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Water for Food
Innovative water management technologies for food security and poverty alleviation

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ABBREVIATIONS

AgWA	Agricultural Water for Africa
AMCOW	African Ministers' Council on Water
AWM	Agricultural Water Management
BRIC	Brazil, Russia, India and China
CAADP	Comprehensive Africa Agriculture Development Programme
CP-MUS	Challenge Program-Multiple-Use Water Systems
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
IDE	International Development Enterprises
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
LDC	Least Developed Country
MDG	Millennium Development Goals
NEPAD	New Partnership for Africa's Development
OECD	Organisation for Economic Co-operation and Development
PPP	Public Private Partnership
SSA	sub-Saharan Africa

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WATER FOR FOOD – INNOVATIVE WATER MANAGEMENT TECHNOLOGIES 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 hectares to almost 300 million hectares today – a seven-fold increase. This revolution in water technology improved crop yields and enabled 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 half their domestic food production.

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 Global agricultural food production already accounts for 70 percent of all water withdrawn from rivers and aquifers.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

Can agricultural water management (AWM) technologies provide innovative solutions that meet this challenge of feeding a growing population by producing more food but with fewer resources? This paper reviews the water-food-poverty nexus and examines the role that AWM technologies may play in achieving world food 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, 2011). 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, South Asia, and the drier regions of sub-Saharan Africa (SSA). Water scarcity is one of the most pressing issues facing humanity today. More than 1.4 billion people live in water stressed river basins and by 2025, this number is expected to reach 3.5 billion. Moreover, over 20 percent of the world's rivers run dry before reaching the sea (World Resources Institute, 2003).

This situation is set to deteriorate. Global food demand is expected to increase by as much as 70 percent by 2050 (FAO, 2006a) as the world's population rises from over 6.8 billon to 9 billion and diets change as a result of socio-economic improvements, particularly in OECD and BRIC (Brazil, Russia, India and China) countries. About 1.4 billion people live in extreme poverty (defined by the World Bank as living on less than US$1.25 a day). Most are living in LDCs (Least Developed Country) in Asia and Africa and to a lesser extent in Latin America and the Caribbean (Figure 1). Even though there is a shift towards urbanisation, poverty is still largely a rural problem (approximately 1 billion people) and this is likely to remain so for the foreseeable future (IFAD, 2011). Not only is poverty highly regionalized and rural, it is also disproportionately female (Rauch, 2009), especially as men are drawn to the cities to seek alternative incomes. In developing countries, women provide around 43 percent of the labour force. In SSA, 62 percent of the region's economically active women are engaged in the agricultural sector (FAO, 2011).

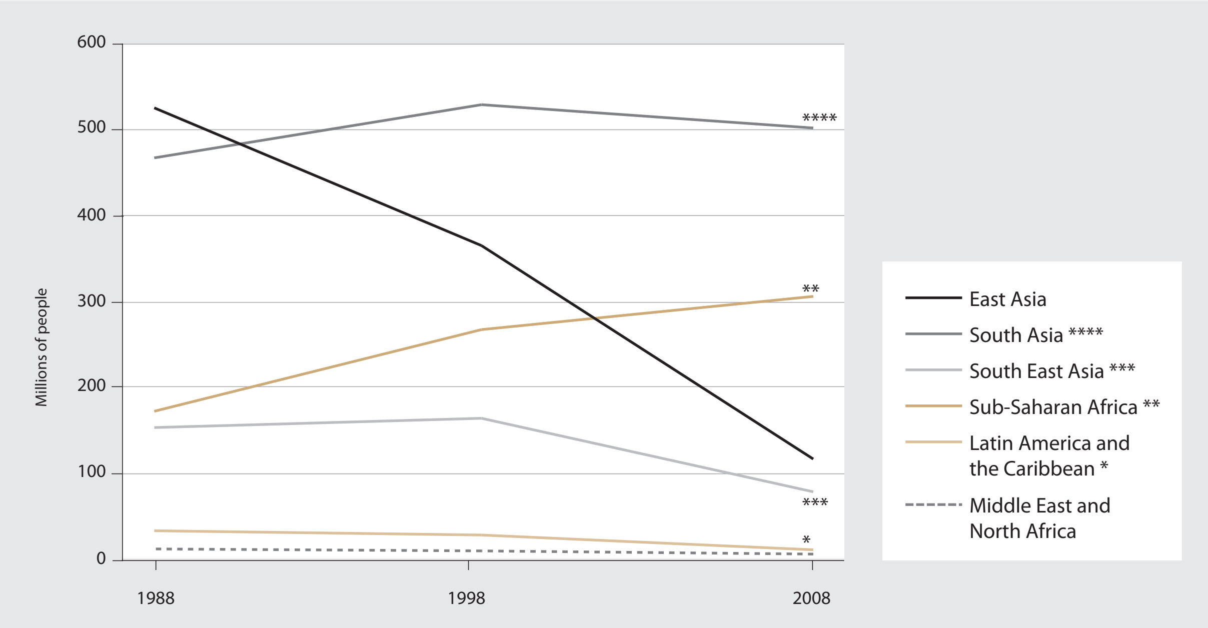
Food demand in LDCs is expected to double as the population in the developing world reaches 7.5 billion by 2050 – including 2.2 billion in south Asia and 5 billion in SSA. Most LDC Governments look to their rural communities to produce more agricultural products but those same communities are impoverished,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

