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Issues Paper on

Water for food

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At its 13th session held in May 2010, the Commission on Science and Technology for Development (CSTD) selected "Technologies to Address Challenges in Agriculture and Water" as its priority theme for the 2010-2011 inter-sessional period. To contribute to a further understanding of the issues and to assist the CSTD in its deliberations at its 14th session, the UNCTAD secretariat will convene a panel meeting in Geneva, from 15 to 17 December 2010.

This paper presents key issues related to the role of science, technology and innovation in addressing challenges in water.

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Water for food – Innovative water management for food security and poverty alleviation

Modern irrigation is one of the success stories of the 20th century. As the world's population doubled irrigated farming expanded from 40 million ha to over 275 million ha today – a six-fold increase. This technological revolution increased food production through improved crop yields and enabling farmers to grow additional crops each year. China, India, Indonesia, and Pakistan together account for almost half the world's irrigated area and they rely on irrigation for more than domestic food production.

But the world's population continues to grow, mostly in the LDCs, and so do concerns about food security and the availability of water to grow crops – already global food production accounts for 70 percent of all water withdrawn from rivers and aquifers. Climate change will only make matters worse.

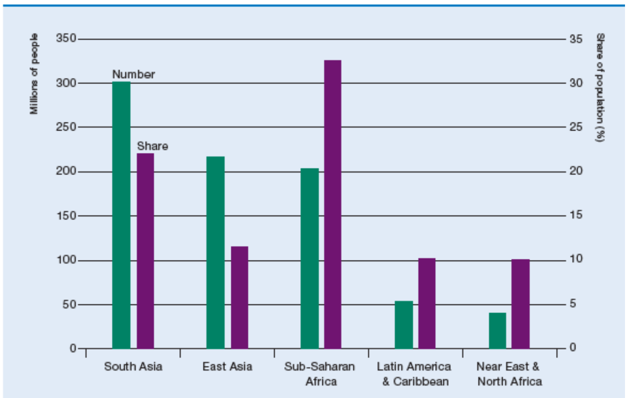
Can technology again produce solutions that can meet this challenge of feeding a growing, disadvantaged population by producing more food but with fewer resources? This paper reviews the water-food-poverty nexus and examines the role that technology might play in achieving world food security and water security.

1 Agriculture and water

Agriculture is central to food security and economic growth in developing countries and provides the main source of livelihood for three out of four of the world's poor (Wheeler and Kay, 2010). But food production requires substantial amounts of water. Globally, agriculture accounts for 70 percent of all water withdrawn from rivers and aquifers. Several regions are already facing acute physical water scarcity. North Africa's renewable water resources are only 286 m^3/capita/year, South Asia has only 1,113 m^3/capita/year, and the drier regions of sub-Saharan Africa (SSA) have only 1,255 m^3/capita/year (FAO, 2010). Water scarcity is one of the most pressing issues facing humanity today. More than 1.4 billion people live in water stressed rivers basins and by 2025 the number is expected to reach 3.5 billion. Moreover today more than 20 percent of the world's rivers run dry before reaching the sea.

But this situation is set to get worse. Global food demand is expected to increase by as much as 70 percent by 2050 (FAO, 2006) as the world's population rises from 6.5 billon to 9 billion and diets change as a result of socio-economic improvements, particularly in OECD and BRIC countries. Currently more than 1 billion people live below the US$1 a day poverty line and 925 million, mostly in the LDCs in Asia and Africa, are undernourished (Figure 1). Global poverty is highly regionalized, rural, and disproportionately female (Rauch 2009). Most rely on agriculture for their livelihood on smallholdings often less than 1ha in area. Urbanisation is changing this picture. Men are drawn to the cities to seek alternative incomes and this is feminizing the rural economy as well as creating urban agriculture.

Food demand in LDCs will double as the population in the developing world reaches 7.5 billion by 2050 – 2.2 billion in south Asia and 5 billion in SSA. Most LDC governments look to their rural communities to produce more agricultural products but those same communities are impoverished, their productivity is low, as is their resource use efficiency.

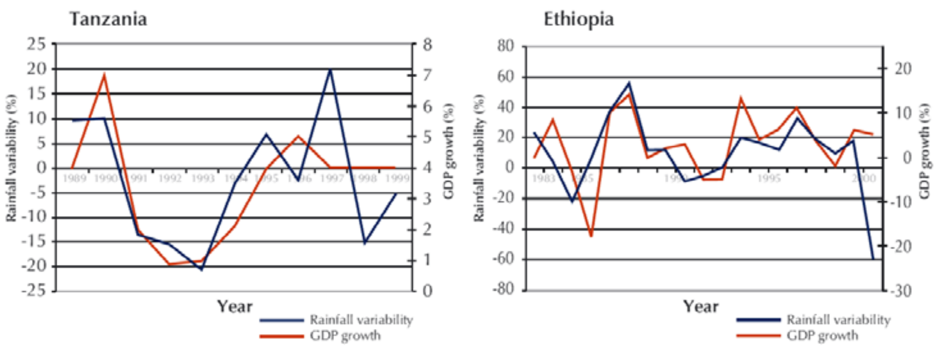


- Figure 1 Share and number of undernourished people by region 2000-2002 (CA, 2007)

The burden of the poor is made worse by the changing nature of rural life – the new 'rurality' (Rauch 2009). Globalisation is transforming the marketplace; new patterns of poverty are emerging as livelihoods adjust; reforms in governance and rural service systems are changing the nature of institutions. All these issues create uncertainty and risk and are likely to have a disproportionate impact on the rural poor and their ability to access and make good use of limited water resources.

Box 1: The link between GDP and rainfall

Such is the fragility of some developing countries that drought impacts directly and severely on economic growth. In Ethiopia for example, 75% of the population depend on small scale and rainfed cropping. During the famine in the early 1990s, rainfall was well below average and economic growth plunged hitting agriculture the hardest (see Figure). A similar situation is observed in Tanzania and is common to other sub-Saharan countries (World Bank, 2006a; 2006b).



2 A 'perfect storm'?

Water resources are already under stress in many parts of the world yet the demand for water will substantially increase in order to meet the additional requirements for food and energy crops. Competition for water will inevitably intensify between the different water using sectors – municipalities, industry, agriculture and the environment. There are increasing pressures to divert land away from food production towards energy crops. Energy consumption is expected to rise significantly as more fertilizers are needed to grow additional crops. The dilemma is that land and water resources are not increasing, rather there are concerns that available water resources will decrease in some critical regions as a result of changes in climate and the available land area for agriculture will continue to decline because of land degradation and urbanisation.

Bennington (2009) brings all these issues together in what he predicts as the 'perfect storm' as these 'dark clouds' converge towards 2030 and beyond to produce problems far greater than the sum of the parts. As most of the population increase will be among those already disadvantaged in the developing world, he predicts increased competition for food, water, and energy; food prices will rise; and more people will go hungry.

2.1 Climate change – another dark cloud

Climate change is yet another 'dark cloud' on the horizon that will impact on water resources which in turn will impact on agriculture and hence food production (Bates, 2008). Globally, agriculture contributes about 18% of greenhouse gas (GHG) emissions, largely through livestock production, land use changes, paddy rice production, and the manufacture and use of agro-chemicals (Smith et al., 2007).

Rising global temperatures will intensify the hydrological cycle resulting in drier dry seasons and wetter rainy seasons, greater uncertainty, and subsequent heightened risks of more extreme and frequent floods and droughts. Across most climate change scenarios, the IPCC project an increase in annual mean rainfall in high latitudes and South East Asia and decreases in Central Asia, the southern Mediterranean, and sub-Saharan Africa. Greater hydrological variability will have wide ranging consequences on livelihoods, ecosystems, and human societies, particularly in semi-arid and arid areas where the poorest nations are concentrated.

Generally, increasing rainfall will simplify water resource problems, but changes in seasonality and intensity may still create problems. Decreasing rainfall, particularly in areas that are already water-short, will have very serious and often disproportional impacts on surface and groundwater supplies. Most existing infrastructure was designed on the assumption that historical weather records provided a good guide to the future. With climate change, yields may be much lower than expected, and risks of flood damage much greater. Melting glaciers will initially increase but then strongly decrease dry-season water supplies to one-sixth of the world's population. Sea level rise will extend the areas of groundwater and estuaries affected by salinisation.

Increasing food production will in turn increase GHGs and this will impact significantly on food security. It will affect food production and availability, the stability of food supplies, access to food, and food utilization (Schmidhuber and Tubiello, 2007). It will counter the drive for increased production in many LDCs and hinder progress to meeting MDG I – reducing by half the portion of people suffering from hunger by 2015). It will increase global and regional inequality in food provision and reduce future agricultural production particularly in tropical regions where many of the poor live (Smith *et al*, 2007). Inequality will increase because many of the poorest producers farm in locations where the climate is already marginal for crop production and will become even less suitable in the future.

Those farmers with limited access to agricultural knowledge and new technology will be less able to adapt their farming practices to a changing climate. For these reasons, the poorest farmers are those most vulnerable to the impacts of climate change (Parry *et al,* 2005).

