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Water storage and hydropower: supporting growth, resilience and low carbon development

A DFID evidence-into-action paper

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Summary

1 Improved water storage is a driver for economic growth. In poor countries with highly seasonal and often unpredictable rainfall, a lack of adequate water storage already causes large and avoidable economic losses from floods and droughts, and constrains long-term growth. The benefits provided by water storage in wealthy countries are reflected by their high per capita rates of water storage.

2 The available evidence indicates significant economic returns accrue from improved water storage, although there has been considerable variation in performance. Dams built for hydropower have tended to provide better economic returns than those built for irrigation or domestic supply. Multipurpose water storage, justified economically on returns from hydropower, may be used to provide additional benefits such as irrigation to support local livelihoods and improve food security.

3 Improved water storage will increase resilience to climate change and support better water and food security in poor and vulnerable countries. This will require actions to improve both natural water storage in rivers, lakes, aquifers, wetlands and soils, as well as built storage. In many countries, built water storage of a range of sizes will offer the most effective means of hedging risks from more variable rainfall. Demand management to ensure efficient use of water is a crucial complement to improved storage.

4 It is important that development of water storage in the future does not repeat the mistakes of the past where high social and environmental costs have been incurred. Future water storage projects must ensure pro-poor outcomes and proper compensation for people displaced by dams, or whose livelihoods are disrupted by changes in river flows. There is evidence that, with good planning, dams can deliver positive gender impacts through increased access to irrigation and water services.

5 Hydropower development has also played an important role in supporting economic growth in wealthy countries, which have developed most of their hydropower potential. Poor countries and regions have developed a fraction of their potential. Hydropower offers an important low-carbon energy solution to meet the massive unmet demand and provides reliable base-load power in poor countries. The development of hydropower needs to balance large and small-scale infrastructure. Decisions should be based on cost-benefit analysis, including life-cycle assessments of emissions, and the shadow price of carbon.

6 Good governance of water storage and hydropower is crucial. This must ensure that the rights of poor and marginalised groups are taken into account in planning, construction and sharing of benefits. It is also crucial that the environment is recognised as a legitimate user of water that provides significant economic returns through ecosystem services. Achieving good governance requires the development of effective policies that are implemented by capable, accountable and responsive institutions that enforce compliance with regulations. Governance of infrastructure on transboundary waters represents a specific challenge, particularly in the absence of legally binding treaties. More needs to be done to support development and implementation of governance arrangements for such infrastructure.

Introduction

1 Water security is commonly understood to be the process of ensuring sufficient quantity and quality of water for health, productive uses and ecosystems, with an acceptable level of water-related risks to people, environments and economies.[1] Water security is essential for economic growth, poverty reduction and environmental sustainability. Its importance will grow with climate change, as the majority of these impacts will be experienced through water.[2] Water security will be the cornerstone of climate resilience and a critical component of adaptation. Without improved water security, countries will be highly vulnerable to climate change and have limited scope for adaptation to changing variability and availability of water. Improved water storage plays an important role in building water security.

2 The purpose of this position paper is to set out the rationale for developing a more strategic engagement by the Department for International Development (DFID) in the provision of water storage and hydropower. This is based on our focus and experience in securing pro-poor outcomes, our analytical skills and on our ability to influence the international system. It reviews the evidence for more water storage and hydropower, and summarises current and possible future DFID support.

The case for water storage is compelling

3 Water storage is a driver -- and often a prerequisite -- for economic growth, and is of particular importance to smooth intra-annual and spatial variations in rainfall that otherwise have significant impacts on growth. An analysis of 163 countries indicated a strong correlation between variability in rainfall and lower GDP, suggesting that improvements in water storage were most needed in poorer countries.[3] Evidence from developed countries shows that as growth continues, improvements in water management, often through institutional and 'soft' interventions, deliver further multiple economic benefits. Investments of the levels seen in wealthy countries have not occurred in most low- and middle-income countries.

4 This lack of investment has profound economic impacts. Inadequate water storage that results in droughts and floods has impacts on a wide range of sectors. For instance, floods in Kenya in 1997-98 led to losses equivalent to 11% of GDP for the year, and drought in 1998-2000 the equivalent of 16% of GDP for each year.[4] These losses were incurred in a range of productive and social sectors as shown in Box 1 below.

5 Ethiopia's GDP fluctuates with rainfall and, as a consequence of the lack of water storage, is estimated to be reduced by one-third of its potential.[5] Floods in Mozambique in 2000 had a direct cost of $600 million, with greater costs associated with rehabilitation of infrastructure, and resulted in GDP growth decreasing from

[1] Grey and Sadoff, 2007
[2] Stern 2006 and IPCC 2007
[3] Brown and Lall, 2006
[4] Data presented in a review for DFID undertaken by GY Associates 2009
[5] World Bank 2006

7.5% to 1.6% in one year. Disasters – primarily water related – are estimated to cost South Asian countries between 2-6% of GDP annually.

Box 1: Main sectoral impacts of the 1997-98 El Niño floods and 1998-2000 La Niña drought (taken from The Republic of Kenya: Towards a Water Secure Kenya, Water Resource Sector Memorandum, World Bank, April 2004)

1997-98 El Niño flood impacts:

- Transport infrastructure damage and destruction with a replacement cost of Ksh 62 billion ($777 million)
- Water supply infrastructure damage equivalent to Ksh 3.6 billion ($45 million)
- Health sector costs equivalent to Ksh 4.5 billion ($56 million)

1998-2000 La Niña drought impacts:

- 42% decline in hydropower production and increase in cost of power production and import substitution equivalent to Ksh 52 billion ($640 million)
- Lost industrial production (due to inadequate power) of Ksh 110 billion ($1.4 billion); some urban industries were forced to relocate
- Agricultural losses and reduced production valued at Ksh 19 billion ($240 million).
- Livestock losses and reduced production valued at Ksh 10.9 billion ($137 million).

