk supply disruptions or where continuity cannot be guaranteed), such as wind and solar power.

Photo: Jesper Baerentzen/SXC

Photo: Getty Images


Photo: Jakob Granit, SIWI

Hydropower is in many ways the most effective type of energy for quick dispatch and certainly is among renewable energy types ("Balancing the Grid", 2012). It can meet base load requirements, can respond quickly to peaks in electricity demand and can store energy effectively, which means that it can function as a systems enabler for other renewable and intermittent energy technologies. Conventional storage hydropower schemes and pumped storage hydropower schemes are perhaps the most suitable in this regard as their sole purpose is to store energy and to dispatch it when needed.

Trend 3: Competing demands for water require major efficiency improvements in agricultural water use efficiency

Agriculture is still the most water demanding sector on a global scale accounting for about 70 per cent of water use, although there are significant regional differences in water allocation patterns. In developing nations, irrigation is usually the dominant water user. The heavy water demand for certain crops, coupled with inefficient farming techniques or technology and low costs for water, have led to disproportionally high consumption levels of water, even in regions facing scarcity of the resource. Food production is also highly energy intensive. Producing one kilogram of meet can consume as much as 20 000 litres of water (World Economic Forum, 2011). Estimates from the U.S show that approximately 16 per cent of the annual energy production is used by the food producing sector (American Chemical Society, 2010).

Making irrigation schemes more efficient is crucial in order to make more efficient use of stored water. A major difficulty in improving irrigation lies in the lack of precision in which water is applied to ground surfaces. Another concern is evaporation from dams and irrigation canals.

Several techniques can be used to increase the distribution precision and lessen evaporation losses of irrigation water. One example is Low Energy Precision Application (LEPA), where the principle design places conveyance tubes close to the receiving surface so that water can be disbursed with better precision to soil sections. The more moderate dispersion of water also brings energy savings ("LEPA Irrigation", 2010). Together with better maintenance of distribution systems, new technology applications like the LEPA can have significant impacts on wasteful water and energy usage related to irrigation and its storage functions.

Reducing evaporation from agricultural water storage facilities is another important component in reducing non-productive water use in the sector. Experimental methods to chemically prevent evaporative losses are currently in place in different parts of the world, particularly Australia. Trials, such as using 'mono layers' – chemically induced films that are sprayed over the reservoir surface area to prevent evaporation – have reduced evaporative losses by as much as 40 per cent in best case scenarios (Brink, Symes & Hancock, 2009). While mono layers have a limited function in terms of its use on storage surfaces of the larger scale, they can effectively support irrigation schemes connected to water reservoirs and significantly reduce evaporation from irrigation channels and other open conveyance systems.

6 Conclusions

This study provided an overview of the current status of large scale artificial water storage development and its functions in the water, energy and food security nexus. It presented a typology of water storage structures that illustrated the potential benefits and common challenges posed by different storage options. It then analysed the risks and potential negative consequences posed by different storage options on local environments and populations that must be evaluated in the initial planning stages when choosing between storage options.

There are great opportunities to expand water storage in suitable situations to provide local water supply, energy and a dependable source of irrigation water for agriculture. Each of these services will be needed in greater volume as global demand for water, renewable energy, and food escalate. There is considerable knowledge that must be applied to ensure that the right options are chosen and best practices are applied at all times. By leveraging the existing expertise and ensuring due diligence, during their construction and operation; nations, regions, and communities can use water storage to help meet their water, energy, food and development needs.

All artificial water storage will impact local populations and the environment. With poor planning, insufficient assessment of environmental and social impacts and inadequate measures to address them, it is possible that the development benefits and services provided by water storage schemes can be outweighed by their negative consequences. This study has highlighted the wealth of existing knowledge, frameworks and guiding principles for water storage development that can ensure that this situation is avoided. By drawing upon these best practices and lessons learned from past experiences in storage development, adverse impacts can be reduced and overall benefits to local populations and societies at large can be maximised.

Well-managed projects and programmes that incorporate options assessments, participatory planning processes, sufficient timeframes and sound measures of compensation have great potential of becoming successful. Considerable advances on how to improve stakeholder participation in water storage planning have been made in recent years. There are several ways this can be done in the project design and implementation process, but the most crucial work is done in the initial project planning stages. More extensive evaluation of the potential risks, benefits and avenues to address environmental and social impacts of different project options has been shown to reduce project costs, increase stakeholder involvement and minimise overall risk associated with project development. Strategic Environment Assessments are one valuable tool in this process that are being applied with increasing frequency in water storage programme development. Solid and sound water resources management is crucial to consider in all storage development. Their application can not only identify measures to substantially mitigate impacts downstream, but can reveal opportunities to increase benefits produced by new or altered ecosystems.