2.2 Some 'white' clouds

All this sounds rather gloomy and there are those who disagree with these predictions. However, the arguments are more to do with the timing of events rather than the nature of the serious crisis the world faces towards the middle of this century. But there are some white clouds as well as the dark ones. In the second half of the 20^{th} century world food production more than doubled in response to a doubling of the population. Agricultural water productivity has risen steadily over the past 40 years and irrigated agriculture is one of the success stories of the 20^{th} century. The large irrigation schemes in India, China, Pakistan, and Indonesia have fed many millions of people who would have otherwise starved. The 'green' revolution, in the 1960s and 1970s, which was essentially based on rice irrigation, lifted Asia out of an imminent hunger crisis although the price was heavy in terms of water and energy.

In the 1990s the importance of water for ecosystems and their resilience became well recognised as did the need for a balance to be struck between water for food, for people, for industry, and for the environment. In response to this, Conway (1997) suggested that the next step for agriculture was a 'green-green' revolution founded on the principles of environmental sustainability. Falkenmark (2006) further introduced the idea of a third 'green dimension' which focuses attention on upgrading rainfed agriculture. Indeed, many developing countries still have a large, untapped endowment of rainfall that can be harnessed using conservation farming practices and supplementary irrigation has a significant role to play in those areas where there are sufficient water resources.

So what does all this mean for global food security? Simply put, the world must produce 70 percent more food – safe food, on less land, with less freshwater, using less energy, fertilizers, and pesticides – by 2050 whilst at the same time bringing down sharply the level of GHG emissions emitted globally (HOC, 2009). It is a daunting challenge but one that can and must be met. In this paper we focus on water and the role that water technologies can play in meeting this challenge whilst recognizing that it is only one piece, but a crucial one, in the complex jigsaw of global food security.

3 We have enough water but …

Water is crucial for growing food – without it crops simply cannot grow. Crops consume large amounts of water, so do we have enough to meet future demand or will supplies run out?

Of the 110,000 km^3 of rain that falls annually on the earth's surface, 36 percent ends up in the sea; forestry, grazing lands, and fisheries, and biodiversity consume 57 percent; towns, cities, and industry use just 0.1 percent (11 km^3); while agriculture consumes 7 percent (7,130 km^3) (CA,2007). Some 22 percent of agriculture's water consumption (1,570 km^3) is 'blue water' – that is water withdrawn from rivers, streams, and groundwater for irrigation purposes. Most of agriculture's water consumption (5,560 km^3) is 'green water' – that is water available to crops from rainfall stored in the soil root zone.

Predicting future water demand is fraught with difficulties. Even those made less than 10 years ago have already been proved inaccurate because no one predicted the rise in energy prices nor the world recession and the impact these would have on food prices. The impacts of climate change too are now only beginning to unfold as are the stresses of population growth and water scarcity. But the simple answer to the question is – yes we have enough water but only if we act now to improve how water is used, particularly in agriculture which is the main consumer (CA, 2007). What is certain is that the future of food security and water security are inextricably connected.

Global agricultural water consumption is expected to rise from 7,130 km^3 to 8,515 km^3/yr by 2050 (CA, 2007). This is based not just on predictions of population increase but also on improving socio-economic conditions and nutrition both of which demand more water. The greatest change over the past 30 years has been the shift away from starch based diets to livestock based meat, eggs, and dairy products to a point were livestock products account for about 45 percent of the global water embedded in food products. Growth has been most rapid in East and Southeast Asia, particularly China, and in Brazil. Today, China alone accounts for 31 percent of world meat production and India produces 15 percent of the world's milk. So predictions are based on anticipated changes in cropping and diets, likely improvements in water productivity in both rainfed and irrigated agriculture, increases in cropped area, the expansion of agricultural trade from water-rich to water-poor countries, and technology transfer through the efforts of national and international research centres. Bruinsma (2009) produced similar predictions for 2050.

4 The rainfed-irrigation nexus

Agriculture is a mix of rainfed and irrigation farming. Globally rainfed farming is the world's most common farming system practiced on 80 percent of cultivated land and accounting for 60 percent of the world's food production. In areas of high and reliable rainfall such as in the northern Europe, crop yields are good and production is reliable. But in areas of low, erratic, and unreliable rainfall, such as the drier regions of Africa where many of the poor and disadvantaged live, crop yields are low and uncertain – grain yields average only 1 ton/ha and water consumption is high because of the high evapotranspiration rates between 2,000-3,000 m^3/ton of crop. This is roughly twice the global average of 1,000-1,500 m^3/ton of crop. However, the ability of most smallholder farmers to make better use of rainwater is not good. It is estimated that the fraction of rainfall used for crop transpiration is low, from 15-30 percent (Wallace, 2000) and sometimes it is as low as 5 percent (Rockstrom and Falkenmark, 2000).

Irrigation globally, is only practiced on 270 million ha – 20 percent of the cultivated land area. But its contribution to global food production is immense – more than 40 percent of the world's food production. About 80 percent of the irrigated area is in Africa, Asia, Latin America, and the Caribbean and there is still room for expansion, particularly in sub-Saharan Africa in places where there is sufficient water available.

Irrigated agriculture offers great potential for growth and poverty reduction. In the right circumstances, irrigation can reduce the risks associated with the unpredictable nature of rainfed agriculture in dry regions and increase cropping intensities in humid and tropical zones by 'extending' the wet season by introducing effective means of water control. It provides a defence against droughts, which are predicted to occur more frequently as the climate changes. Irrigation can increase crop diversity, produce higher yields, enhance employment and lower food prices (IFAD, 2008). Indirectly it can stimulate input and output markets, stabilize output and economic activities thus providing substantial benefits across economic sectors.

But, like rainfed farming, there are concerns about water wastage. Wallace and Gregory (2002) suggest that in many schemes only 13-18 percent of water delivered is actually transpired by the crop. This 'inefficiency' is an overriding concern among those in irrigation but it may not be as serious as it at first seems. Not all water wasted is completely 'lost' and may in fact be a source of water for someone else, though the water quality may be degraded.

But rainfed and irrigation farming are not separate and distinct ways of growing crops – natural rainfall contributes to irrigation farming and irrigation is used to supplement inadequate rainfall. Agriculture exploits both blue and green water often at the same time, to meet crop water requirements. This approach to thinking about water is breaking down the traditional divisions between blue and green water and is shifting water resources planning from being only about runoff (blue water) to a process that values both blue and green water. This is the essence of 'rainwater management' or 'agricultural water management' (AWM) (Falkenmark, 2006).

4.1 In Asia[1]

In Asia, 700 million people subsist on less than US$1/day. They rely heavily on irrigation farming and accounts for 70 percent of the world's irrigated area, almost one third of the region's cropped land (Mukherji *et al*. 2009). Agricultural output has been largely technology driven. Many large irrigation schemes were built in the 1960s and 1970s to supply water to smallholders and this provided the engine to drive Asia's green revolution. This enabled the region to become food self-sufficient by providing timely and reliable water supplies, which in turn led to greater cropping intensities, high yielding rice varieties, and the use of fertilizers that pushed up productivity. But poverty still exists, and is particularly a problem in South Asia. By 2050 there will be an additional 1.5 billion in Asia, half of whom will still live in rural areas in spite of the increase in urbanization. Diets too are changing rapidly among the wealthier population as they turn to meat and milk based diets which require much more water than vegetarian diets. In East and Southeast Asia meat consumption has risen by almost 30 percent in the past 10 years (FAO, 2009) – a trend that looks set to continue.

Both land and water resources across the region are limited and, although there is rainfed farming, it is irrigation farming that is expected to deliver most of the additional food, mainly from existing irrigation systems through raising yields and the productivity of land and water resources. Some food is expected to come from trading in food grains. But the existing schemes, which once dominated agricultural production, are now in decline because of poor maintenance, salinity, and water logging. Investment in irrigation was discouraged because of lower food prices and poor rates of return. The result is that many of the large scale, centrally managed irrigation systems are in need of modernization to cope with modern farming practices and the changes in food demands. Efforts to rehabilitate them are mixed.

[1] South Asia: India, Pakistan, Bangladesh, Nepal, Sri Lanka, Bhutan, Maldives and Afghanistan
East Asia: China, Japan, Mongolia, North Korea and South Korea
Southeast Asia: Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, and Vietnam
Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

To counter this, millions of smallholders in South and Southeast Asia are now taking matters into their own hands and investing in locally adapted technologies such as small storage ponds, pvc piping, and pumping equipment in order to access groundwater and gain greater control over their water supplies (Mukherji *et al*. 2009). This puts the reliability, timeliness, and adequacy of irrigation in the hands of the farmer. This new ‘water-scavenging’ economy, as it is known, is now highly visible in South Asia and the North China Plains. It is based on groundwater abstraction and encouraged by a booming low-cost Chinese pump industry. China has pared down the weight and cost of small pumps and currently exports some 4 million pumps annually. In India more than 60 percent of the nation’s irrigation now comprises smallholders pumping groundwater, known as ‘atomistic irrigation’. But the success of this ‘smallholder’ approach to farming is now beginning to create large scale problems as the many thousands of mostly unregulated withdrawals are over-exploiting groundwater and water tables are falling in some places by as much as 3m/year. This calls into question the long-term sustainability of this informal irrigation economy. As Postel (2010) states ‘we are meeting some of today’s food needs with tomorrow’s water’. She estimates that groundwater across northern India is being depleted annually by 54 cubic kilometers. The high energy consumption of lift-based irrigation when compared to gravity systems also makes long-term sustainability an issue.