6 In comparison, the US Army Corps of Engineers have invested in the order of $200 billion in flood management and mitigation since the 1920s with resulting benefits estimated at $700 billion[6] and economic losses from flood damage of under 0.5% of GDP. The majority of developed countries have well-developed storage capacity. The USA has 6,000 m^3 per capita and Australia 4,500m^3 per capita. Even the UK, with its temperate climate and 'easy' hydrology with regular rainfall throughout the year and abundant natural storage in lakes, lochs and groundwater, has in the region of 471m^3 per capita of constructed reservoir storage. This should be compared to the meagre 165m^3 per capita in Ethiopia, a country with highly concentrated and unpredictable rainfall, and the still limited 750m^3 in South Africa.

7 Most developing countries have a more difficult hydrology than developed (particularly north European) countries. Rainfall is concentrated into short wet seasons or monsoons with prolonged annual dry periods, and unpredictable and variable rainfall and water flows between years, and in some cases sequences of very dry years. Some developed countries, however, do have a difficult hydrology and their experience shows that improved water storage can support economic growth.

8 The USA and Australia provide ample evidence of the role of water storage in economic growth. Australia continues to consider that construction of water storage and more effective water management will be key to their climate change adaptation strategies.[7] In the USA, the development of water storage infrastructure and hydropower in the early 20th century transformed the south-eastern USA, one of America's poorest regions, within one generation eradicating malaria, improving livelihoods and providing near universal access to water supply, sanitation and power.[8] This was achieved through multipurpose hydraulic infrastructure that both

[6] It is assumed this is net present value, although this is not stated in Grey and Sadoff (2007)
[7] Garnaut review 2008
[8] Grey & Sadoff 2007

managed flood and drought risks and ensured water was available for productive uses.

9 Investments in water infrastructure in the south-west USA had a similar impact on economic development. As a result of these investments, the Colorado River has 1,400 days of water storage (based on live storage capacity and average annual flows)[9] providing a high level of water security. Such development has, however, resulted in significant reduction in environmental flows and impacts on migratory fish. Costly efforts are underway to remediate this, but analyses show that better design to provide environment flows from the outset would not only have saved subsequent reoperation costs, but could have delivered wider economic benefits. [10]

10 The storage on the Colorado River should be compared to the 30 days of storage on the Indus, which is recharged from glacial meltwater and monsoonal rains that are relatively weak and fall within a short time period. Pakistan has been able to cope with such low rates of built storage in part because of extensive natural storage in aquifers, but these are being heavily exploited and groundwater levels are falling rapidly. Even so, the limited river storage has been critical to the development of agriculture and energy in Pakistan.

11 The USA and Australia also provide ample evidence of the environmental and social costs of water storage and of the dangers of an over-emphasis on built water storage in improving water security. In the USA environmental impacts have been significant, with a reduction in the proportion of free flowing rivers. It is estimated that the 75,000 large dams in the USA have modified at least 600,000 miles of American rivers (about 17% of American river length).[11] In the late 1960s, the US Congress passed into law the Wild and Scenic Rivers System to preserve selected rivers in a free-flowing condition. The provisions of this act do not prohibit development nor do they affect existing water rights and institutions. In 40 years, the national system protected over 11,000 miles of 166 rivers in 38 states and Puerto Rico – or a little more than 0.25% of American rivers. Dams are now being decommissioned in the USA, where no longer economically viable, to restore more natural functioning of the river ecosystem.

12 There remain concerns over the sustainable use of water in the USA, and there is an urgent need for better demand management and changes in dam operation. It has also become increasingly recognised that relying on infrastructure alone is not the most efficient means of flood management and that infrastructure measures should be combined with non-infrastructural measures, such as managed flooding. Where infrastructure alone is used, residual risks from excessive floods can be extremely high.

13 In Australia, the Murray-Darling River is highly regulated with much storage infrastructure, which has delivered major economic benefits. However, it is now clear that current rates of diversion and use are not sustainable, with significant ecological impacts on the river and its floodplains. As a result, new caps on water withdrawals

[9] Ibid.
[10] Krchnak et al 2009
[11] Wild and Scenic rivers, 2009 – www.rivers.gov/

have been imposed and the Federal Government is now buying back water rights. This illustrates the need for infrastructure to be planned taking into account all withdrawals and demands for water and for dams to be operated properly to avoid over-allocation. Serious multi-year droughts have shown that, despite the development of its hydraulic infrastructure, Australia remains to some extent 'hampered by hydrology'.[12] A key lesson is that the development of water storage must be placed within an overall context of integrated water management and include demand management actions.

The economic arguments for water storage

14 The losses to economies because of poor water storage provide an indication of the likely economic benefits that could be accrued. Generalised estimates of the overall economic return from investments in water storage are difficult to derive. One study[13] calculated the water storage needs of countries with significant monthly variation in rainfall. This used the water demand to grow sufficient food to feed each country's population (the principal use of water globally), the intra-annual and inter-annual variation in rainfall and the amount of storage (built or natural) available. This identified 23 largely poor countries where further investments were required in seasonal water storage, of which 14 had currently 10% or less of the storage required to meet seasonal water demands. The majority of these countries were in Africa, but also included several South Asian countries. This study concluded that for these countries, investment in water storage would be likely to deliver significant economic returns.

