Agricultural water storage in developing countries

Matthew McCartney[1] and Vladimir Smakhtin[2]

[1] International Water Management Institute, PO Box 5689, Addis Ababa, Ethiopia
[2] International Water Management Institute, PO Box 2075, Colombo, Sri Lanka

Abstract

This paper addresses the need for agricultural water storage in developing countries. Rainfall variability is an important factor in development and translates directly into a need for water storage. In many places rainfall variability is likely to be amplified (even where the total amount of rain increases) as a result of climate change. If planned and managed correctly, various forms of water storage can increase water security and agricultural productivity thereby contributing to improved livelihoods and reduced rural poverty. However, ill-conceived water storage is a waste of financial resources and, rather than mitigate, may aggravate negative climate change impacts. Systems that combine complementary storage options are likely to be more adaptable and acceptable than those based on a single storage type. More systematic planning and management is required to avoid the mistakes of the past and to ensure more effective and suitable storage systems for the future.

Key words: climate change, rainfall variability, water storage

Introduction

For many of the world's poorest people, rainfall variability is a major impediment to their livelihoods. The inability to predict and manage rainfall, and consequent runoff, variability is a key contributing factor to their food insecurity and poverty. Frequently periods with too much water are followed by periods with too little and intermittent water scarcity is often a direct consequence of rainfall variability. This is likely to be exacerbated by climate change (Boko et al., 2007). Consequently water management will become much more difficult and, without doubt, many poor farmers will become even more vulnerable than they are currently. A recent study indicated that, though there will be considerable variation across the continents and between crops, climate change may result in a decline in mean yield of approximately 8% across both Africa and South Asia (Knox et al. 2011).

In sub-Saharan Africa 94% of agriculture is rain fed. In Asia, which contains the highest proportion of irrigated agriculture in the world, 66% is rain fed. Rainfall in both regions is highly unpredictable with extreme variations, not just seasonally but also between years. Droughts occur frequently and agricultural yields are often constrained by insufficient water. Lack of predictability both in the amount and timing of rainfall makes rain fed farming extremely difficult. In the absence of storage, if rains fail or simply come too early or too late the entire agricultural cycle can be disrupted.

Furthermore, national economies, highly dependent on rain fed agricultural production, are exceedingly vulnerable to fluctuations in rainfall. Although there are opposing views, there is little evidence that water scarcity by itself is a major factor limiting economic growth in most countries (Barbier, 2004). However, in contrast, rainfall variability has been shown to be a significant factor in economic growth (Brown and Lall, 2006). For example, it is estimated that unmitigated hydrological variability currently costs the economy of Ethiopia more than one-third of its growth potential. As in much of Africa and Asia, the country's lack of hydraulic infrastructure and limited capacity to manage water resources undermine attempts to manage variability (World Bank, 2006).

Under these circumstances, even relatively small volumes of water storage can, by safeguarding domestic supplies and by supporting crops and/or livestock during dry periods, significantly increase agricultural and economic productivity and enhance people's well-being. For millions of smallholder farmers, reliable access to water is the difference between self-sufficiency in food and hunger. Consequently, it has an important role to play in poverty reduction, sustainable development and adaptation to climate change. However, throughout Africa and Asia the climate and socio-economic conditions vary significantly and will be affected by climate change in a myriad of diverse ways. Hence, storage options need to be carefully tailored to suit exact needs.

This paper focuses on physical water storage. It argues for the need to rethink water storage in a future of rapidly rising population and increasing uncertainty related to climate change and for better planning and management of the full range of agricultural water storage options available.

The water storage continuum

When it comes to storage, water resource planning focuses today primarily on large dams. Indeed, many of the world's 50,000 large dams were built for irrigation (ICOLD, 2003). However, for agriculture, dams are just one of a range of possible water storage options. In fact agricultural water storage can be considered a *continuum* of surface and subsurface options which include natural wetlands, enhanced soil moisture, groundwater aquifers, ponds and small tanks, as well as large and small reservoirs. The effectiveness of these options varies, but each of them provides a buffer during dry periods. Broadly, the deeper and/or the larger the storage, the more reliable the water supply it can help ensure; and the more 'natural' it is, the less complex and less costly it is to develop, manage and access (Figure 1). However, none of these options is a *panacea*. All have strengths and weaknesses which depend, in part, on their inherent characteristics (Table 1) but they are also affected by site-specific conditions and the way the storage is planned and managed. Consequently, the impact of different types of storage on poverty can vary significantly, with some types being much more effective in certain situations than others (Hagos et al., 2010).