4.2 In Africa

In contrast to Asia, Africa, particularly sub-Saharan Africa (SSA) has little irrigation and agriculture is dominated by rainfed farming. Agriculture is largely subsistence based and concentrated on low-value food crops (AfDB *et al*, 2007). Over 330 million people, some 45 percent of the population, live on less than US$1/day. Agricultural productivity is the lowest in the world and output has not kept pace with population increase. Since 1980, over 80 percent of output growth has come from expanding the cropped area. In other regions of the world expansion of cropped area has been less than 20 percent. Technology has not driven a jump in productivity in the way it has in Asia.

Rainfed farming predominates but rainfall is erratic and unreliable, rainy seasons are short and there are often long gaps between rainfall events. Both droughts and floods are hazardous. Over the past century, droughts in Tanzania have caused more than 30 percent of all declared disasters while floods have caused 40 percent, often in the same place and in the same season (NRSP, 2002). Climate change predictions suggest that this will get worse as the extremes of droughts and floods increase. ‘Just one more good storm’ is a constant lament among African farmers who must make a living in some of the driest regions of the world (NRSP, 2000).

Rainfed farming is where the greatest potential exists for improving output and productivity. Even modest low-cost technological improvements and modest increases in yield could have significant impacts on production and poverty reduction.

Irrigation in Africa is concentrated in the north along the Mediterranean and, except for Egypt and The Sudan which rely on the River Nile, irrigation is mainly from groundwater. But renewable groundwater resources are being severely over-exploited and fossil water reserves are also being mined. This is driven by governments providing substantial subsidies on irrigation equipment, pumps, and energy in order to satisfy the desire to be self sufficient in staple foods. This situation is not sustainable.

In SSA the picture is quite different. The share of the cultivated area equipped for irrigation is only a third of the world average and just one-sixth of the value for Asia. Past experiences of investment in irrigation are not good. International donors have shown little interest in AWM over the past 30 years following disappointing investments in irrigation in the 1960s and 70s. National governments too have struggled to keep water for food on the national water agenda in spite of the fact that in most African countries food production is the largest consumer of water.

The reasons for this are numerous and complex. They range from relatively low population densities to the lack of market access and incentives for agricultural intensification, low quality soils, unfavorable topography, and inadequate policy environments. Together with development costs, which are considerably higher than in Asia, these conditions seriously limit the economic feasibility of irrigation development projects (IFAD, 2008).

Yet renewable water resources per capita are substantial and suggest there is a large untapped endowment of water that could be used for irrigated agriculture. Only 7,110 million ha (4 percent of cultivated land) is equipped for irrigation in SSA. This almost doubles when North Africa is included – Egypt accounts for 20 percent of all irrigation in Africa. Even within this modest total it is estimated that about 20 percent is not operational (Svendsen *et al*, 2009). However, the figures represent the more formal irrigation schemes and do not include the many thousands of hectares of informal private, smallholder irrigation that is practiced across the region in valley bottoms, along flood plains, and in peri-urban areas using wastewater, and which do not appear in official government statistics. In Nigeria, it is estimated that over 1.5 million ha of informal irrigation takes place in 1-2 ha plots using small pumps, in contrast to the formal irrigation schemes of 293,000ha.

Africa produces 38 percent of its crops (by value) from only 7 percent of cultivated land on which water is managed which suggests that additional investment in irrigation would pay dividends. The disproportionate contribution to agricultural production of Africa's small irrigated area suggests that returns on additional investment in irrigation would be high, both in terms of greater food security for the continent and greater production of export-quality agricultural goods (Svendsen *et al*, 2009).

The different agro-ecological zones across the continent will require different approaches and there is a need to move from a top-down to a bottom-up livelihoods-based paradigm. Should a "green revolution" happen in SSA, it is likely to differ considerably from that in Asia, given the significant differences in resource endowments, demographics, lack of appropriate technologies, public perspectives regarding government support for intensive agriculture, and the completely different economic context at both local and international level (IFAD, 2008).

5 What is technology's role?

What role has technology played in getting to where we are now and equally important what options and opportunities does technology provide for the future? Technology is not just central to effective water management; it is essential and often provides the stimulus for development in LDCs. Decisions about technology are among the first to be made in the development process and it is important to make the right choices.

The large public irrigation schemes depend on technology for major water storage, flow control and measurement, lifting water, and for data collection on which management decisions are based. Without these technologies managers cannot begin to manage and distribute water properly. But the high costs of large schemes and concerns about their social and environmental sustainability and the lack of benefits for the poorest farmers have slowed new developments in recent years.

In many LDCs attention has shifted away from the challenges of engineering large irrigation schemes to a focus on smallholders who manage rainfall and/or irrigate small farms and home gardens, often less than 1 ha in area. They usually have direct access to surface or groundwater and make their own decisions about how they will use water. They practice a mix of commercial and subsistence farming where the family provides the majority of the labour and the farm is the principal source of income. In such situations technology can greatly reduce the drudgery of lifting and applying irrigation water and it can help to solve water management problems by making it easier and simpler to apply water to crops in an adequate and timely manner. But it must be the right technology for the circumstances and it must be well designed and constructed if it is to give good reliable service. Above all it must be simple to construct, use, and maintain.

Technology must also make effective and sustainable use of so called eco-system services. These valuable services to society come from the 'green infrastructure' – healthy rivers and watersheds to filter out pollution, mitigate floods and droughts, recharge groundwater, and maintains fisheries. In this way resilience is built into the water delivery systems and water use.

What technology? – is a key question but it is not the only aspect to consider. It must be posed in the context of where it is being used (location), by whom (people), and how it will be introduced.

There are many different water technologies available, some new ones have come on-stream but most promising are existing technologies which are seeing a new lease of life as they are adapted to new circumstances. Generally, technologies fall into two main categories, those which make better use of available water – water saving options that help to increase water productivity (the benefit derived from each litre of water) – and those which make more water available – water storage to cope with seasonality, increasingly variable and unpredictable rainfall, flooding, and drought. This is often referred to as the 'twin-track' approach, the emphasis depending on the local circumstances. In many of the drier regions of the world for example, traditional blue water resources are already over-exploited and the costs of making more water available are increasingly prohibitive. Yet the response by decision-makers is often to develop bigger versions of familiar technologies – larger dams, deeper wells, bigger pumps, water transfer from one catchment to another. The alternative is to focus on improving the management and the wise use of existing resources. But in dry areas this can go hand in hand with opportunities to capture more green water locally and so make more available as well.

Below are some of the more promising technologies. But whatever technology is used, success will be determined more by the capacity of smallholders to take risks and adopt them in situations where services are erratic, costs are high, and markets are unpredictable rather than what is potentially possible.

Box 2: Some principles for intervening in smallholder irrigation

New inventions that match the performance criteria of affordability, suitability and high returns are unlikely in smallholder irrigation and so it is likely that the main focus will be on adapting and optimising existing technologies.

Adapting existing irrigation technologies and affordability are the critical issues for developing irrigation systems for smallholders.

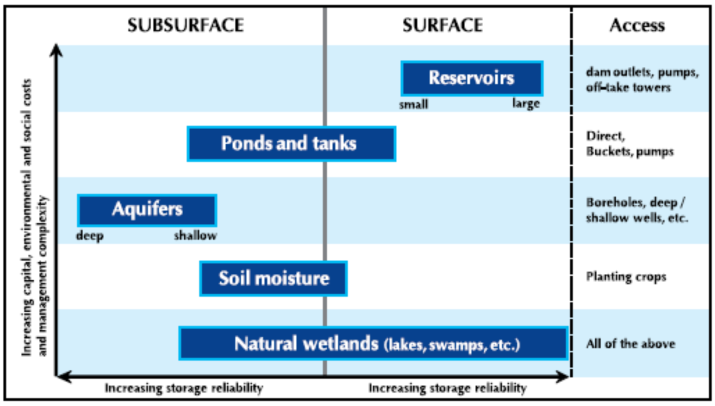
The first principle of affordability is that the initial purchase price of a product must be low enough to be affordable within the constraints of current disposable income

Only in the past decade have there been attempts to fill the gap between buckets and 5kW motorised pumps and to devise water lifting devices and distribution systems that are suited to plots of less than 0.1ha. Such innovations have begun to create new markets that can open up opportunities for smallholders

(Unpublished World Bank Handbook on smallholder irrigation, 2002)

5.1 Water storage

Water storage has perhaps the greatest potential to deliver the improvements in water management that we need. Storage is a (very) old technology and is one that has been exploited throughout history. To most people, water storage means dams and environmental and social problems. Over 45,000 large dams have been built for storage across the world and some 40 percent are used for irrigation purposes. But dams are just one means of storage. McCartney and Smatkhtin, 2010) recently described storage as a continuum involving both surface storage – natural wetlands and reservoirs; subsurface storage – groundwater aquifers and soil water storage that can be accessed by plant roots; and tanks and ponds that straddle the two as they store surface water or gather shallow groundwater (Figure 2).