15 Using data from this study, an indicative value for the additional food that could be grown in Ethiopia, if sufficient water storage was available, was calculated to help inform the development of this position paper.[14] This was based on providing 3,000 calories per capita per day and using a value of 175 per tonne of grain (based on import costs) and indicated that an additional $2.8 billion of food products, or 10% of the total GDP in 2008, could be delivered.

16 The building of dams may be undertaken for a number of reasons that include social as well as economic objectives. Problems remain over how costs and benefits of dams are calculated. Many projects have not adequately assessed and valued the ecosystem and social costs of building dams, making an accurate cost-benefit analysis difficult. Recent research on significant values of ecosystem services may help rectify this. There have also been failures account for distributional costs, where one community loses and others gain, to deliver the compensation and wider benefit-sharing.

17 The World Commission on Dams (WCD) reviewed a number of projects to assess the economic and financial performance of large dams.[15] This concluded that single purpose hydropower dams had a good overall record of financial and economic performance, but noted a wide variation. The single purpose dams for domestic water supply that were reviewed generally had poor economic

[12] Grey and Sadoff 2007
[13] Brown and Lall 2006
[14] Analysis by GY Associates 2009
[15] World Commission on Dams 2000

performance, with economic internal rates of return of below 10%. However, in circumstances where alternative sources are inadequate to meet the demands for water, particularly from urban areas, dams for domestic supply may still need to be built as a public service, despite lower than expected economic performance.

18 Large dams for irrigation were also found to regularly fail to deliver expected economic performance, although this may change in the future as food prices are unlikely to fall back to previous low levels. With economic development there will be increased demand for food - and for more water intensive food such as meat products. The provision of irrigation water may also be important to secure or improve local livelihoods as rainfall becomes less predictable; thus building reservoirs may be warranted to provide the water to support irrigation projects.

19 The WCD found that, in general, multipurpose dams were found to have a similar economic and financial performance within the three main sectors as single purpose dams. In some cases, however, the overall benefits from multipurpose dams are very significant. For instance, it has been estimated that the total economic benefits from the Aswan High Dam were $1,260-1,830 million, or about 2.7%-4% of GDP in 1997, based on 1997 values.[16] The main gains came from power, tourism and navigation. The total investment costs for the dam were $1 billion, but operation and maintenance costs are undocumented and the cost of lost ecosystem services has been high. Based on other dams, such as Tarbela in Pakistan, profits from power sales are expected to significantly exceed operation and maintenance costs.[17] In some of the multipurpose dams reviewed, energy generation was used to subsidise less economically productive uses: for instance the Grand Coulee Dam in the USA, where the return from hydropower effectively covered the losses made through the associated irrigation programme.

20 An analysis for the Copenhagen Consensus 2008 of the development of a hypothetical large multipurpose dam on the Blue Nile in Ethiopia indicated that the total present-value costs range is $2,493 to $3,743 million (depending on whether a 3%, 4.5% or 6% discount rate is used).[18] The expected present value benefits were estimated to vary between $5,610 and $13,842 million (using the same discount rates). This gives a cost-benefit ratio of between 1.8 at a 6% discount rate to 3.7 at a 3% discount rate. Given the current UK guidance is to use a 3.5% discount rate for 0-30 year investments, this suggests that such a development would have significant economic benefit.[19]

21 Indirect economic benefits may also arise from dams, for instance through creation of employment, increased land productivity, manufacturing and added value of crops produced. A selection of case studies compiled by the World Bank yielded two examples with figures for estimated indirect benefits using a social accounting model. This suggested a multiplier effect of 1.78 -1.9 for a large multipurpose dam in the Punjab and 1.41 for two small check dams installed to supply irrigation in

[16] Based on reviews of the literature provided by Franke Urban, IDS, under a short-term query via the Tie-Up resource centre in 2008
[17] Ibid.
[18] Whittington et al 2008
[19] http://www.hm-treasury.gov.uk/data_greenbook_index.htm

Haryana.[20] If operated appropriately, dams may allow improved management of downstream ecosystem services, such as floodplain fisheries, if releases allow controlled floodplain inundation.

22 The WCD and other research has pointed to clear evidence of the economic benefits from building large dams, but have rightly noted that planning and delivery need to significantly improve. The WCD did not address small dams, but these have been found to deliver significant economic benefits at local scales. On the other hand, small dams can create vector breeding habitats close to human settlements, increasing rates of malaria and schistosomiasis . Work in Ethiopia suggested the economic benefits outweighed the costs of small dams, despite higher disease incidence among irrigators, and noted that the health problems associated with small dams would be relatively easy to resolve.[21] The World Health Organization has worked on environmental management (managing water in ponds, irrigation canals and reservoirs in more natural cycles) as a method of disease vector control.

Governance is critical for water storage development

23 There are many examples worldwide where poorly planned water storage has resulted in adverse social and environmental outcomes. People displaced by reservoirs have often lost livelihoods and had little or no access to the benefits from improved water storage that would have compensated these losses, such as rural electrification around hydropower dams. Downstream impacts on water-based livelihoods and commercial interests, such as those based on fisheries, have suffered catastrophic losses from reservoir design and management that have reduced downstream flows. Drinking water supplies have sometimes been affected; for example, in West Africa dam storage reduced inundation of floodplains that was the principal source of groundwater recharge and resulted in greater problems securing sufficient water supplies in rural communities. Compensation schemes have failed to offset livelihoods loss and have often been delivered late. There have also been important impacts on freshwater ecosystems, which have been identified by some organisations to be under greater stress and risk of collapse than other ecosystems.[22]

24 A particular concern in the provision of water storage and associated infrastructure is the degree to which women are disproportionately affected by adverse impacts and have limited access to benefits from such infrastructure. The WCD noted that in many cases women have borne a disproportionate amount of the social costs of water storage provision.[23] In Sri Lanka, for instance, the Mahaweli dam construction was associated with the introduction of a new rule that families were allowed to nominate one heir to their land (usually a son). This undermined the pre-existing inheritance rules that allowed women the right to co-own and control land. Similarly in India, tribal women do not have land rights and thus have not received compensation for land they have lost to reservoirs. Wider social impacts, including increases in domestic violence and sexually transmitted diseases, including HIV and AIDS, have also occurred where planning has been poor and gender-blind.