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, and 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.

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 among the different water using sectors – municipalities, industry, agriculture and the environment. There are increasing pressures to divert land away from food production towards

Figure 1. Rural people living in extreme poverty (IFAD, 2011).
(Millions of rural people living on less than US$1.25/day)



Source: IFAD, 2011

energy crops. There are concerns that available water resources will decrease in some critical regions as a result of climatic changes and the available land area for agriculture will continue to decline because of land degradation and urbanisation.

The range of issues has created a 'perfect storm' with 'dark clouds' converging 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, there may be increased competition for food, water, and energy; rises in food prices; and increases in the number of people going hungry (Beddington, 2009).

2.1 Climate change – another 'dark cloud'

Climate change is yet another 'dark cloud' on the horizon that will impact water resources which in turn will impact agriculture and hence food production (Bates *et al*, 2008). Globally, agriculture contributes about 18 percent 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; UNCTAD, 2010).

Rising global temperatures will result in drier dry seasons and wetter rainy seasons, greater uncertainty, and increased risk of more extreme and frequent floods and droughts. The Intergovernmental Panel on Climate Change (IPCC) projected an increase in annual mean rainfall in high latitudes and Southeast Asia and decreased rainfall in Central Asia, the southern Mediterranean, and SSA. Such changes will impact people's livelihoods and ecosystems, particularly in semi-arid and arid areas.

Decreasing rainfall, particularly in areas that are already water-short, will impact both surface and groundwater supplies. Melting glaciers will initially increase but then strongly decrease dry-season water supplies. This will affect the design of new water infrastructures. Design is normally based on historical weather patterns but this will no longer be helpful in predicting what may happen in the future.

The poorest farmers are at greatest risk from the impacts of climate change (Parry *et al*, 2005). Increasing food, feed, and biofuel production will in turn increase GHGs and this will significantly impact both the availability of food and food security (Schmidhuber and Tubiello, 2007). Climate change will counter the drive for increased food production in many LDCs and hinder progress towards meeting the first of the Millennium Development Goals (MDGs), which aims to reduce by half the proportion of people suffering from hunger by 2015. Additionally, climate change will increase inequality because the most vulnerable farmers live in places with marginal crop production and limited access to agricultural knowledge and technology.

2.2 Some 'white' clouds

The prognosis sounds rather gloomy and there are skeptics who disagree with these predictions. However, the arguments have more to do with the timing of events rather than the nature of the serious crisis the world faces towards the middle of the 21st century. But there are some 'white clouds' as well as dark ones. In the second half of the 20th century world food production more than doubled. Agricultural productivity rose steadily over the past 40 years and irrigated agriculture is one of the success stories of the 20th century. The large irrigation schemes in India, China, Pakistan, and Indonesia have fed millions who would have otherwise starved. The 'green' revolution, in the 1960s and 1970s, essentially based on rice irrigation, helped lift Asia out of an imminent food 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 to strike a balance among water for food, people, industry, and for the environment. The idea of a 'green-green' revolution (Conway, 1997) emerged, which was founded on the principles of environmental sustainability. A third 'green dimension' (Falkenmark, 2006) was later introduced, focusing 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.