- Figure 2 Different types of storage (McCartney and Smatkhtin, 2010)

Storage can make more water available by capturing water when it is plentiful at times of high flows and making it available for use when there are shortages. Storage can also be used to balance supply and demand over much shorter periods such as storing water from rivers flows during the night and making it available for farmers to use during the day. This not only makes available water that would have otherwise gone to waste, but it also increases the flexibility of irrigation systems by improving the reliability and timeliness of supplies so that farmers can better schedule their irrigation to meet crop water requirements and so reduce water losses. Groundwater storage offers similar benefits and is one of the reasons why 'water scavenger' irrigation using groundwater has been so successful in Asia. Recharge is the link between surface and groundwater storage. Canals and reservoirs now provide opportunities to recharge groundwater and to act as a buffer between water supply and demand for irrigation (see Box 3).

McCartney and Smatkhtin (2010) point out that storage options have wide application and water is accessed and used in a variety of ways. In some cases the storage is managed by a small group of farmers and others by larger more formal institutions. So each has its own niche in terms of technical feasibility, socioeconomic sustainability, and institutional requirements.

The impact of storage on poverty varies considerably. In China and in India there are examples of successful water storage used to improve the management of canal irrigation by providing farmers with water as and when they need it. The Sudan has a long tradition of night storage canal irrigation. Examples of reservoir storage along canal systems exist in Nigeria. In Ghana the storage story is mixed with some reservoirs leading to diversification and more stable and reliable income for farmers, whilst others nearby under similar conditions failed to bring about any significant change (McCartney and Smatkhtin (2010). This raises the importance of the context in which technology interventions are made.

Box 3: Conjunctive use of a small reservoir and an aquifer

With improved tubewell technology now available and within reach of small farmers, many storage reservoirs, which were previously used as irrigation tanks in the arid and semiarid tracts of India, have now been converted to recharge ponds and tubewells have taken the place of irrigation canals. In Tamil Nadu, India a small storage reservoir and 60 shallow tubewells enabled 53 farmers to grow one crop each year. In 1986 the farmers decided to permanently close the reservoir sluices and to use the stored water for recharging the aquifer. From then on, farmers using only water from the tubewells have grown two crops per year over the past 14 years.

Small and large reservoir combinations

In China, Sri Lanka, and other countries large storage facilities supply water to numerous small tanks within a river basin. These act to dampen supply and demand mismatches from large reservoirs. In southern Sri Lanka, linking a large storage reservoir with five small, existing, cascading reservoirs resulted in a 400 percent increase in crop production in the command area.

Source: Adapted from McCartney and Smakhtin (2010) Originally in Keller et al. 2000

5.2 Re-inventing canal irrigation

Canal irrigation is synonymous with surface flooding – basins, borders and furrows. On a world scale this is the most dominant irrigation technology. Those not familiar with the world of irrigation may be forgiven for thinking that most irrigation today is about sprinkler and trickle irrigation. But the reality is that 95 percent of irrigation still relies on surface flooding, most of the remaining 5 percent is sprinkler irrigation and a small percentage uses trickle methods. This balance is unlikely to change in the next 50-100 years at least and particularly so in the LDCs. For this reason, technologies that seek to improve canal irrigation should have a high priority.

Canal irrigation, particularly in Asia is not working well and it is argued that it is no longer fit for purpose. But smallholders are finding ways of dealing with this by buying pumps and exploiting local groundwater, often recharged from canal seepage, rather than relying on the uncertainties of canal water. But the extensive canal networks cannot be so easily abandoned and replaced with small pump schemes. So the option is to find ways of 'reinventing canal irrigation' by making it as responsive as groundwater irrigation.

Canals are difficult to manage hydraulically, and in many systems tail-enders suffer from a lack of water because those at the head tend to take more than their share to the detriment of those at the tail end – this is the classic 'top-ender tail-ender' problem. There are technologies available that can solve this problem but the system would require re-engineering and this can be costly. More local and cheaper options solutions are possible. In the Indian state of Maharashtra a water user association has installed pipelines to replace canals in order to distribute water from tertiary canals and ensure a more equitable share of water. In another scheme, farmers have invested in a storage tank and then distribute water through specially designed equal discharge pipelines (Bhamoriya *et al*, 2009). Pipelines, although initially more costly than canals to build, can offer better control over water supplies, making the system more responsive to farmer demands (Van Bentum and Smout, 1994).

In China public canal irrigation schemes are improving by incentivizing irrigation managers by bringing their rewards in line with those of the farmers (Johnson III *et al*, 1998).

5.3 Modern irrigation technologies

Modern irrigation technologies, such as sprinkler and micro irrigation are often seen as one of the keys to increasing food production on smallholdings which make up a large proportion of the land farmed in LDCs (Cornish, 1998).

Clearly modern irrigation technologies are not suited to the major rice growing areas in South and Southeast Asia, nor are micro irrigation technologies suited to growing staple grains. But Cornish suggests that modern methods do offer considerable potential for making best use of available water in Africa which includes 13 out of the 18 nations in the world having less than 1,000 m^3/capita/day. He suggests that micro-irrigation be targeted at selected environments where water costs are high, soils, topography and water quality make surface irrigation impracticable, high value cash crops can be grown and marketed, and where the farmer desires to increase his/her income. Although written some 12 years ago, these rules for engaging in modern irrigation still hold true today.

5.3.1 Micro-irrigation

Micro irrigation technologies are commonly used in water scarce areas in developed countries and are an intervention that has potential to use water with minimal wastage. They generally fall into two categories – low cost technologies which are used for small plots and gardens (see below); and the state-of-the-art micro-irrigation systems which are used on large commercial agri-business enterprises. These technologies can improve productivity, raise incomes through improved crop yields and outputs, and enhance household food security.

Although micro-systems do provide the potential for water saving by reducing the water wastage that often occurs with other methods such as surface flooding, these benefits are not always realised in practice. Indeed the amount of water used by the crop is the same whether the water is supplied from a micro-system, sprinkler, or a surface flooding method. Much depends on how the techniques system are managed rather than the technique *per se*.

Micro-systems have been extensively marketed in India among smallholders and commercial farmers for over 30 years in line with government policy but with mixed results. The systems were heavily subsidized, in some cases up to 90 percent of the cost, but the response from farmers has been luke warm. This has been attributed to several factors including lack of access to groundwater, lack of cash and the absence of adequate credit facilities. There are also concerns that micro-systems are promoted for reasons that do not match with the farmers' main concerns. While the government promotes the systems for long term investments for water saving and sustainable agriculture, the farmers look for more immediate and assured benefits, such as lower costs and increased incomes. So despite active promotion the appeal of these technologies has remained with the larger commercial farmers rather than the smallholders.

5.4 Low-cost technologies

The investment costs and the inherent risks of modern technologies can be just too high for many smallholders and so a number alternative low-cost technologies have been developed to fill the gap. Small-plot irrigation technologies include treadle pumps (see water lifting); affordable drip irrigation kits such as the *Pepsee* easy drip technology, bucket and drum kits, micro sprinklers, micro-tube drip systems and others that have been designed by NGOs such as the International Development Enterprises (IDE); and water storage options. These technologies are characterized by low initial investment costs, relatively short payback periods, and high farm-level returns on investments. In addition, widespread use of small-plot irrigation methods can generate employment opportunities on and off farms in rural areas. Treadle pumps and drip systems are somewhat labour-intensive, but local entrepreneurs can establish businesses that build, service, and repair the irrigation equipment. Such activities stimulate greater demand for farm products and other non-tradable goods and services.

Box 4: Micro-irrigation in Kenya

KickStart, an international non-governmental organization, developed a low-cost micro-irrigation pump which is purchased by local entrepreneurs and used to establish new, small agricultural businesses. These pumps allow users to irrigate their crops year-round and not depend solely on seasonal rainfall.

Being able to irrigate crops during the dry season allows pump owners to take advantage of the higher crop prices in the marketplace. Successful models of micro-irrigation in India and Nepal have increased crop yields and reduced water consumption in addition to increasing income and household food security. Since 1996 KickStart has been one of the leaders in micro-irrigation technologies through the development and sales of its manually operated "MoneyMaker" pumps. "Farmerpreneurs" are increasing their incomes by as much as ten-fold transforming subsistence farms into highly profitable enterprises.