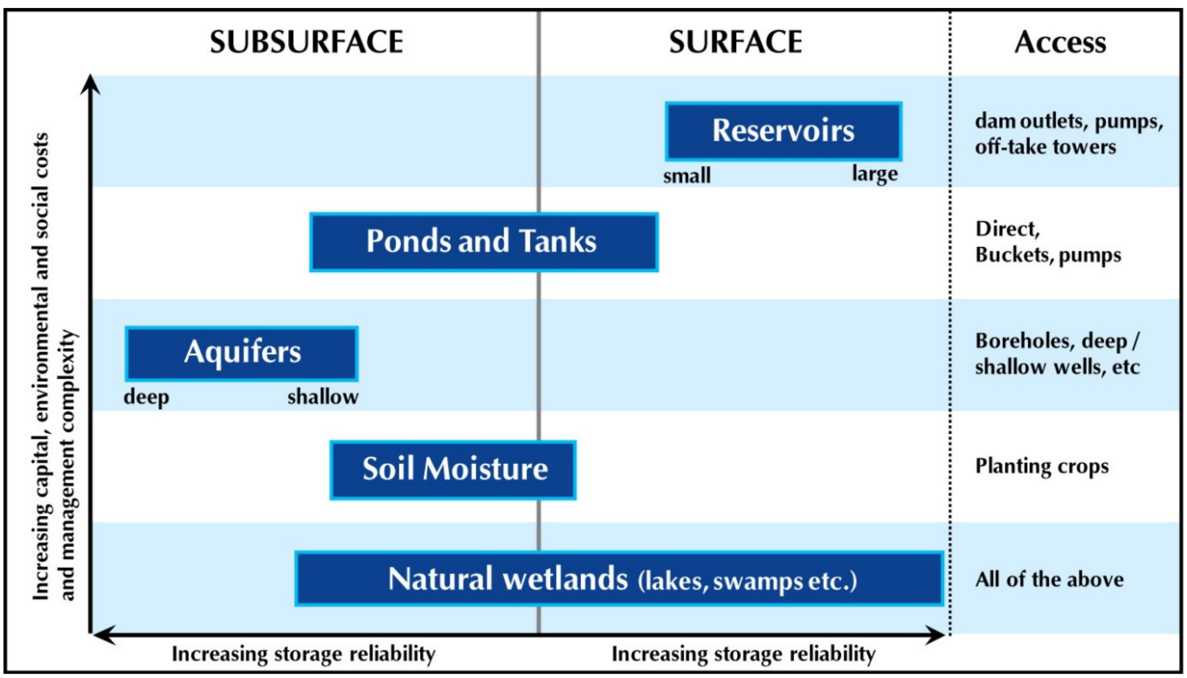

Figure 1: Conceptualization of the physical water storage continuum.

Table 1: *Comparison of different agricultural water storage options and the possible implications of climate change*