2.3 Focusing on water technologies

What does this mean for global food security? The UK House of Commons report (HOC, 2010) put it thus: "the world must produce 50 percent more food – 'safe food'[1], on less land, with less freshwater, using less energy, fertilizers, and pesticides – by 2030 whilst at the same time bringing down sharply the level of GHG emissions emitted globally". It is a daunting challenge but one that can and must be met.

This paper focuses on agricultural uses of water and the role that innovation and technologies can play in meeting this challenge whilst recognizing that agricultural water technologies are only one piece, but a crucial one, in the complex jigsaw of global food security.

3. There is enough water

Crops consume large amounts of water, so is there enough to meet future demand? The simplistic answer is yes – but only if we make better use of what is available (CA, 2007).

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

Predicting future water demand is fraught with difficulties. Forecasts made less than 10 years ago have proven to be inaccurate because no one could have accurately predicted the rise in energy prices nor the world recession and the impact these factors would have on food prices. The impacts of climate change are now only beginning to unfold as are the stresses of population growth and water scarcity. We have enough water 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.

If water usage continues at the present rate, global water consumption will almost double by 2050. However, a more optimistic assessment suggests it may rise from 7,130 km^3 to 8,515 km^3/yr by 2050 (CA, 2007). This is not only based 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 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. In 2009, China was the top meat producer making up 27 percent of the overall meat production while India produced 15 percent of the world's milk and milk products (FAO, 2010d). Predictions are based on anticipated changes in cropping and diets, likely improvements in water productivity in 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[2].

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 practised 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 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 disadvantaged live, crop yields are low and uncertain – grain yields average only 1 ton/hectare 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. The ability of most smallholder farmers to make better use of rainwater is limited. The fraction of rainfall used for crop transpiration is only 15-30 percent (Wallace, 2000) and sometimes it is as low as 5 percent (Rockstrom and Falkenmark, 2000). The remaining portion is lost through surface runoff, drainage, and unproductive evaporation (IWMI, 2009).

Globally, irrigation is only practised on about 300 million hectares (in 2010), or 20 percent of the cultivated land area (FAO, 2010a). But irrigation's contribution is substantial with more than 40 percent of the world's food production. About 84 percent of the irrigated area is in Africa, Asia, South America (IWMI, 2004). 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 economic 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 and introducing effective means of water control. It can provide a defence against droughts, which are predicted to occur more frequently. 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. In many irrigation schemes in semi-arid areas, particularly among LDCs, less than 20 percent of the water delivered is actually transpired by crops (Wallace, 2000). This 'inefficiency' is an overriding concern among those in irrigation.

Although rainfed and irrigation farming are often considered to be separate and distinct ways of growing crops, in practice they overlap – natural rainfall contributes to irrigation farming and irrigation is used to supplement inadequate rainfall. Agriculture exploits both blue water (rivers, wetlands, lakes and ground water) and green water (rain water and soil moisture), 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 dealing with runoff (blue water) to a process that values both blue and green water. This is the essence of 'agricultural water management' (AWM) (Falkenmark, 2006).

4.1 What about drainage?

Irrigation and rainfall are usually the main issues in AWM and so they attract most attention. But in many situations drainage, the reverse of applying water to crops, also plays a key part. Excess water is drained from the land in order to provide the right moisture conditions for crops to grow.

Drainage technologies are well known and established across the world but drainage is one of the neglected areas of AWM that deserves more recognition.

In arid and semi-arid areas, where irrigation is indispensable for agriculture, drainage can prevent water logging and the build up of salts in the soil profile which comes from poor quality irrigation water. In 2002, salinization affected about 20-30 million hectares of the world's 300 million hectares (7-10 percent) of irrigated land (FAO, 2002). In 2008, this increased to 40-60 million hectares (FAO, 2008). About 10-20 percent of irrigated land is already equipped with drainage, but 40-60 percent is in need of drainage but there are no facilities installed. The problem is most acute in South and Central Asia and the Near East where arid climate prevails and irrigation is widely practiced (FAO, 2002).

Drainage is also important in the humid and sub-humid tropics, such as East and Southeast Asia and parts of West and Central Africa, where the main objective is to remove excess water from high or intense rainfall. Lack of drainage and inadequate protection from flooding are major obstacles to agricultural development and constrain farmers from intensifying and diversifying their cropping.

In temperate zones, in Europe and North America for example, drainage also helps to maximize production by improving soil moisture and the timeliness of farm mechanisation operations.