Source: Pandit el al, (2010)

An important aspect of garden irrigation is that it is predominantly undertaken by women who farm vegetables for home consumption and for local markets. Studies in Nepal (Upadhyay, 2005) and India IWMI, 2009) show that micro-irrigation kits provide women with opportunities to generate income from small gardens thus enhancing household and family nutritional security. In SSA, women now head many rural households as men migrate to urban centres in search of work. So agriculture and irrigation is becoming feminized and technology must adapt to this change. Small garden kits and storage tanks enable women to irrigate crops while undertaking other household duties.

Box 5: Women farmers solve their own irrigation problems

A small-scale irrigation project was established on the outskirts of Khumasi for a group of women growing vegetables for the local markets. The scheme uses open irrigation channels supplying many plots, less than 0.1 ha each owned by a different person. The scheme was designed and built to supply water on a rotational basis and each woman was given an allotted time when she would receive water. The women objected to the scheme and said that the rotation was unworkable because they had lots of other household and family duties that took priority over irrigation. They solved the problem themselves by building small storage tanks on their farms. This allowed them to receive water when it was available and to irrigate their crops when it was convenient to them.

Source: Kay (2001)

Rainwater harvesting is also practiced on a small scale around households and home garden to grow fruit trees, water small livestock, and support fish ponds. Techniques include collecting rainwater runoff to store in small tanks, drums, and off-stream storage reservoirs. This requires only limited investment, no regular external input, are simple to manage, and can be built close to homesteads. They fit well with the livelihoods of the rural poor.

5.5 Water lifting

Few farmers and households in LDCs have the luxury of a gravity or pressurised water supply. Most smallholder and garden irrigation requires some form of water lifting and these are usually characterised by their energy source – human and animal power, fossil fuel, electricity, and renewable energy sources such as sun, wind, and water.

Many smallholders still rely on lifting water by hand using buckets and other similar containers which can serve not only for lifting water but also for transporting it from source to field. But these technologies, though appropriate for many, are limiting, inefficient in terms of energy use, and time consuming. They rob the poor of the opportunity to take up alternative income generating tasks.

> Box 6: Labour is also not necessarily a cheap option for lifting water
>
> A healthy farmer expends about 250Watt-hours of energy each day and so in four days he will use 1 kWatt-hour. At a poverty rate of US$1 per day this would be valued at US$4.0. This is similar to the amount of work that a small petrol engine pump can produce with a litre of fuel at about US$1.0 per litre. So if labour has alternative wage earning work then investing in pumps can pay dividends..

Most hand-operated mechanical pumps are designed for domestic water supply purposes and are not well suited to the high water volume requirements of irrigation. Treadle pumps changed such views on the use of human power by transferring the driving force from arms to legs, which are much stronger. They were first developed in Bangladesh in the 1980s for lifting relatively large volumes of water through small lifts of up to 1.0 metres for rice irrigation. Its acceptance among farmers has been described as extraordinary and over 500,000 pumps are now used daily in that country (Kay and Brabben, 1999). Treadle pumps are seen as a 'stepping stone' between hand lifting and motorized pumping. They are now widely used across Africa and the initial capital cost is low – between US$50-120 – and so investment is modest though not without risk. The transfer of technology from Bangladesh to Africa was not without its problems. The pumps have now been successfully re-engineered by various commercial companies and by NGOs so that they can now cope with the different operating conditions that prevail such as undulating land and deeper groundwater sources. Although the current number of pumps installed is not known, it is estimated that there are many thousands in operation in Niger, Kenya, Zambia, Zimbabwe, and Malawi. In some countries, notably Kenya, a commercial market has been established with supply chains so that spares and pump maintenance services are available. Some treadle pumps have now been adapted to sprinkler and drip irrigation systems. The only fear is that such products are seen as a technological fix provided by manufacturers interested in sales and are so they are likely to be used in situations where much simpler traditional technologies would be more appropriate.

Animal power has been used since ancient times, especially in Asia, but these devices are now almost entirely superseded by motorized pump sets. The availability of small, cheap petrol, diesel, and electric pumps that smallholders can afford, the development of cheap well drilling technology, rural electrification, and subsidized energy has seen a rapid growth in this technology across the world. Pumps provide a level of freedom that smallholders did not have on the larger state-owned schemes. They can now irrigate as and when crops need water and when it is convenient to irrigate, say during the day rather than at night. In India alone it is estimated that some 26 million small pumps are in regular use exploiting groundwater to the point where this source now exceeds irrigation from canal sources. Whilst India has benefited from well marketed, cheap Chinese pumps, Africa has not faired so well. In West Africa small Japanese pumps are widely used which are well constructed but expensive. They are often seriously over-powered for the task and so fuel costs are unnecessarily high. A pump with 1.5-4 kW power costs in the region of US$ 300-US$ 600, and a diesel pump would be US$ 990. In contrast Indian-made ones tend to cost around US$ 180 while Chinese-made pumps are considerably cheaper at around US$ 110. There is considerable room here to introduce cheaper, more appropriate pumps and the possibility of local manufacture or at least local assembly to bring down prices.

In places where there is a public supply of electric power near farmland, electric pumps can be an attractive option. But set against this is the uncertainty the supply of electricity and the dependency of farmers on an unpredictable energy source.

Renewable energy sources do not have the long-term and loss-free energy storage inherent in fossil fuels. The energy supply is therefore usually unreliable, while the equipment needed to capture and apply a useful amount of power to a pump is expensive.

Solar power is widely used for applications requiring relatively small power inputs in remote locations – telecommunications and small isolated potable water supplies are typical examples. Despite many years of intensive research attempting to develop cheap and robust solar energy gathering devices, they remain expensive relative to their power output, and both they and the associated equipment for bringing the energy to a pump are quite delicate and sensitive. Experience of their use in remote locations for pumping potable water has been mixed, with pumpsets often out of operation for long periods awaiting repair or spare parts. Solar-powered devices must be kept on the list of potential technologies, hoping for future improvements in cost and robustness, but in the short term they are not yet cost-effective except for a few low-power and specialised applications.

Box 7: Pumped irrigation in Nigeria

Farmers in northern Nigeria lost their traditional use of the fadamas along the rivers following the construction of dams to control the river floods for urban water supply and irrigation. As an alternative they turned to small-scale irrigation using shallow groundwater recharged by the river and lifting it by shadouf or calabash in the dry season to grow vegetables for local and city markets. In the early 1970s a few farmers, with help from relatives, bought small pumps from private traders. In 1982-83 an agricultural development programme based in Kano sold over 2 000 pumps for cash to individuals or small farmer groups. Engineers introduced low-cost well technologies from India, which reduced well construction by two thirds with a commensurate increased return on tubewell investment.

This has been one of the most successful irrigation developments in Nigeria with many thousands of pumps being used by private farmers. Maintenance is well established and so farmers have confidence in the technology. However, external monitoring was necessary to avoid depletion of the aquifer.

Source: Kay (2001)

Wind power has been used extensively for lifting water, usually for pumped drainage in places with very flat land and persistent winds. Relative to their water-lifting output, both ancient and modern wind-powered devices are large and expensive in comparison with other technologies now available. They tend not to be very reliable, or at least to need a good deal of attention and maintenance. An additional factor is the regional and seasonal availability of strong winds. Over most of the cultivable lands of SSA wind speeds are not high for much of the time. Thus, although its scope as an intermediate technology must not be ignored, the potential use of wind power for water-lifting is unlikely to be large.

All these renewable energy sources are in principle attractive for resource-poor people because the energy itself comes without financial cost or muscle-work, and they should all be included in any inventory of relevant technologies. But the high initial costs of usefully exploiting the energy and the technological limitations mean they are unlikely to make a big positive impact on livelihoods in LDCs. However, they should be kept under review to assess any promising technical developments.

5.6 Smarter water management

One of the biggest untapped potentials for smarter water management in all types of enterprises lies in more creative use of information technologies such as meters, sensors, controllers, computers, and even cell phones. These may seem hi-tech options but in view of the rapidly expanding use of cell phones in LDCs there is scope here to provide valuable information and advice to farmers in remote places and who do not have access to extension services.

In Ugandan villages for example, farmers have access to the wealth of information on the Internet by calling their questions in to a free telephone hotline (Question Box, 2010). The operators, who speak the local language, search for the answers and call the farmers back and provide information on crop prices, weather forecasts for irrigation and water management, plant diseases, and more.

GIS (geographic information system) technology is also finding new ways of supporting water management. The World Wildlife Fund (WWF) recently identified more than 6,000 traditional water tanks (small reservoirs to capture rainfall or runoff) in a single sub-watershed in western India. WWF determined that if the tanks were restored to capture just 15-20 percent of local rainfall, they could hold some 1.74 cubic kilometers of – enough to expand the irrigated area in the region by 50 percent and at a quarter of the cost per hectare of a typical dam and diversion project proposed for the region. (Gujja *et al* in Pittock, 2009)

5.7 Non-conventional water sources

5.7.1 Wastewater re-use

Most domestic and industrial water is not consumed, rather it is used and returned to the catchment either directly discharging into rivers or seeping into groundwater. It is only lost when it is discharged into the sea or into the desert where it is beyond economical recovery. So this is a resource that can be re-used. In most European countries wastewater, suitably treated to a high standard, is regularly discharged into rivers where it is diluted within the main flow then re-used downstream by households, industry, agriculture and the environment. Water in the River Thames in the UK, for example, is reputed to be used seven times before it is discharged into the sea.