	Inherent Benefits	Inherent Risks	Possible risks from climate change	Possible social and economic implications
Natural wetlands	• Water storage is provided as an ecosystem service without the need for costly infrastructure	• Excessive utilization of water in, or upstream of, natural wetlands may undermine other ecosystem services	• Reduced rainfall and runoff inputs resulting in desiccation • Higher flood peaks resulting in wetland expansion and flooding of fields/homes • Improved habitat for disease vectors	• Increased failure to provide community/household needs • Loss of water dependent ecosystem services • Increased risk of water borne diseases
Soil moisture	• Generally low cost options that can be implemented by individual farmers and communities	• Where land holdings are extremely small, farmers may be unwilling to use precious land for these interventions. • Limited storage - will not provide water for more than a few days without rain	• Reduced infiltration or water logging/erosion resulting from modified rainfall intensities and durations • Depleted soil moisture arising from higher evaporative demand • Reduced soil quality (including water holding capacity) resulting from modified rainfall and temperature	• Decreased productivity – more frequent crop failures and reduction in yields
Groundwater	• Evaporation losses are low or non-existent. • Multi-year storage that is largely decoupled from seasonal variability	• Detailed geological information is required to locate wells and estimate yields • Depending on geology, may contain high concentrations of toxic chemicals (e.g. arsenic)	• Reduced recharge resulting from modified rainfall intensities • Reduced recharge resulting from land-cover modification and increased soil moisture deficits • Saline intrusion in near-coast aquifers	• Falling water levels make it increasingly costly to access groundwater • Poor water quality make groundwater unsuitable for use
Ponds and Tanks	• Generally relatively low cost options, implementable by communities and NGOs.	• High evaporation losses • Water contamination (e.g. from water flowing in and livestock entering the water) • Risk of siltation • May provide breeding habitat for disease vectors	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing rates of pond/tank depletion • Infrastructure damage caused by larger floods • Improved habitat for disease vectors • Increased risk of eutrophication, salinization and siltation	• Increased failure to provide community/household needs • Increased labor requirements and costs to repair structures • Increased risk of water borne diseases
Reservoirs	• Large volumes of water stored, which can be used for multiple purposes. • The only option that enables production of electricity and can offer protection from floods	• Significant capital investment • Often displacement of large numbers of people • Significant environmental and social impacts arising from changes to river flows • May provide breeding habitat for disease vectors	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing the rate of reservoir depletion • Infrastructure damage caused by larger floods • Improved habitat for disease vectors • Increased risk of eutrophication, salinization and siltation	• Increased failure to meet design specifications (irrigation and hydropower etc.) • Increased costs due to the need to redesign infrastructure (e.g. spillways) • Increased risk of water borne diseases

With the exception of large dams, in most places past storage development has occurred in a piece-meal fashion, largely through local initiatives and with minimal planning. It is generally characterized by the absence of data or poor data management, insufficient communication with local stakeholders and water resource authorities, and lack of any integrated planning (Johnston and McCartney, 2010). In some cases (e.g. where reservoirs are silted, boreholes are dry and ponds have caused severe negative health impacts) it is clear that, despite the best of intentions, the lack of information and planning has resulted in less than optimal investments. For example, of around 4,000 rainwater harvesting ponds constructed in the Amhara region of Ethiopia between 2003 and 2008, the majority were not functioning by 2009 (AMU, 2009). Failures have been attributed to a range of factors, including: poor site selection, poor design, technical problems (e.g. failure of lining materials leading to seepage) and lack of commitment by communities for maintenance (Eguavoen, 2009).

The impact of climate change on water storage options

To date, there has been very little systematic analysis of alternative storage options and the role that these alternatives may play in poverty reduction and climate change adaptation. Climate change will increase rainfall variability and increase average temperatures so affecting both the supply and the demand side of the irrigation equation. In some areas, annual precipitation will decline, decreasing river flows and groundwater recharge (Figure 2). In other places, total precipitation may increase but it will fall over shorter periods with greater intensity so that dry spells are longer. Higher temperatures will increase evaporative demand so that crops will use more water. Although the effects will vary from place to place, farmers will generally need to adapt to less soil moisture and higher evaporation. This means larger volumes and more frequent use of supplemental water (Figure 3).