[20] Bhatia et al 2008.
[21] Ersado, 2005
[22] WWF communication to DFID in response to an early draft of this paper
[23] Most of the examples in the following text are taken from WCD 2000

Funders of dam projects were found to have placed insufficient attention on gender in project preparation and implementations stages. Although the WCD noted these problems had been associated with particular projects, it is important to be clear that these reflect poorly designed and implemented planning and construction processes, and need not have occurred.

25 The WCD also noted that there was evidence that water storage projects had delivered benefits for women. Projects in Egypt, Tunisia and Sri Lanka were found to have led to land reforms that benefited poor women. In the Senegal River, irrigation schemes increased ownership of irrigated plots by women, although this remained very low at 6%. The WCD also noted that where dams have improved the supply of services these are likely to have benefited women; for instance the resettlement programme associated with the Akosombo dam, in Ghana, led to significant increases in access to social services. Improved living standards associated with irrigation and dams also may have positive gender impacts. For example, improving family incomes from irrigation at the Atslantas dam, in Turkey, enabled farmers to give both girls and boys higher education. These examples indicate that the provision of water storage and associated infrastructure has the potential for positive impacts on gender, but that this must be incorporated in planning from the outset.

26 Given the importance of water storage to economic growth, past experiences highlight the urgent need for better planning of water storage infrastructure and for decisions to build reservoirs to be based on an assessment of all available options for improving water security. The development and management of reservoirs should ensure more equitable and pro-poor distribution of benefits at local as well as national scales.

27 The good governance of water resources as a whole, and water storage in particular, is critical if these mistakes are not to be repeated. Good policy frameworks must be in place to guide the development of water storage and these must be allied to the development of capable and accountable institutions. Policy frameworks must ensure that the rights (cultural as well as social and economic) of poor and marginalised groups, including indigenous peoples, are recognised. The institutions developed must be capable of implementing policies and enforcing compliance with regulations and norms.

28 A key element in such policies is to ensure that local costs are not ignored where macroeconomic benefits are significant. Where existing benefits from water are withdrawn, alternative benefits must be provided that are greater than simply compensation for lost rights. Policies must also recognise the importance and legitimacy of the environment as a water user and make provision for protecting environmental flows. The use of strategic environmental assessments in determining environmental impacts and identifying options that minimise adverse impacts should be incorporated into the planning process.

Climate change will increase the need for water storage

29 Increasing variability in rainfall is expected to be a major consequence of climate change. There is much uncertainty in predicting changes, but some regions, notably Southern and North Africa, are likely to get drier even within relatively short

time frames.[24] Others, such as the Indian subcontinent, are likely to experience increasing average precipitation, but this is likely to be within the same period of time as current monsoons.

30 Predicting climate change impacts on water resources is far from straightforward. Changes in rainfall will interact with changes in temperature and land-use and thus changes in evapotranspiration and water demand. The type of precipitation will determine what and how quickly the hydrological response is to changing precipitation. Watershed management may become an increasingly important tool for climate change mitigation; water management needs to be accepted as a legitimate land-use, rather than a by-product of other uses.

31 In areas where there is significant snowfall, changes in precipitation will be mediated through the cryosphere and thus may take a significant time to manifest themselves. In very dry environments, small reductions in rainfall may lead to much greater reductions in streamflow. For instance, it has been estimated that a 10% reduction in rainfall in the Murray-Darling basin will lead to a 35% reduction in streamflow.[25] To cope with the increased variability and unpredictability brought about by climate change, there needs to be a suite of activities to improve water management. Water storage infrastructure will play a critical role in managing the adverse impacts of changing precipitation and as a driver of resilient regional growth.

32 In basins where glacier meltwater contributes to river flow, climate change is likely to lead to a loss of water stored in glaciers with impacts on river flows. These impacts are already being seen in the Andes[26] and other mountain ranges. Glacier melting will have a very pronounced impact on mountain communities, as flows in local rivers and springs reduce, and as risks of glacial lake outburst floods increase.

33 The Himalaya-Karokroam-Hindu Kush (HKH) ranges contain the largest volume of ice outside of the polar regions. Glacier meltwater forms an important part of low season flows, although this varies across the region. Glacier meltwater is more important in the west, where it contributes up to 40-50% of the low season flow of the Indus,[27] than in the east where it may account for only 10-15% of the low season flows in the Ganges.[28] The disappearance of mountain glaciers in Asia will have a significant impact on water resources. The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) included a statement that the likelihood of glaciers in the Himalaya disappearing by 2035 was very high[29] - a claim that is now accepted as very likely to be incorrect. Nonetheless, the evidence for glacier retreat in the HKH ranges is robust and the loss of glaciers over the longer-term will impact on low season flows of a number of major rivers. DFID is planning to undertake a systematic review of the evidence of the impact of glacier melting on water resources in the region to support better policy-making.