Providing fair and adequate compensation for people whose lives are profoundly affected by storage construction is a continued process that requires the full commitment of project developers and owners. This study has highlighted some key principles compiled from the literature in this area. In short, measures must be evaluated and firmly approved by recipients in the planning phase, they must correspond sufficiently to agreements made between developers and affected stakeholders, and they should provide for a sustainable livelihood of an equal or improved quality of life for the affected party. Measures should be in place and resolved before actual construction begins. Institutions must have the ability to create and manage resettlement programmes and be able to disburse direct compensation. Storage construction, and even relocation, can provide development opportunities to local populations when compensation schemes are aptly applied to establish a diverse local economy.

It is important to note that many times storage projects depend on water flowing in river systems that often cross administrative, social and political borders. Water resources management in this case becomes a regional public good that can provide other public benefits (e.g. biodiversity, flood risk reduction, water quality improvements, recreation, and aesthetics) and private commodities (e.g. electricity, food products, manufactured items). Increased cooperation between stakeholders on the management of water resources and of large scale multiple use storage structures is a prerequisite to reach more optimal and sustainable outcomes (Granit, 2012).

In summary, this report has shown how large-scale water storage can provide major benefits, as it supports economic development, builds water security and buffers against increasing rainfall variability. Well-designed water storage and hydropower systems can also enhance both climate change mitigation – by providing clean energy production – and adaptation, through flood protection and by storing water supply that can be used during drought.

Photo: Jakob Granit, SIWI

7 References

About The Equator Principles. (2011). Retrieved February 07, 2012, from www.equator-principles.com/index.php/about-the-equator-principles.

American Chemical Society. (2010). Wasted food, wasted energy: The embedded energy in food waste in the United States. Washington: American Chemical Society.

Aquifer. (2007). Retrieved August 8, 2012, from www.eoearth.org/article/Aquifer

As glaciers melt, Bhutan faces increased risk of mountain tsunamis. (2012). Retrieved August 8, 2012, from www.time.com/time/world/article/0,8599,2098960,00.html.

Australian water information dictionary. (2012). Retrieved January 24, 2012, from www.bom.gov.au/water/awid/id-632.shtml.

Balancing the grid with pumped storage. Retrieved January 25, 2012, from www.renewableenergyworld.com/rea/news/article/2011/08/balancing-the-grid-with-pumped-storage.

Bevelhimer, M.S. & Coutant, C.C. (2006). Assessment of dissolved oxygen mitigation at hydropower dams using an integrated hydrodynamic/water quality/fish growth model. Tennessee: Oak Ridge National Laboratory.

Bizer, J.R. (2001). International mechanisms for avoiding, mitigating and compensating the impacts of large dams on aquatic and related ecosystems and species: Background paper nr. 3. Prepared for IUCN/UNEP/WCD. Gland: International Union for Conservation of Nature (IUCN).

Brink, G.N., Symes, T.W. & Hancock, H.N. (2009). Development of a 'smart' monolayer application system for reducing evaporation from farm dams: Introductory paper. Queensland: University of Southern Queensland.

Bueno, C. & Carta. J.A. (2004). Wind powered pumped hydro storage systems: A means of increasing the penetration of renewable energy in the Canary Islands. Amsterdam: Elsevier.

Cederwall, K. (2006). Dam safety and climate change. In: Dams under debate 2006 (pp. 29-37). Stockholm: Formas.

Chambers, D. & Higman, B. (2011). Long term risk of tailings dam failure. Montana: Center for Science in Public Participation.

Chanson, H. & James, P. (1998). Rapid reservoir sedimentation of four historic thin arch dams in Australia: In: Journal of Performance of Constructed Facilities: ASCE, Vol. 12, No. 2(pp. 85-92). Virginia: The American Society of Civil Engineers.

Chronology of major tailings dam failures. (2011). Retrieved April 11, 2012, from www.wise-uranium.org/mdaf.html.

Correa, I. (1999). Urra dam project, Colombia: Association of producers for communal development of La Cienaga Grande de Lorica – ASPROCIG. In: World Commission on Dams (2000). Dams and development: A new framework for decision-making. London: Earthscan Publications Ltd.

Dams and migratory fish. Retrieved October 15, 2011, from www.internationalrivers.org/node/1639.

Dams: v1.01. (2012). Retrived April 27, 2012 from http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01.