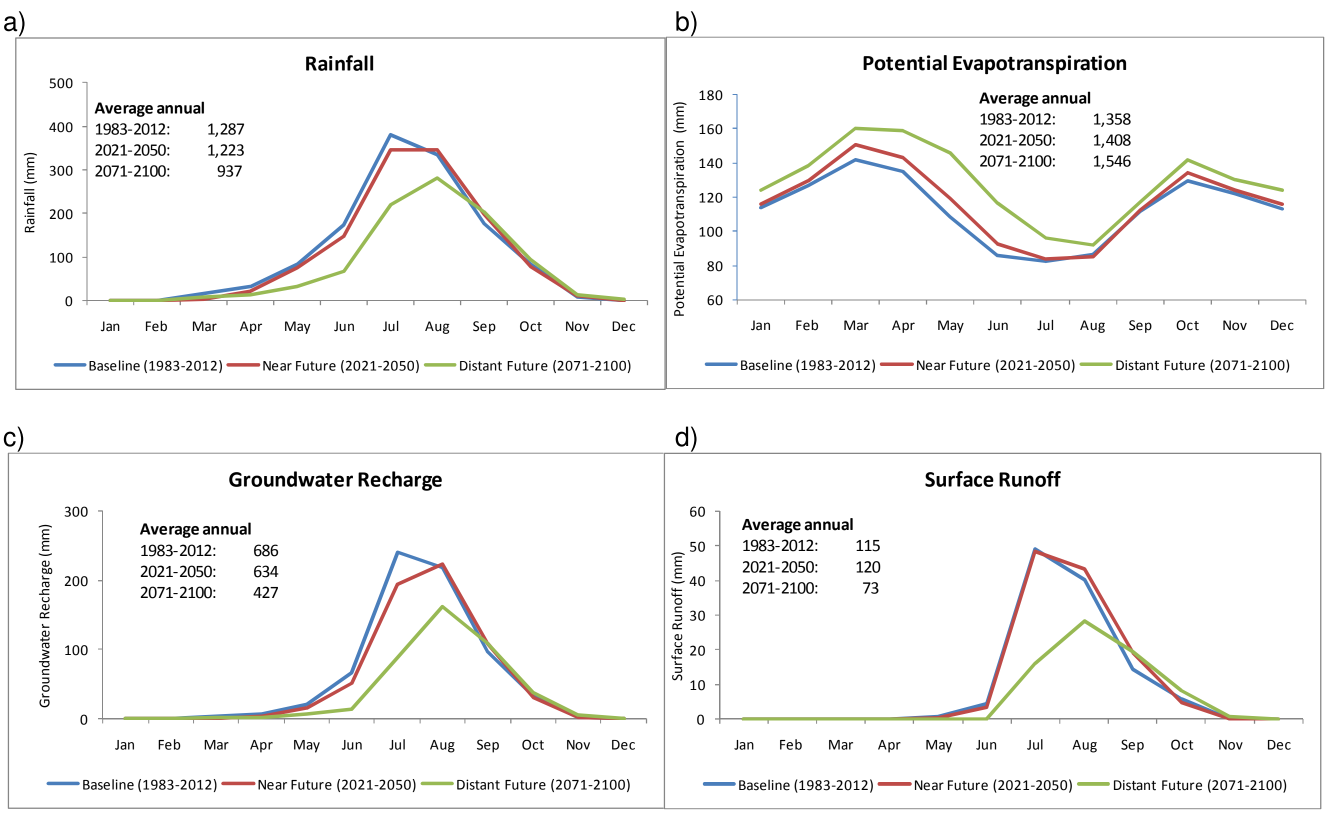

Figure 2: Example of possible changes in mean monthly a) rainfall, b) potential evapotranspiration, c) groundwater recharge and d) surface runoff, in the Lake Tana sub-basin of the Blue Nile, Ethiopia (derived using the CCLM regional dynamic model with AIB emissions scenario)

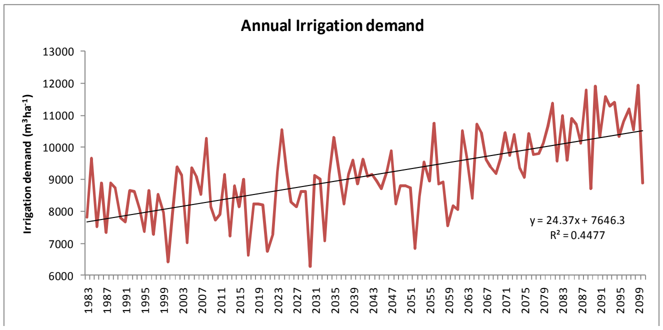

Figure 3: Example of possible change in irrigation demand (1983-2100) in the Lake Tana sub-basin, taking into account changes in precipitation and evaporation demand (derived using data from the CCLM regional dynamic model with AIB emissions scenario)

By modifying both water availability and water demand, climate change will affect the need, the performance and the suitability of different water storage options. All storage options are potentially vulnerable to the impacts of climate change (Table 1). In some situations certain storage options will be rendered completely impracticable whilst the viability of others may be increased. For example, climate change may have significant impacts on soil moisture. In arid regions, the percentage change in soil moisture can be greater than the percentage change in rainfall (Chiew et al., 1995). Hence, longer dry periods may mean that soil water conservation measures fail to increase and maintain soil moisture sufficiently to prevent crop failure. Groundwater recharge may be reduced if rainfall decreases or its temporal distribution changes in such a way that infiltration declines. Many aquifers near the coast will be at risk from saltwater intrusion as a result of sea level rise. Ponds and tanks may not fill to capacity or the frequency of filling may be reduced so that they are unable to provide sufficient water for irrigation. Changes in river flows may mean that reservoir yields and, hence, assurance of water supplies decline. Storage in ponds, tanks and reservoirs may also be reduced more rapidly as a consequence of increased evaporation and/or greater sediment inflows. Furthermore, both large and small dams as well as ponds and tanks may be at increased risk of both eutrophication and flood damage. Natural wetlands also face a range of climate change related threats arising from changes in hydrological fluxes (i.e., surface water and groundwater flows, evaporation, etc.) as well as increased anthropogenic pressures resulting directly and indirectly from climate change.