[24] Brookshaw and Graham 2009, using IPCC definitions
[25] Reports cited in the Garnault review
[26] For instance, Barnett et al (2005) show a reduction of 25% in glacier covered area in Peru alone over the last 30 years
[27] Sources quoted in Xu et al 2007
[28] Rees and Collins 2004, Alford et al 2009
[29] IPCC 2007

34 Some predictions indicate that South Asia will receive increasing rainfall within an intensified monsoon in coming decades.[30] The provision of more water storage on rivers to capture rainfall could offset the expected reduction in low season flows. This will clearly require lengthy and extensive negotiations between countries in a politically fragile region, but is likely to offer the only robust and sustainable solution to a looming water crisis.

35 In areas getting drier, infrastructure may be needed to increase surface water storage and to enhance natural groundwater recharge. In some dry environments, for instance Ethiopia, larger reservoirs such as that behind the Tekeze dam, with 'extra' storage may provide a buffer and increased flexibility to deal with sedimentation, droughts or providing environmental flows.[31] In other situations, a focus on small infrastructure, increasing recharge to groundwater, improved 'green' water management[32] and demand management interventions will be required.

Water wars or rivers of peace?

36 Climate change has the potential to increase conflict over waters shared between communities, neighbouring states or provinces within federal countries and between countries. Conflicts between states within federal countries and between local communities already occur in some dry areas. Currently, conflict between countries over water is relatively rare and cooperation rather than conflict is the norm[33]. Decreasing availability or increasing variability of water could change this and fuel conflicts in already fragile regions such as South Asia.

37 Building cooperatively managed storage, the reoperation of existing infrastructure to reallocate or improve predictability of water flows, improving overall basin management to manage demand, improving natural storage and ensuring more equitable sharing of benefits offers the potential to reduce the risk of such conflicts. This may involve in some cases building new infrastructure, but actions to improve natural water storage, more efficient management of existing infrastructure and improved demand management will be important and in some cases the primary focus.

38 But in all cases such approaches fundamentally rely on building trust and effective political processes. This means, for instance, undertakings by upstream riparians to develop infrastructure of benefit to downstream riparians, typically providing cheap electricity or improved flood management, and not to use infrastructure to divert water for - purposes that deliver no net downstream benefit. It may in some cases also mean development of infrastructure in one country jointly funded by other riparians with an associated degree of control by all parties

[30] Hadley Centre 2009 and IPCC 2007
[31] Acreman et al 2009
[32] Green water is water held in soils, root zones and vegetation as opposed to 'blue' water held in water bodies such as rivers, lakes, aquifers etc
[33] International Water Event Database 1950-2005 and Human Development Report 2006

Hydropower: an important mitigation option

39 Hydropower is an important potential source of low-carbon energy and currently accounts for 19% of global electricity generated.[34] In addition to supporting low-carbon growth, providing power through hydropower and other means is likely to increase adaptation options for poor people.

40 Current estimates suggest that 778 GW from hydropower has been developed out of a technically exploitable potential of 1,883 GW, with a further 124 GW under development.[35] At present only a tenth of the technically exploitable potential of 200 GW from small hydropower[36] has been developed. Unlike some other renewable energy sources, hydropower can provide reliable and cost-effective base-load electricity. Hydropower has significant potential for providing high-value peaking power when demands, and usually price, are at their highest. It also can be linked to smarter grid approaches by using load following generation to allow power generation to follow short-term variations (on a small-scale minute to minute) changes in demand.

41 At present 1.6 billion people worldwide, overwhelmingly in low-income countries, lack access to household electricity with access falling as low as 3% in some regions of sub-Saharan Africa.[37] Reliable power supplies are essential for economic growth and provide important social and public health benefits. The difference in hydropower development between rich and poor countries is stark, as shown in table 1 below.

Table 1: Hydropower developed by region

Developing regions	Percent potential developed	Developed regions	Percent potential developed
Africa	7	Europe	75
Asia	22	USA	69
Country examples			
Ethiopia	1% of 30-40 GW	France	98% of 26 GW

42 There has been considerable debate over the degree to which hydropower is a low-carbon form of energy and over the greenhouse gas (GHG) emissions associated with hydropower schemes. Some GHG emissions are caused through the construction of dams, access roads and transmission networks. Some or all of these emissions would also be incurred through the use of alternative sources of energy. Where run of the river hydropower schemes are used, emissions can be expected to be only marginally above background (if at all) and far lower than from alternative supplies.

43 Reservoirs can be sources of ongoing GHG emissions, but the scale of their contribution remains an area of debate. GHG emissions are a feature of all freshwater bodies, thus the question is whether impoundment in reservoirs increases these beyond a background level. The evidence suggests that certain types of reservoirs – primarily shallow, plateau-type reservoirs in tropical climates – are the

[34] Sadoff and Muller 2009
[35] WEC 2007
[36] Definition vary, but always greater than 1-25GW
[37] World Bank 2009a

most significant GHG emitters. Deeper tropical reservoirs and those in more temperate climates exhibit much lower emissions. Emissions may also be time limited, for instance in temperate climates emissions tend to be higher than surrounding lakes, but fall back to similar levels within 10 years.[38] Most life-cycle assessments have concluded that the majority of hydropower projects have overall net GHG emissions similar to those of other renewable energy sources and significantly lower than those from thermal plants. Nonetheless, it is important that contributions of reservoirs to GHG emissions are assessed.

44 The International Rivers Network have suggested that GHG emissions are in fact higher and point to the presence of methane (a more potent GHG) in impoundments, which may be released through pulses or bubbling. Arguments remain on the importance of this. The International Hydropower Association (IHA) suggest that only 1% of all GHG emissions are methane, and they note research that shows many natural systems emit more methane than that estimated for some reservoirs; the overall impact thus partly depends on what natural system the reservoir replaces.