4.2 In Asia

Asia[3] is one of the main areas where water scarcity and AWM development are directly linked to extreme poverty and hunger (Figure 1). About 700 million people subsist in extreme poverty. Irrigation farming in Asia accounts for 70 percent of the world's irrigated area and almost one third of the region's cropland (Mukherji *et al,* 2009). Many large irrigation schemes were built in the 1960s and 1970s to supply water to smallholder farms 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.

However, inappropriate fertilizer and pesticide usage has caused ecological damage and water pollution from fertilizer runoff. A general lack of water management in Asia has also led to salinization and waterlogging. Salinization alone affects over 40 percent of Asia's irrigated land in dry areas (IFAD, 2009c). In countries such as China and India, the increased use of surface water for irrigation has raised the water table causing water logging; on the other hand, increased use of groundwater irrigation over the past decades has caused water tables to drop on average by ≤ 1 metre per annum. In both cases stream flows have decreased (Scanlon *et al*, 2006). Additionally, water quality has also become a serious issue in China where 7 percent of the irrigated land (equivalent to 4 million hectares) are supplied with polluted water. According to China's Ministry of Environmental Protection, in 2008, 46 percent of the 26 lakes and reservoirs monitored for its environmental state were experiencing eutrophication, or oxygen depletion (quoted in AWP, 2010).

Water pollution and overuse exacerbates poverty, which is particularly a problem in South Asia. By 2050 there will be an additional 1.5 billion people in Asia, half of whom will still live in rural areas in spite of the tendency towards urbanization. Diets too are changing rapidly among the wealthier population as they turn to meat and dairy foods which require much more water than vegetables. In East and Southeast Asia, meat consumption has risen by almost 30 percent in the past 10 years (FAO, 2009).

Land and water resources across the region are limited and, although there is rainfed farming, irrigation farming 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 supplies are expected to come from international trade. But the existing schemes that once dominated agricultural production are now in decline because of poor maintenance, salinity, and water logging. Further 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.

Millions of smallholder farmers 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 (polyvinyl chloride) piping, and pumping equipment in order to access groundwater and gain greater control over their water supplies (Mukherji *et al,* 2009). This gives farmers more control over the reliability, timeliness, and adequacy of irrigation. This new 'water-scavenging' economy, as it is known, is now highly visible in South Asia and the North China Plains. Groundwater abstraction is 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 smallholder farmers pumping groundwater, known as 'atomistic irrigation'. But the success of this 'smallholder' approach to irrigation 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 (Mukherji, 2009). This calls into question the long-term sustainability of this informal irrigation economy unless steps are taken to increase groundwater recharge. As Postel (2010) states "we are meeting some of today's food needs with tomorrow's water". Groundwater across northern India is estimated to deplete annually by 54 cubic kilometres. The high energy consumption of lift-based irrigation when compared to gravity systems also makes long-term sustainability an issue.

4.3 In Africa

Africa is another region where water and poverty are linked together (Figure 1). For instance, SSA alone, over 330 million people, some 45 percent of the population, live in extreme poverty. Agricultural productivity in the region is among the lowest in the world and output has not kept up with population growth. Since 1980, over 80 percent of output growth has come from expanding the cropped area (AfDB *et al*, 2007). This is in stark contrast to other regions where increases in cropped area have been less than 20 percent with changes in technology and innovation driving additional productivity. This is clearly not the case in SSA (Svendsen, 2009). Furthermore, SSA has little formal irrigation schemes and agriculture is dominated by rainfed farming which is largely subsistence based and concentrated on low-value food crops (AfDB *et al*, 2007).

Although rainfed farming predominates, rainfall in many of the drier regions of Africa is erratic and unreliable, rainy seasons are short and there are often long gaps between rainfall events. '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, 2001). But floods as well as droughts are hazardous. Over the past century, floods have caused more than 40 percent of all declared disasters in the United Republic of Tanzania while droughts have caused only 30 percent - often in the same place and in the same season (NRSP, 2002a). Climate change predictions suggest that this may worsen as the extremes of droughts and floods increase. The fragile nature of agricultural production in SSA and its dependency on rainfall is illustrated in Box 1.