In all cases the externalities associated with different storage types are also likely to be affected by climate change. For example, malaria transmission in the vicinity of some ponds, tanks and reservoirs may increase as a result of modified rainfall patterns and higher temperatures; though the extent to which this comes to pass is dependent on a large number of complex factors (including the effectiveness of malaria eradication programs), not just the creation of suitable vector habitat (Gething et al. 2010). Impacts of dams on downstream river flows - and the livelihoods of people depending on those flows - may be exacerbated by climate change resulting in the need to release a greater proportion of water stored in reservoirs to maintain the riverine environment and ecosystem services on which people depend. These, and similar factors, will affect both the effectiveness and suitability of different storage options in any specific situation.

Re-thinking water storage

Climate change, in conjunction with population growth, will increase the importance of water storage in many developing countries. Appropriate storage will reduce peoples' climate vulnerability by increasing water and food security as well as adaptive capacity (Figure 4). However, all water storage options are also potentially vulnerable to the impacts of climate change (Table 1) and, as water resources are increasingly utilized and climate variability increases, planning and management will become ever more difficult. In all situations maximizing the benefits and minimizing the costs of water storage options will, as in the past, require consideration of a wide range of complex and inter-related hydrological, social, economic and environmental factors. However, in a departure from the past, future planning needs to be much more integrated across a range of levels and scales, with much greater consideration of the full range of possible options. To date, although there have been many studies of the effects of climate change on hydrological regimes, there has been very little systematic research into the potential impacts of climate change on different water storage options, or how to plan and manage water storage under a changed climate. Despite the high levels of uncertainty it is important that climate change projections and scenarios are used to improve planning of all types of water storage.

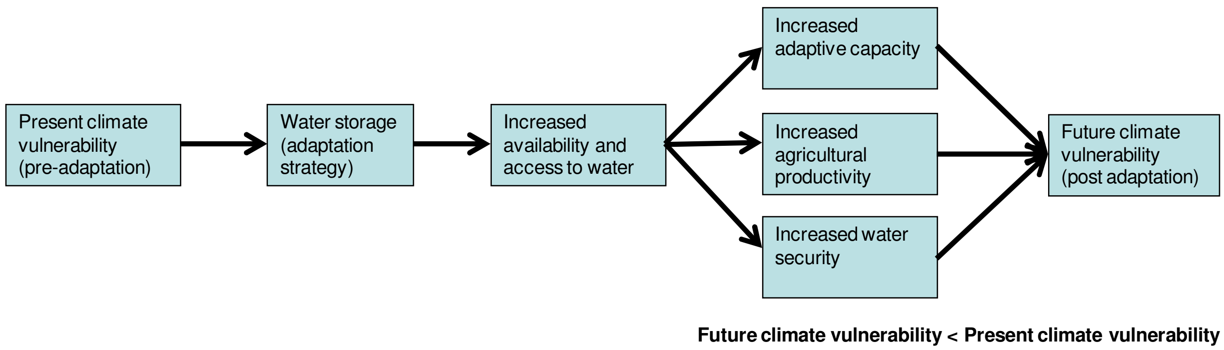

Figure 4: Water storage as an adaptation strategy to reduce climate vulnerability

A key to planning water storage is the determination of current and future needs, making appropriate choices from the suite of storage options available. In any given situation this requires understanding both biophysical and socio-economic issues that influence the *need*, *effectiveness* and *suitability* of the different water storage options. In the past, there has generally been little explicit consideration of these issues, even in large dam construction projects. For storage options other than large dams, where planning is generally less formalized, needs are usually regarded as self-evident and alternative options are rarely considered.