45 There are interventions to reduce the potential for GHG emissions in reservoirs, for instance by clearing vegetation from flooded areas thus reducing the stock of organic material that will decompose to release GHGs. Some ongoing emissions remain likely because of natural organic material being washed into the reservoir and pollution from upstream human settlements from rivers and streams. It is clear, however, that such emissions would occur in any case from natural systems.

46 The IHA calculate that current hydropower offsets 2.1 billion tonnes of CO_2 and that developing further hydropower potential would offset a further 7 billion tonnes of CO_2. They also note that GHG emissions from most hydropower plants are 100 times lower per unit than coal fired generation plants and 40 times lower than natural gas combined cycle turbines.[39] A whole life-cycle calculation, including construction and decommissioning costs, is required to define the true carbon balance as, for example, 1 kg cement clinker produces 1 kg CO_2.

47 The contributions of GHG emissions from water storage must be set within the overall context of emissions from all sources of energy. Without further investment and support for hydropower, there are real dangers of countries making climate-damaging choices in power provision that will contribute to further GHG emissions. For instance, there has been serious discussion in Nepal of installation of diesel power generators to deal with crippling power cuts, despite the enormous potential for hydropower, which is estimated at 40-80 GW (broadly equivalent to the entire electricity production of the UK). This discussion is, in part, driven by lack of support and funding for further development of hydropower and limited export of power. Developing hydropower potential would support economic growth both for Nepal, through earnings from exported energy, and also for her neighbours who would have access to more plentiful clean energy. This could drive more resilient and low-carbon regional economic growth.

[38] Acreman et al 2009
[39] IHA undated

48 The United Nations Framework Convention on Climate Change (UNFCCC) does not currently include hydropower where there is associated large storage within clean development mechanisms (CDM). This is in part because of issues over the environmental and social consequences of large dams when done badly, and because of concerns over GHG emissions from large reservoirs. It is important in the future that decisions made about hydropower are based on cost-benefit analysis of all available options including life-cycle assessments of emissions and the shadow price of carbon.

49 Environmental and social concerns around dams can largely be overcome by following the recommendations of the WCD and it is clear that good planning, design and operation of reservoirs can reduce GHG emissions. It is important that the potential role for hydropower is given greater priority within the instruments available for climate financing. However, it is clear that the further development of hydropower should be carried out only after an assessment of all available options for low-carbon power generation. The emerging best practice guidelines from the Hydropower Sustainability Assessment Forum (HSAF) will help in ensuring that environmental (including GHG emissions) and social consequences are properly addressed.[40]

Large or small infrastructure?

50 Much of the debate around dams and reservoirs focuses on large infrastructure, but reservoirs of all sizes play important roles in enhancing water security at local levels. Investing in networks of smaller reservoirs can be alternatives to the construction of single large facilities.[41] Such small reservoirs may be tailored for local needs, more directly address local livelihoods and poverty, and permit more input and control from local users. Dispersed networks of small reservoirs may provide more flexibility, thereby reducing hydrological risk and hedging drought risks.[42]

51 Managing many small reservoirs can be a challenge, however, making it difficult to ensure appropriate environmental and social safeguards are implemented. There are also generally greater evaporation losses from small reservoirs than from large reservoirs. For instance, in Mugabe, Zimbabwe, over 90% of water from a small community reservoir was lost to evaporation, although the 10% used was very important to livelihoods and wellbeing of the community.[43]

52 Environmental and social impacts of small reservoirs are more widely distributed, but it is difficult to generalise as to whether their cumulative impacts will be greater or less than a few large reservoirs. Where the reservoirs are small enough not to impede fish migration or alter river flows and sediment movement, such as with many run-of-river schemes, their impact may be low. Small multifunctional water storage will provide a wider range of benefits including local water storage for domestic and small-scale industrial use, and habitat for small-scale aquaculture.

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[40] IHA 2006
[41] Acreman et al 2009
[42] Ibid
[43] Ibid

53 In regions expected to become drier there may be a stronger rationale for constructing more small and medium-sized reservoirs as opposed to fewer large dams. In addition to hedging drought risks, the costs of abandonment and new build are more affordable than those associated with large reservoirs. Small reservoirs have long been an adaptive response from people traditionally living in arid and semi-arid climates. There are also numerous examples of 'hydro-civilisations', such as that from Ankhor Wat, that built economic strength and food security on the basis of effective management of water through relatively small infrastructure.

Large dams

54 Much of the negative perception about reservoirs refers to those produced by large dams, which represent some 6000 km^3 of water storage worldwide (see box 2). Large reservoirs can result in large inundated areas, with ecological and social consequences. However, many of the adverse consequences of large reservoirs can be reduced through proper design of infrastructure, putting in place environmental safeguards and adequate compensation, as well as support to the communities that must be relocated. It is also important to note, however, than any assessment of the impact of large reservoirs must look at local, national and regional level impacts and benefits.

Box 2: Types of large dams (taken from 'Dams and Development', Report of the World Commission on Dams, 2000)

There are various definitions of large dams. The International Commission on Large Dams (ICOLD), established in 1928, defines a large dam as a dam with a height of 15m or more from the foundation. If dams are between 5-15m high and have a reservoir volume of more than 3 million m^3, they are also classified as large dams. Using this definition, there are over 45 000 large dams around the world. The two main categories of large dams are reservoir type storage projects and run-of-river schemes that often have no storage reservoir and may have limited daily pondage. Within these general classifications there is considerable diversity in scale, design, operation and potential for adverse impacts.