Diatoms. (2012). Retrieved February 21, 2012, from http://hms.stanford.edu/profiles/diatoms.htm.

Energy Information Administration (2010). International Energy Outlook 2010. Washington: Energy Information Administration.

Ett samtal om samernas rättigheter som urfolk i deras hemland Sápmi. (2009). Retrieved March 19, 2012, from www.sametinget.se/11144.

Fahim, H.M. (1981). Dams, people, and development: The Aswan high dam case. Oxford: Pergamon Press.

Uppsala mitt i Sápmi: Rapport från ett symposium arrangerat av Föreningen för samiskrelaterad forskning i Uppsala, Upplandsmuseet 4–5 maj 2011. Retrieved March 19, 2012, from www.slu.se/Global/externwebben/centrumbildningar-projekt/centrum-for-biologisk-mangfald/Dokument/publikationer-cbm/cbm-skriftserie/skrift55.pdf.

Global climate change vital signs of the planet. (2012). Retrieved February 07, 2012, from http://climate.nasa.gov/effects/.

Global patterns of dissolved silica export to the coastal zone: Results from a spatially explicit global model. (2012). Retrieved April 27, 2012, from www.pbl.nl/en/publications/2009/Global-patterns-of-dissolved-silica-export-to-the-coastal-zone_-Results-from-a-spatially-explicit-global-model.

Granit, J. (2011). Reconsidering Integrated Water Resources Management: Promoting economic growth and tackling environmental stress. In: Coping with global environmental change, disaster and security: Threats, challenges, vulnerabilities and risks. New York: Springer-Verlag.

Granit, J. (2012). The collective action dilemma in managing transboundary freshwaters: An analysis of an outcome-driven framework. Dissertations from the department of physical geography and quaternary geology, No 33. Stockholm: Stockholm University.

Granit, J. & Lindström, A. (2011). Constraints and opportunities in meeting the increasing use of water for energy production. In Proceedings of the ESF strategic workshop on accounting for water scarcity and pollution in the rules of international trade. Amsterdam 25 – 26 November 2010. (Ed. Hoeckstra, A.Y., Aldaya, M.M., and Avril. B.) Value of Water Research Report Series No. 54. Delft:UNESCO-IHE.

Granit, J. J., King, R.M.& Noël, R. (2011). Strategic environmental assessment as a tool to develop power in transboundary water basin settings. In: International Journal of Social Ecology and Sustainable Development. Pennsylvania: Information Resources Management Association.

Greenhouse gas emissions (2012). Retrieved February 07, 2012, from www.epa.gov/climatechange/emissions/.

Grimm, C.D. (1991). Turmoil and transformation : A study of population relocation at Manantali, Mali. Unpublished PhD thesis. Binghamton: State University of New York.

Hart, D. (1980). The Volta River project: A case-study in politics and technology. Edinburgh: Edinburgh University Press.

Hydropower Usage and History. (2010). Retrieved May 14, 2012, from www.revermont.org/main/technology/hydro/.

International Hydropower Association (IHA). (2010). Hydropower Sustainability Assessment Protocol. London: International Hydropower Association.

Isaksson, N & Lundström, H. (2005). Dammsäkerhetsutvärdering samt utformning av dammregister och felrapporteringssystem för svenska gruvdammar. M.Sc Thesis, Uppsala Universitet, Institutionen för geovetenskaper.

IVA. (2002). Vattenkraften i Sverige: En Faktarapport Inom IVA-Projektet Energiframsyn Sverige i Europa. Eskilstuna: Multitryck.

Kulsum, A., Mercier, J.R., Verheem, R. (2005). Strategic Environmental Assessment: Concept and Practice. Washington DC: World Bank.

Lehner, B., Reidy Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P., Endejan, M., Frenken, K., Magome, J., and Nilsson, C. (2011). High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. Front Ecol Environ 2011; 9(9): 494–502, doi: 10.1890/100125.

LEPA irrigation offers water & energy savings. Retrieved January 11, 2012, from www.senninger.com/2010/04/12/lepa-irrigation-offers-water-energy-savings/.

Levine, G.J. (2003). Pumped hydroelectric energy storage and spatial diversity of wind resources as methods of improving utilization of renewable energy sources. Michigan: Michigan Technological University.

Mander, H. & Nagraj, R.(1999). Dams, displacement, policy and law in India1986: Contributing Paper for WCD Thematic Review 1.3 Displacement. In: World Commission on Dams (2000). Dams and development: A new framework for decision-making. London: Earthscan Publications Ltd.