Wastewater reuse is high on the agenda in countries across North Africa and the Middle East where water is already scarce. Syria reports 67 percent reuse of sewage effluent, Egypt 79 percent, and Israel 67 percent, mostly for irrigation and for environmental purposes (FAO AQUASTAT). However, there is a continuing debate over whether this water is actually 'available' for exploitation. It is unlikely for example that the 0.79 billion cubic metres of effluent produced in Egypt each year is just sitting there waiting for someone to use it. Egypt's water strategy for 2017 suggests that this entire amount is already accounted for in its water balance.

There are cultural barriers to re-using wastewater in many countries particularly as there may be question marks over the quality of water treatment. Even using this diluted water for certain crops such as fruit and vegetables would be anathema. However, treated water use for growing processed crops such as grains and root crops and biofuels may be less of a problem.

Using wastewater for agricultural purposes can involve substantial addition costs over and above those for using fresh water. Wastewater will still require treatment to avoid health risks even when the crops are not directly consumed. Wastewater is produced mainly by cities and larger towns where there is a concentration of people and industry, which may make it feasible and economically viable to invest in the required infrastructure. However, cities are often some distance from where this treated water can be used for agricultural purposes and so canals and/or pipelines will be needed to transport the water. Also the timing of wastewater availability (usually an even flow over the year) does not coincide with agricultural water demand (usually over a 3-month growing season) and so some means of water storage will be essential if all the water is to be effectively used. All this can add considerably to the costs of re-using water for agriculture.

Effluent in most small towns and villages in LDCs goes untreated and although the risks to health are extremely high, wastewater is often used for agriculture, and even for domestic use where education is poor and alternative clean supplies are not readily available or accessible. This connects the issues of food security with the major challenges facing domestic water supply and sanitation in LDCs.

5.7.2 Desalination

Desalination is an option that is often visited as a potential source of water for irrigation but at present it is considered too expensive at US$0.5-1.5 per cubic metre and there are concerns about the water being too pure and lacking in micro-nutrients for irrigation (FAO, 2006b).

Desalination is a process to remove salt from saline water to produce freshwater. Desalination processes have developed significantly over the past 30 years and this has led to the general acceptance of two main technologies – thermal and membrane – which together account for almost 98 percent of the world's current desalination operating capacity – now in excess of 35 million cubic metres per day, much of which is in the

Middle East. This is used mainly for drinking water and for industry. Estimates suggest that less than 10 percent of desalinated water is used for irrigation and this is mostly in Spain where desalination is heavily subsidised. Both processes are energy intensive and produce good quality water. Current trends suggest that the costs are falling through economies of scale and continued developments in membrane technology.

Planners and policymakers still look at desalination as a 'silver-bullet' solution to water shortages but seem to miss the perverse irony – that by burning more fossil fuels, desalination will likely worsen the problem they are trying to solve while making local water supplies more and more dependent on increasingly expensive fossil fuels (Postel, 2010).

A third option involves the use of solar energy for desalination but this is very much in its infancy. Solar stills produce water vapour by mimicking the natural water cycle but over a much shorter time period. However, yields are low averaging only 2-5 litres/day and depend on sun-hours. They are a useful option for providing basic energy and water needs in remote regions where it is not possible or cost-effective to connect to the public electricity supply, and where physical water scarcity is most severe. They are small in scale, low maintenance, and have low environmental impact. But they are not a serious option for growing crops in arid climates.

5.8 Improved rain-fed agriculture

Substantial improvements are possible in rainfed agriculture. Tapping into this potential requires innovative strategies to manage the sudden excesses of water and frequent dry spells. Integrating soil and water management focused on soil fertility, improved rainfall infiltration, and water harvesting can significantly reduce water losses, improve yields, and water productivity – the strategy is to get 'more crop per drop'. The greatest potential for improvement lies in areas that face the greatest water challenges where most of the hunger and poverty exists.

Box 8: Water harvesting in Tanzania

Micro water harvesting systems were being introduced into the drier regions of Tanzania to improve maize production. The idea was that this would give smallholders more control over their farms. However, when they were invited to evaluate the micro-catchment trials, farmers understood the benefits of rainwater harvesting but were reluctant to adopt the system. They were more interested in the greater potential of using macro-catchment systems and argued in favour of more ambitious attempts to harvest runoff on a larger scale. So far the limited trials with macro systems for maize are mixed. Proper control over distribution of harvested runoff within the cropped area can be problematic for deficit-irrigated crops. There was also clear evidence that failure to provide proper control over the distribution of runoff can lead to serious erosion. Too much water can be as big a problem as too little. The need for cooperative group action can also give rise to disputes over water sharing. So whether farmers will continue to prefer macro-systems to micro-systems as they acquire more experience in using them for maize production remains to be seen. However, one significant outcome of the research is that government sees runoff as a beneficial resource rather than just a hazard which causes soil erosion.

Development of rainwater harvesting is now included in the Tanzania National Water Resources Management Policy.

Source: Hatibu (1999)

Soil and water conservation measures can help to make better use of rainfall by increasing water infiltration and water storage in the soil. They include terracing, contour bunds, infiltration pits, tillage, integration of tree crops, and green manuring. These techniques require little or no capital investment. But the challenge for the poor is to identify pragmatic options for gradual improvement which are manageable by part-time farmers with limited skills and limited access to regular extension advice.

Because the majority of the world's poor and hungry live on rainfed farms in South Asia and sub-Saharan Africa, raising the farms' productivity using these techniques would directly boost food security and incomes. So it is both disappointing and worrying that these technologies, though widely known about, are not being widely promoted, implemented and practiced.

5.9 Conservation agriculture

Conservation agriculture is part of rainfed farming practiced on 95 million ha worldwide, primarily in North America, Brazil, Argentina but to a much a lesser extent in Africa and Asia. This is not directly a water technology but improved water management is one the benefits. Conservation agriculture exploits soil and agro-ecosystem resources in order to optimise crop yields rather than maximise them. Soil cover is permanently maintained with minimal soil disturbance using 'zero-tillage' systems. Crops residues protect the soil which enhances soil and water conservation and improves soil organic matter. This in turn improves water infiltration and storage in the soil during rainfall events.

In Africa the method is beginning to spread in Kenya, Tanzania, and Zambia where some farmers have doubled or even tripled their grain yields. In Zambia, conservation agriculture has helped vulnerable households survive drought and livestock epidemics. More than 200,000 farmers are now using this technique. In the 2000–01 drought, farmers who used conservation agriculture managed to harvest one crop, while others farming with conventional methods faced total crop failure. In Ghana, more than 350,000 farmers now use conservation agriculture (IFAD, 2008).

6 What needs to be done

Water technologies are available to help meet the challenge of food security. But history tells us that exploiting the endowed potential of water and land will not be easy and investing in water alone will not increase food production. Agriculture requires many and varied inputs. Complementary investments are needed in a wide range of farm products and services – fertilizer, seeds, farm power, micro-credit, good roads, post harvest infrastructure, access to markets – and conducive institutions that support farmers and empower them to take responsibility for their livelihoods. Taking all this into account is what makes increasing food security extremely complex and is one of the main reasons why the development community pulled out of irrigated agriculture in sub-Saharan Africa following disappointing investments in irrigation infrastructure in the 1960s and 1970s.

Most industrialized countries have the infrastructure, strong institutions, and the capacity to sustain the levels of water and food security they currently enjoy. But most LDCs lack these essential physical and social structures that underpin sustainable development. Until recently agriculture and food have not been high on the international and political agenda, not only in the LDCs but also in OECD countries as well. Agriculture has not been seen as a major water issue. There are also many players involved in developing agriculture and most LDCs lack the capacity to plan, manage, and implement AWM. Both farmers and professionals lack strong AWM skills, there are few institutional structures that support them, and the broad socio-economic environment in which these individuals and their institutions work is not always conducive to strong market-led agricultural development.

Funding is also crucial. Asian governments kick-started their green revolution in the 1970s by spending 15 per cent of their budgets on agriculture. The World Bank estimates that a 1 per cent increase in agricultural GDP in Africa will reduce poverty by 3 or 4 times as much as a 1 per cent increase in non-agricultural GDP (HOC, 2009). Yet donor countries spend less than 5 per cent of their development aid on agriculture.

The good news is that, as a result of the various crises in recent years, agriculture is now coming back onto the world agenda and the international community is beginning to re-engage in agricultural investment. There is now a growing recognition that integrating agricultural systems – resource management, production, markets, and consumers – is essential for sustainable and profitable agricultural growth. But 'more of the same' will not be good enough and the pitfalls of the past must be avoided.

There is plenty of advice available on *what* needs to be done.