55 The concerns over the social and environmental impacts of large dams led to the establishment of the World Commission on Dams that reported in 2000. The WCD noted that whilst large dams had provided benefits, they had also been associated in some cases with significant environmental and social costs. However, the WCD did not suggest that large dams should not be built, but rather that the planning, design and construction of water storage should be improved and address key environmental and social issues from the outset. The WCD was a lengthy and expensive process that involved wide-ranging consultation and the preparation of a large and detailed report. A key recommendation of the WCD was for extensive consultation during the planning of dams. Implementing this recommendation in low-income countries is likely to require more significant grant financing and technical assistance from donors.

56 To help guide future dam development, the WCD report sets out five core values, seven strategic priorities and 26 guidelines for review and approval of projects at five stages of decision-making (see table 2 below). The UK Government agreed with the recommendations of the WCD, although did not formally publish a position on this. Most other agencies, including the Multilateral Development Banks, have endorsed the five core values and the seven strategic priorities. The guidelines, however, have attracted more debate largely related to interpretation of whether

these are set only as guidance or are considered as standards or benchmarks. The World Bank, after consultation with their debtor countries, have a position that the guidelines are useful, but constitute non-binding guidance for dam planning, design, construction and management.

57 The HSAF - an initiative of the IHA, The Nature Conservancy and WWF - are developing a 'sustainability assessment protocol' for hydropower, including those with large storage. This has involvement from major private sector hydropower developers, as well as multilaterals, civil society and key partner countries, such as China. This initiative is seen from both the hydropower developers and the environmental NGOs as a means to implement the WCD recommendations in a practical manner. Other major financiers, such as the World Bank, are engaged with the HSAF but retain their own (sometimes stricter) safeguards.

Table 2: The core values and strategic priorities from World Commission on Dams (WCD)

The five core values	The seven strategic priorities
Equity	Gaining public acceptance
Efficiency	Comprehensive options assessment
Participatory decision-making	Addressing existing dams
Sustainability	Sustaining rivers and livelihoods
Accountability	Recognising entitlements and sharing benefits
	Ensuring compliance
	Sharing rivers for peace, development, and security

58 There remain concerns that large reservoirs represent maladaptation to future climate change, because their size and expected longevity potentially puts them at risk of reduced efficiency with changing rainfall patterns. Additional risks are also faced with sedimentation, particularly if climate change results in more frequent flood events and increased erosion. This could clearly be an issue for older infrastructure that did not factor in climate changes. For infrastructure currently being planned or designed this raises the need for more flexible and scenario-based planning.

The need for multipurpose water storage

59 In some settings, the most effective way of developing storage is to serve multiple needs rather than for single purposes. Storage that serves the need for irrigation, domestic and industrial water supply, power generation and recreation can be more efficient and cost-effective than storage serving single purposes. It may also be essential to achieve reasonable economic rates of return, particularly where uses include domestic supply, which has a poor record on economic performance. Existing single purpose dams can be converted into multipurpose dams, for instance by retrofitting of turbines onto existing dams for hydropower development.

60 Multipurpose dams are not without their problems. Different uses of water have different and sometimes conflicting requirements in terms of storage, use and releases. For example, demands for energy during peak times may require water to be released from dams when irrigators require water to be stored for later use. Ensuring reasonable allocation between water-using sectors is critical and requires

careful management to deliver the full range of economic, social and environmental uses of water.

Transboundary rivers

61 Rivers shared by two or more countries represent a particular challenge to the development of water storage and hydropower infrastructure. The development of infrastructure on rivers shared with neighbours has the potential to increase tensions, although to date most evidence suggests that armed conflicts are very rare.[44] Building water storage and hydropower facilities on transboundary rivers offers real opportunities for cooperation and regional integration.

62 Governance of transboundary waters, and the infrastructure developed along them, is a very problematic issue for many shared rivers. Although there are some good examples, the majority of transboundary waters are not covered by legally binding treaties.[45] Whether or not treaties exist, development of major infrastructure along shared waters needs to apply the principles of equitable and reasonable use, an obligation not to do harm and ensuring prior notice and consultation, as outlined in the 1997 UN Convention on international waters.[46]

63 Building dams on transboundary rivers offers opportunities to improve the efficiency of storage and reduce wider environmental and social impacts. The development of infrastructure in a cooler, upper riparian country will reduce evaporative losses to a greater extent than those developed in warmer, lower riparian countries. Most upstream areas are less densely populated and the topography often results in much smaller flooded land areas and less displacement. Both the more temperate climate of most upstream countries and the potential for deeper and narrower reservoirs will also reduce the likely GHG emissions.

64 Investments on transboundary rivers are only realistic when systems are in place for sharing benefits between upper and lower riparians in a way that is considered equitable and reasonable. This also means that investment needs to be shared and not fall only on the upper riparians. There are already good examples of how this approach is being taken forward in the Nile Basin, where historically tensions between countries sharing waters have been high. Egypt, Ethiopia and Sudan have now agreed to undertake feasibility studies to build multipurpose storage on the Blue Nile in Ethiopia to provide energy, irrigation and flood management for all three countries.

65 Taking a benefit-sharing approach has the potential to develop strategic regional infrastructure that serves the needs of countries both within and outside the river basin in which the infrastructure is built. Examples include building of hydropower plants in the Congo that would be able to provide electricity to countries as distant as Egypt and South Africa, or indeed to southern Europe. The energy produced could also support much greater processing of raw materials within Africa, increasing added value and supporting macroeconomic growth. Such developments, however, need to deliver benefits for local communities in addition to

[44] International Water Event Database 1950-2005
[45] Pegasys 2009
[46] UN, 1997

macroeconomic benefits and be supported by good governance to allay concerns about energy security when relying on other countries for power production.