Oklahoma flood control dams saved state over $2 million during recent heavy rains. Retrieved October 04, 2011, from http://southwestfarmpress.com/government/oklahoma-flood-control-dams-saved-state-over-2-million-during-recent-heavy-rains.

Papush, L. (2011). Silicon cycling in the Baltic Sea: Trends and budget of dissolved silica. Linköping: Linköping University.

Phinney, S. & McCann, R. (2005). Potential changes in hydropower production from global climate change in California and the western United States. Los Angeles: Aspen Environmental Group.

Programs in Oklahoma. Retrieved October 25, 2011, from http://water.usgs.gov/wid/html/ok.html#HDR0.

Purposes of dams. (2012). Retrieved August 8, 2012, from www.icold-cigb.org/GB/World_register/general_synthesis.asp

Reservoir Emissions (2012). Retrieved February 07, 2012, from www.internationalrivers.org/global-warming/reservoir-emissions.

Robinson, S. (2000). The experience with dams and resettlement in Mexico: Prepared for thematic review I.3: Displacement, resettlement, rehabilitation, reparation and development. In: Dams and Development: a New Framework for Decision-Making (2000). London: Earthscan Publications Ltd.

Run of the river: How it works. (2012). Retrieved February 18, 2012, from www.shawater.co.uk/content/runOfRiver/howitworks.php.

Salem-Murdock, M. (1989). Arabs and Nubians in New Halfa: A study of settlement and irrigation.

Salt Lake City: University of Utah Press.

Shahin, M.M.A. (1993). An overview of reservoir sedimentation in some African river basins. Delft: International Institute for Infrastructural, Hydraulic and Environmental Engineering.

UNEP/DDP. (2007). Dams and development: Relevant practices for improved decision-making. Nairobi: United Nations Environment Programme.

Wet de, C (2000). The experience with dams and resettlement in Africa: Contributing paper thematic review I.3. In: World Commission on Dams (2000). Dams and development: A new framework for decision-making. London: Earthscan Publications Ltd.

Wetlands. (2012). Retrieved August 8, 2012, from http://water.epa.gov/type/wetlands/index.cfm

What is hydropower's history? (2012). Retrieved February 21, 2012, from www.ieahydro.org/What_is_hydropower's_history.html.

Why dams fail. (2010). Retrieved May 23, 2012, from www.fema.gov/hazard/damfailure/why.shtm.

Wikström, A. (2007). Modelling flow detention through temporary storage in the landscape using Artificial Neural Networks: A case study of Lake Mälaren. M.Sc Thesis, Lund University, Division of Water Resources Engineering.

William, R. J. (1999). Dams and disease: ecological design and health impacts of large dams, canals and irrigation systems. London: E&FN Spoon.

Wines, M, (2011, May 19). China admits problems with Three Gorges Dam. The New York Times. Retrieved from www.nytimes.com/2011/05/20/world/asia/20gorges.html.

World Bank. (1998). Recent experience with involuntary resettlement: Togo-Nangbeto Report No. 17543. Operations Evaluation Department. Washington DC: World Bank.

World Bank. (2004 a).World Bank safeguard policies overview: An unofficial World Bank document. Washington D.C: World Bank.

World Bank. (2004 b). Water resources sector strategy: Strategic directions for World Bank engagement. Washington DC: World Bank.

World Commission on Dams (2000). Dams and development: A new framework for decision-making. London: Earthscan Publications Ltd.

World Economic Forum. (2011). Global risks sixth edition: An Initiative of the risk response network. Geneva: World Economic Forum.

Zardari, M. (2011). Stability of tailings dams: Focus on numerical modelling. Ph.D thesis, Luleå University of Technology, Department of Environmental and Natural Resources Engineering, Division of Mining and Geotechnical Engineering.

SIWI

The Stockholm International Water Institute (SIWI) is a policy institute that generates knowledge and informs decision-making towards water wise policy and sustainable development. SIWI performs research, builds institutional capacity and provides advisory services in five thematic areas: water governance, transboundary water management, water and climate change, the water-energy-food nexus, and water economics. SIWI organises the World Water Week in Stockholm – the leading annual global meeting place on water and development issues – and hosts the Stockholm Water Prize, the Stockholm Junior Water Prize and the Stockholm Industry Water Award.

Stockholm International Water Institute, SIWI
Drottninggatan 33, SE-111 51 Stockholm, Sweden
Phone +46 8 522 139 60 • Fax +46 8 522 139 61 • siwi@siwi.org • www.siwi.org