6.1.1 More research – and information dissemination

It is often said that the challenge lies in putting into practice what has already been written and talked about poverty alleviation. But the pathways from research to helping communities and individuals to improve their livelihoods are many and varied and can be difficult to take. Indeed, this process has become a researchable issue in their own right if the pitfalls of trial and error are to be avoided.

Most researchers set out with the intention of influencing policy and/or improving the livelihoods of the poor. But little thought is given as to how this will be achieved in practice and do not see their potential role in uptake promotion nor are they usually trained for this. They tend to follow a linear pathway from developing new technologies and practices to writing papers and reports often aimed at a limited audience and with little incentive to communicate their findings to those who would most benefit from them. New ways of disseminating this information are needed which take account of the needs of those receiving it. This does not just mean farmers; it includes information presented in an appropriate manner for politicians, agro-entrepreneurs, extension staff, and the general public. In East Africa, researchers are now being encouraged to focus on uptake and the approach is to build a 'community of champions', now totally over 800 whose role is to promote AWM with a carefully prepared uptake promotion strategy (NRSP, 2004). Researchers in natural resources need to bring social scientists into the team so that their efforts a more people focused.

NGOs also have a key role to play when it comes to linking research with practice. They are usually much better than researchers at connecting with people, especially the poor and so they can play a very useful role.

6.1.2 Build new institutions

New institutional arrangements are needed which centralize the responsibility for water regulation yet decentralize water management responsibility and increase user ownership and participation.

At a national level, monitoring, collecting, and synthesizing data on water resources is an essential part of managing and regulating water resources. So too is communication across government departments who have water management responsibilities. Bridges need to be built between the various ministries that deal with water, food, agriculture, environment and finance. In too many countries responsibility for AWM falls between the Ministry of Agriculture which deals with agricultural water management and the Ministries of water resources, irrigation, and the environment which deal with other water matters. Communication between ministries and other bodies involved in water management will be an essential ingredient in achieving Integrated Water Resources Management.

Decentralization is a key policy for many LDC governments but local management relies on sustainable local institutions capable of engaging local communities and articulating their needs as well as analyzing, designing and implementing policies and innovations. The essence of such organisations is social capital and this will need strengthening if decentralization is to succeed.

Box 9: Strong social capital supports tradition rice irrigation

Traditional rice irrigation terraces in South East Asia rely on strong social capital to organize and manage labour-intensive construction and maintenance of the terraces and to synchronize cropping patterns for effective water and pest management. Without strong social capital this system would not survive.

Source: NRSP, (2003)

While there is broad consensus on these principles among international organisations, there is still a long way to go to get this adopted politically by national policy-makers and transformed into operational and context-specific strategies.

6.1.3 Develop AWM capacity

A key constraint to developing water for agriculture in most LDCs is the acute lack of capacity at all levels. Capacity development is not just about training farmers, local professionals, and government-based research and extension service personnel who provide services to farmers. It is also about developing the institutional structures within which people can work – water abstractor groups, extension support services – and providing a favourable socio-economic environment which actively promotes a policy of increasing food production and in which agricultural water investment can flourish. For example, reducing tariffs on imported pumpsets or other irrigation and soil improvement technologies would help to lower costs and make agriculture more profitable (FAO, 2004).

Building capacity is a long, slow process of dialogue, coordination, participation and knowledge sharing among farmers, the state, finance and donor organizations, non-governmental organizations, community based organizations and research centres.

6.1.4 Initiate Public Private Partnerships

Public Private Partnerships (PPPs) operate in some LDCs and offer a new approach to irrigation development by involving the private sector in smallholder farming in what has traditionally been a government/aid funded activity. These need not be two separate sectors of the economy. Rather there are opportunities for cooperation between the two and for smallholders to join with commercial farmers for the benefit of both – a potential 'win-win' situation.

In Zambia smallholders and emerging commercial farmers are being encouraged to cooperate (Tardieu, 2009). Smallholders benefit from access to the value chain and learn more about modern farming techniques and acquire management skills. Commercial farmers benefit from economies of scale – being able to purchase crops from neighbouring smallholders and adding value such as maize milling and bio-fuel processing. Including smallholders in commercial irrigation schemes can also reduce unit water costs. The approach is based on three principles – irrigation schemes must be financially sustainable particularly smallholder schemes; they must be professionally managed; and there must be inclusive business opportunities for both input supply and for marketing of produce.

The approach is not without its challenges, not least of which is the limited technical and commercial capacity within the government bodies in Zambia to engage in PPP with private stakeholders and financial partners. But valuable lessons for success have already been learned including – making sure the schemes are large enough (250-1,000ha) to be professionally managed and financially sustainable; Joining irrigation and marketing service provision is a way to mitigate financial risks; and there are ways of addressing the lack of competent private operators in the irrigation sector.

6.1.5 Focus more on the role of women

Women are important in agriculture and water management. FAO (2007) estimates that Southeast Asian women provide up to 90 percent of the labour involved in rice cultivation and in sub-Saharan Africa women produce up to 80 percent of basic foodstuffs for household consumption and sale. Given the important role women play in agricultural production around the world, focusing on the unique challenges women face and their lack of resources is an important key to increasing overall agricultural productivity (Meinzen-Dick, 2010).

Agricultural productivity is often lower for women because they have limited access to a wide range of physical assets including agricultural inputs, technological resources, and land. They also lack the capacity to deploy these assets. For example, women may have access to land but lack access to water for irrigation or lack the knowledge of how to properly use the water. So a broader understanding is essential in order to remove the obstacles that women face. As both research and extension in LDCs is dominated by males, it is high time that such systems reflected this important gender issue.

Box 10: Women in agriculture

According to the Africa Regional Review, "Successful extension must involve women, youth and the most vulnerable people in the rural communities."

Source: Mokwunye (2009) in Meinzen-Dick (2010)

In a workshops in West Africa and North Africa the consensus was "Women have many roles in agriculture: farm production, marketing, food preparation, etc. Evidence shows that empowering women will result in [lower] child mortality, school enrollment and declines in child malnutrition. Women also have a better track record in collaboration and sustaining social capital. Based on evidence from micro-finance schemes, investments used by women have shown higher returns as those used by men"

Source: Smets (2009) in Meinzen-Dick (2010)

6.1.6 Focus more on youth

'Youth are our future' is a well meaning phrase but this is usually interpreted as meaning support for vulnerable young people. Over 25 percent of the world's population is between 10 and 24 and in some African countries it is 35 percent – most are born into poor rural families. Youth is largely 'invisible' in natural resources development yet their potential for contributing to economic growth and food security is significant. It is argued that the time has come to mainstream youth in natural resources related development policies and to put aside the 'received wisdom' that the young are not interested in deriving a livelihood from land and water resources (NRSP, 2004).

6.1.7 Increase water-food trade

Some 85 percent of the water used by the world's half billion or so farms produces food commodities that remain within the producer economies. Only 15 percent of farm output in terms of embedded water is traded internationally and meets the food and water needs of over 70 percent of the world's 200 or so water deficit economies. This trade in water embedded in food products – virtual water – between water-rich and water short nations will play an increasing role in enabling better distribution of food to countries that find it difficult to grow sufficient staple food crops. But the aqua-politics of importing food vs self-sufficiency will not be easy to resolve. Poorer countries may wish to continue over-exploiting water resources to feed their populations. Industrializing the economies of water-scarce countries is seen as one long term means of raising GDP in preference to a continuing dependency on agriculture and particularly low-value food and fodder crops (World Bank,

6.1.8 Strategy in Asia

In Asia new strategies for improving agricultural water management are being established. Mukherji (2009) sets out a useful 5-point strategy:

- Modernizing yesteryear's schemes for tomorrow's needs
- 'Going-with-the-flow' by supporting farmers' initiatives

- Looking beyond conventional participatory irrigation management and irrigation management transfer recipes
- Expanding capacity and knowledge
- Investing outside the irrigation sector

6.1.9 Strategy in Africa

In sub-Saharan Africa the 'Comprehensive Africa Agriculture Development Programme' (CAADP) established by the New Partnership for Africa's Development (NEPAD) in 2002 has set the agricultural development agenda for the whole region with a pillar focusing on land and water development. A group of key donor agencies have now set out an implementation strategy that promotes institutional and policy reforms and investment in viable and sustainable projects. In response to this the African Minister's Council on Water (AMCOW) called on NEPAD to inaugurate a new partnership – Agricultural Water for Africa (AgWA) – that would re-engage African countries, donors, and regional and international organisations in the development of water for food production, economic growth and poverty reduction. This partnership is now being actively developed and its mandate includes (AfDB et al, 2008):

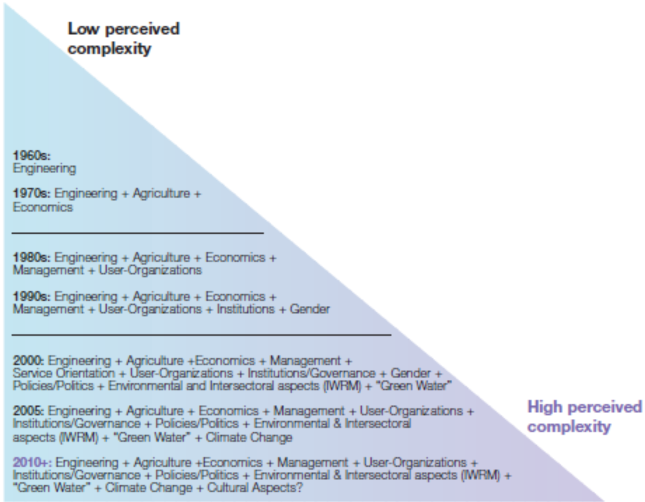
- Advocacy – AWM needs strong positive messages – water for food, water for wealth, water for life – if AWM is to be more effective. Advocacy for AWM is an immediate priority.
- Mobilizing resources – providing an authoritative platform to influence investments decisions and promote the allocation of more funds towards AWM.
- Sharing knowledge – facilitating the exchange of experience and learning with a view to improving sector performance.
- Harmonizing partner programmes – this is seen as critical to capturing synergies, taking advantage of complementarities, avoiding duplication of efforts and, ultimately, enhancing development impact and sustainability of investments.