Making use of alternatives to constructed storage

66 Improving water storage capacity does not rely solely on the construction of infrastructure. Natural infrastructure - lakes, rivers, swamps and groundwater - are critical components of water storage. The more natural infrastructure available for water storage, the lower the need for constructed storage. Thus a large proportion of storage in the UK utilises natural infrastructure. In Sri Lanka, it has been estimated that the Muthurajawela Marsh gave an annual value of more than $5 million in flood mitigation, based on the costs of constructing flood management works from a nearby marsh.[47] In New York City, investments in the catchment to manage hydrological and biological processes in the Catskills Mountains meant that the city spent only 10% of the estimated US$7 billion costs of building upgraded water treatment facilities. Managing catchments effectively is also crucial and can lead to significant economic benefits through supporting local livelihoods, water quality improvements and flood risk management. Examples include the $145 million annual marginal value from the 10 wetlands in the Zambezi basin.[48]

67 Natural storage can be enhanced, for instance, through managed groundwater recharge. One consequence of the limited storage of surface water in some developing countries has been a reliance on unsustainable abstraction of groundwater to support irrigation and other productive uses, as seen in parts of India. Enhancing and managing groundwater storage will be an effective means of improving overall water storage and requires action to improve aquifer recharge, protect and manage groundwater stores effectively and the effective management of green water.[49]

68 Managed Aquifer Recharge (MAR) involves building infrastructure or modifying the landscape to encourage greater recharge. A variety of methods can be deployed, including spreading (e.g. infiltration ponds), in-channel modifications (e.g. sand storage dams), direct pumped recharge through boreholes or wells, bank filtration or rainwater harvesting. MAR not only increases the volume of groundwater recharge, but can also be a mechanism to treat contaminated wastewater, given the effectiveness of the sub-surface environment in attenuating, removing or diluting pollution. In addition to the above, specific actions can be taken to improve groundwater storage, for instance through hydrofracturing in karst aquifers. All improvements in groundwater recharge and storage must be complemented by more effective management to ensure that groundwater is used efficiently, and by protection to reduce the potential for water quality degradation.[50]

Other strategies for improving efficiency of water use

69 A further critical component of any strategy to maximise the availability and use of water is demand management to ensure that water is used efficiently and effectively. Demand management covers a wide range of actions, from technology

[47] Emerton et al 2004
[48] Ibid
[49] World Bank 2009b
[50] See Schmoll et al 2006 for an in-depth discussion

selection, allocations between different water using sectors, pricing, legislation and regulation. Experience shows that demand management interventions must be tailored to particular cultures and situations.[51]

70 Alternatives to water storage include the reuse of wastewater and the use of more marginal water resources – for instance through mining fossil water or desalination. Most of these have important environmental impacts. In the case of desalination, there are concerns over GHG emissions because of the high energy needs. Unless properly implemented and carefully regulated, there are public health concerns over transmission of pathogens from wastewater reuse. Wastewater re-use is also a source of GHG emissions, both from the treatment process but also through releases of methane and nitrogen dioxide.[52] There has been limited quantification of GHG emissions from sanitation to date, a problem that a number of key commentators have noted needs to be addressed.[53]

71 Other alternatives include the use of virtual water and virtual storage (essentially political decisions around the use of scarce resources) as a means of valuing the importance of water in global trade.[54] Virtual water as a concept has been in existence for some time, but has yet to translate into a globally agreed framework for action on managing scarce waters.

72 There has also been increasing interest in quantifying water footprints of countries and industries as a means to understanding and managing the impact on global water resources. This is particularly relevant where countries with limited water resources produce water intensive products that are exported to wealthier, and often wetter, countries. However, estimates of water footprint must be set within the context of the impact in the location – for instance, this will vary with available water resources, the benefits accrued by poor people from growing and producing goods with a local water footprint and so forth. Without such a context, water footprints could result in perverse outcomes that damage poor people. It is useful that industries, such as brewers, are actively looking at their local and international water footprints and using this to reduce their environmental impact, but this should also be complemented by wider activities to improve water resources management.[55]

73 A further trend is for wealthy countries, and their private sectors, to lease or buy land in other countries to grow food or biofuels. Recent work[56] has identified China, South Korea, Saudi Arabia, Qatar and United Arab Emirates as states providing foreign direct investment in land. Recipients include African countries (Sudan, Ethiopia, Madagascar and Mozambique), and Asian countries (Pakistan, Kazakhstan, Cambodia, Laos, Philippines and Indonesia) and parts of Europe (e.g. Ukraine). It is also noted that significant private investment from Europe and North America also occurs, but often receives much lower media attention. These land deals can be significant. For instance, in Sudan the 2002 Special Agricultural Investment Agreement granted Syria a 50-year lease over a land area of about

[51] Acreman et al 2009
[52] Bogner et al 2007
[53] Bates et al 2008, Bogner et al 2007
[54] Allan 1998
[55] SABMiller 2007
[56] Cotula et al 2009

12,600 hectares. In Ethiopia, Ghana, Madagascar and Mali, foreign direct investment in land from 2004 to 2009 was $422.3 million (or 88% of total investment) and in spatial terms accounted for 1,402,727 hectares (or 78% of total investment).

74 Foreign investment in land can provide an important contribution to the food, virtual water and energy security of the investing countries. However, countries such as Sudan are often also facing increasing water stress, thus land leases to other countries, or international corporations, may have major implications for local water rights, particularly for marginalised groups. On the other hand, such investments may offer an important development opportunity -- by leveraging flow of capital and expertise - that could be used to address chronic underinvestment.[57] This could only be achieved if business models are set up to ensure such outcomes are secured. There is a need to more fully understand the potential impacts of such leases and how better deals can be constructed that yield benefits to both sides.

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[57] Ibid

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