The details of climate change are unknown so planning must allow for great uncertainty. Future water storage must be more reliable and resilient and less vulnerable than in the past. All water storage options have strong comparative advantages under specific conditions of time and place. Hence, storage "systems" that combine and build on complementarities of different storage types are likely to be more effective and sustainable than those based on a single option. Combinations of surface and groundwater storage or large and small reservoirs, can dampen mismatches between supply and demand, and are already used successfully in some places. For example, conjunctive use of surface and groundwater is becoming an increasingly common practice in Tamil Nadu in India and has resulted in increased crop yields (Keller et al, 2000).

The optimal combination of storage options will vary depending on local biophysical and socio-economic circumstances. However, there will rarely be an ideal combination and in most instances trade-offs will need to be considered. Without a greater understanding of which types of storage are best suited for specific agro-ecological and social conditions, and in the absence of much more systematic planning, it is probable that many water storage investments will fail to deliver intended benefits. In some cases they may even worsen the negative impacts of climate change. To avoid inappropriate storage options, future planning needs to be much more evidence-based. To this end, studies are needed to better understand: the social and environmental impacts of different storage options; the implications of scaling up small-scale interventions; and, very importantly, the reasons for the successes and failures of past interventions. Systematic methods for evaluating the suitability and effectiveness of different options, both individually and within larger systems, need to be developed.

Conclusions

Rainfall variability is an important factor in development and translates directly into a need for water storage. Across many of the developing countries of Africa and Asia, existing variability and insufficient capacity to manage it, lies behind much of the prevailing poverty and food insecurity. These continents are predicted to experience the greatest negative impacts of climate change. By making water available at times when it would not naturally be available, water storage can significantly increase agricultural and economic productivity and enhance the well-being of people.

In the past, water resource planning has tended to focus on large dams but dams are just one of a range of possible water storage options that need to be considered. The storage type to be used in any given location must be fit for purpose. Each of the variety of options can, under the right circumstances, make important contributions to poverty reduction. However, none is a panacea. All have costs as well as benefits and in any given location the poverty reducing impact of different water storage options varies.

Future population growth, in conjunction with climate change, will increase the importance of water storage in many developing countries. However, as water resources are increasingly utilized and climate variability increases, planning will become even more difficult. Without greater understanding of which types of storage are best utilized under specific agroecological and social conditions and in the absence of much more systematic planning, there is the risk that many water storage investments will fail to deliver intended benefits.

References

Arba Minch University (AMU) 2009. Inventory of water storage types, their distribuiton and characteristics in the Abbay River Basin. Unpublished report prepared for IWMI. Addis Ababa, Ethiopia.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo R. and Yanda, P. 2007: Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press,Cambridge UK, 433-467.

Chiew, F.H.S., Whetton, P.H., McMahon, T.A. and Pittock, A.B.1995. Simulation of the impacts of climate change on runoff and soil moisture in Australian catchments. Journal of Hydrology 167, 121-147.

Eguavoen, I. 2009. *The aquisition of water storage facilities in the Abay River Basin, Ethiopia*. ZEF Working Paper Series, 38: Bonn, Germany: Center for Development Research

Gething, P. W.; Smith, D. L.; Patil, A. P.; Tatem, A. J.; Snow, R. W. and Hay, S. I. 2010. Climate change and the global malaria recession. *Nature* 465: 342-346.

Hagos, F.; Gayathri, J.; Awulachew, S.B.; Loulseged, M. and Yilma, A.D. 2010. Poverty impacts of agricultural water management technologies in Ethiopia. Water Policy (forthcoming)

International Commission on Large Dams (ICOLD) 2003. World Register of Dams, 2003. International Commission on Large Dams, Paris, France. 340 pp.

Johnston, R. and McCartney, M.P. 2010. Inventory of Water Storage Types in the Blue Nile and Volta River Basins Colombo, Sri Lanka: International Water Management Institute (Working Paper 140) doi:10.5337/2010.214 48pp.

Keller, A.; Sakthivadivel, R. and Seckler, D. 2000. *Water scarcity and the role of storage in development.* Colombo, Sri Lanka: International Water Management Institute (IWMI). (IWMI Research Report 39) 27pp.

Knox, J.W., Hess, T.M., Daccache, A. and Perez Ortola, M. 2011. What are the projected impacts of climate change on food crop productivity in Africa and S Asia. DFID Systematic Review. Final report. 71 pp.

World Bank, 2006. Ethiopia: managing water resources to maximize sustainable growth: A World Bank Water Resources Assistance Strategy for Ethiopia. The World Bank Agriculture and Rural Development Department. Washington DC USA