7 Where, for whom, and how?

The experience of agency and government-led interventions has shown mixed results and a critical gap exists between planning and successful implementation. Approaches focus too much on *what* needs to be done rather than on *where* and with *whom* to do it. And most importantly *how* to do it is largely ignored as decision-makers and donor agencies try to avoid the complex interactions between individuals, the state, and service providers, and the limited capacity to translate plans into practice. So what options are available to change this culture?

The debate continues on *where* to use technologies and for *whom,* as there are no simple universal 'blue print' solutions. The choices depend on local people and circumstances. But the biggest question that still largely remains unanswered is *how* to do it? Having selected appropriate interventions for specific locations and target groups, how can government and agencies successfully intervene in complex and changing AWM systems that have specific technical, environmental, socio-economic, and institutional challenges?

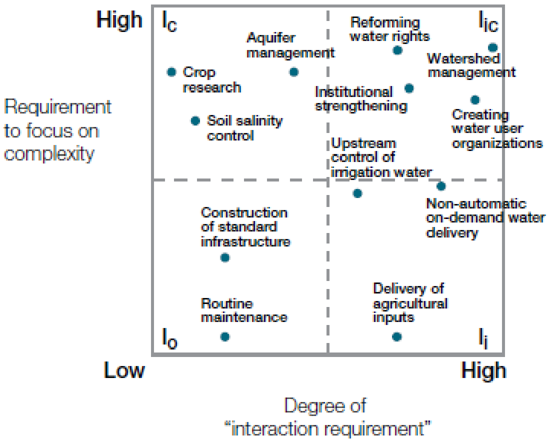
Huppert (2009) offers a way forward. Recognising that AWM systems are complex is seen as an important first step and realising that AWM is also embedded in the wider political and socio-economic fabric of civil society (Figure 3). Taking account of all this can make intervention just too complicated and difficult to implement. But ignoring it can also lead to rigid systems that cannot respond to change. So the development pathway lies somewhere between the paralysis that comes from trying to take account of everything and the folly of focusing in on a single criterion solution.



- Figure 3 The growing complexity of managing irrigation systems (Huppert, 2009)

Huppert (2009) suggests that many interventions fail because of the way they are approached. He suggests that for many situations the conventional 'project' approach with blue-print solutions, budgets, and timetables may actually be part of the problem rather than part of the solution. He recommends that interventions are unbundled according to their inherent complexity so that the actions taken can be made more appropriate to the intervention (Figure 4). Some interventions are relatively straightforward, such as canal maintenance, may indeed succeed with a conventional approach. But changing agricultural production from rainfed to irrigated agriculture are much more complex and require a great deal of interaction both between individuals and between organisations. Recognising this and the implications for management and the capacities needed to intervene successfully can then be addressed. These more complex interventions will place new demands both on AWM service providers – who will need skills to work as facilitators, moderators, and change agents – and farmers who must become responsible managers, rural entrepreneurs, citizens and go beyond the conventional demands of participation.

Another important issue that Huppert (2009) raises is that improving AWM in LDCs is usually based on the assumption there is good governance and a supportive institutional framework. Introducing 'modern' formal institutions such as Water User Groups within local social structures can be problematic as the local organisations often reflect traditional, indigenous, and local norms which can clash with urban institutions biased towards the interests of consumers and non-agricultural sectors. Furthermore, introducing improved AWM is often done on 'pilot' scales where subsidy schemes for replication and upscaling of successful experiences are not within the fiscal realm of LDCs.



• Figure 4 Selected types of interventions in AWM system (Huppert, 2009)

Some agencies are now learning how to intervene in such complex issues. In Bolivia for example, local institutions are strong but national ones are weak, and a 'top down' approach to modernizing irrigation schemes in Cochabamba was not successful. A more successful, alternative strategy was adopted which built on local institutional strength and engaged with local farmers and communities using indigenous knowledge and recognizing local water rights (Huppert 2009).

Box 11: How to intervene – a case study in the Jordan valley

The Jordan Valley Authority (JVA) ensures irrigation water delivery to farms by opening and closing valves at each farm which are installed in enclosed concrete boxes. This was perceived as a complex task as the valves must be operated to meet the diverse cropping patterns in the valley and so it was fulfilled by qualified staff. Because of staff constraints this proved difficult to manage and the unpredictability of the water supply due to unforeseen water scarcity just added to the problems of managing the supply. There was little or no interaction with farmers but some farmers would break open the boxes and open valves to get access to the water. JVA rebuilt the boxes and tried to prevent farmers from illegally opening valves but this was not successful.

In recent years JVA has realized that water delivery under conditions of diverse cropping patterns and unpredictable water supplies is a complex service requiring a much greater interaction with farmers. Water user groups were established to work with JVA staff and to take responsibility for operating valves and allocating water among themselves in periods of scarcity and uncertainty. As a result it has been possible to establish a continuous process of balancing farmers' needs and actual water availability and to have the farmers, themselves, organize water delivery to the farms. Damage to valves and boxes is no longer a problem.

Source: Adapted from Huppert (2009)

Last but not least is the need to deal with corruption. In irrigation, the more complex the system the more vulnerable it is to corrupt practices. Problems like this can become endemic throughout the hierarchical structure of an irrigation bureaucracy. But like other difficult problems it can be resolved given innovative thinking. One approach is to improve the information available to farmers so that local AWM service providers do not have an unfair advantage when they give advice. In this context, Internet and cell phone technologies can be useful tools. Another approach is to change incentive schemes to bring together the interests of farmers and service providers. The challenge is to motivate local service providers to provide a good service (Huppert 2008).

8 In conclusion

This paper has tried to set out the challenges facing those LDCs where food and water security are most acute. The general consensus is that there is enough water to meet this challenge. Technology can provide the tools for the job; it is up to the various stakeholders – smallholders, researchers, policy-makers, governments – to find new ways of using them wisely. To carry on with the 'business as usual' model is not an option.

SOME KEY MESSAGES:

Water scarcity is becoming a major issue not just in LDCs but also in OECD countries as well, driven by global warming, population growth, and social and economic change.

Agriculture uses 70 percent of the world's available water resources and so the wise use of water for agriculture is a key to water and food security, economic growth, and poverty reduction in LDCs.

These basic facts are not well understood and so water for agriculture needs a much stronger, coordinated voice both nationally and internationally so that it can get the attention and investment it deserves.

Agricultural development in the LDCs is mainly in the hands of smallholders. Water technologies appropriate to their needs will play a crucial role in meeting the food security challenge. But technologies alone will not be enough. To be useful they must form part of a comprehensive investment in a range of farming and value chain market-orient services.

Most benefit will come from using existing technologies and adapting them to new situations so they are appropriate in terms of location, people, and purpose. Research must focus on this process of adaption rather than on developing new technologies *per se*. Researchers must also focus more on uptake and dissemination of information and tailor it for different audiences, not just farmers, but politicians, extension services, schools, and the general public.

New institutions are needed which centralize the responsibility for water regulation yet decentralize water management responsibility and increase user ownership and participation of smallholders.

Many LDCs lack capacity for AWM. But this is more than just training, it must embrace institutional development and the creation of an enabling socio-economic environment in which agriculture can flourish.

Public Private Partnerships offer new opportunities to improve agricultural water management as well as the prosperity of smallholders.

Institutional structures and technologies that recognise the role of women in agriculture are required. So too is a recognition of the role that youth can and must play in the future management of natural resources.

There is a lot of good advice available on *what* needs to be done. But the question of *how* to do it is rarely addressed. A new pro-poor approach to AWM is needed which addresses both *what* to do and *how* to do it if interventions are to benefit poor people.

> If everyone on the planet were to adopt a lifestyle similar to that experienced in OECD countries, then we would need the equivalent of 3.5 worlds to satisfy the resource requirements.

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