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 North Africa is concentrated in the north along the Mediterranean and, except for Egypt and the Sudan which rely on the Nile River, irrigation is mainly from groundwater. But renewable groundwater resources are severely over-exploited and fossil water reserves are also being mined. This is driven by governments providing substantial subsidies for irrigation equipment, pumps, and energy in order to achieve self-sufficiency in staple foods. However, this situation is just not sustainable (World Bank, 2007).

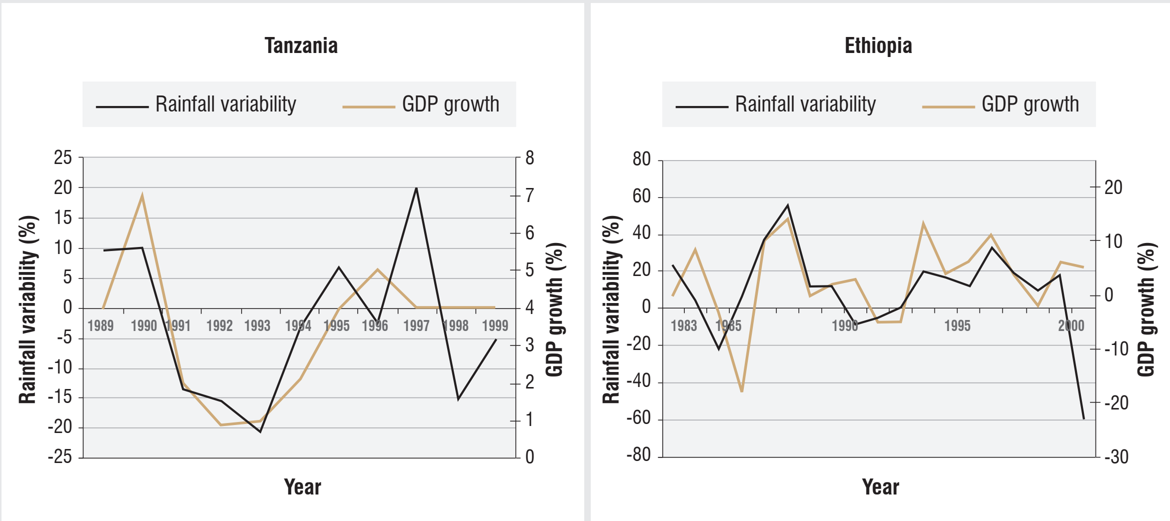
In SSA the irrigation picture is quite different. The share of the cultivated area equipped for irrigation is only a third of the world average and just one-sixth of the value for Asia. Past experiences of investment in irrigation are not good. International donors have shown little interest over the past 30 years following disappointing investments in irrigation in the 1960s and 1970s. 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, unfavourable topography, and inadequate policy environments that fail to recognize the predominance of women in agriculture. 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 in Africa are substantial and suggest there is a large untapped endowment of water that could be used for irrigated agriculture. In SSA only 7 million hectares (4 percent of cultivated land) is equipped for irrigation. This area 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 of the irrigated area is not operational (Svendsen *et al*, 2009). These figures represent the more formal irrigation schemes and do not include the many thousands of hectares of informal private, smallholder irrigation across the region in valley bottoms, along

Box 1: The link between GDP growth and rainfall

Such is the fragility of some developing countries that drought directly and severely impact economic growth. The figures below illustrate the pattern of rainfall and GDP growth from 1989 to 1999 in the United Republic of Tanzania and from 1983 to 2000 in Ethiopia. In Ethiopia, 75 percent 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. A similar situation is observed in the United Republic of Tanzania and is common to other sub-Saharan countries.



Source: World Bank, 2006a; 2006b cited in Van Aalst, M. et al., 2007

flood plains, and in peri-urban areas using wastewater, which do not appear in official government statistics. For instance, in Nigeria, several hundred thousand hectares of the fadamas wetland valleys are estimated to be informally irrigated (IWMI, 2007).

Nevertheless, Africa produces 38 percent of its crops (by value) from only 7 percent of cultivated land on which water is managed, suggesting 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 which recognises the role that women play in agriculture. 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 levels (IFAD, 2008).

4.4 In Latin America and the Caribbean

The third region in which poverty persists, though not to the same extent as in Africa and Asia, is Latin America and the Caribbean (Figure 1). The region's population has grown rapidly from 244 million in 1966 to 515 million in 2000 and is expected to reach 705 million by 2030. About 11 million live in extreme poverty, but in contrast to Asia and Africa, most live in urbanised areas (IFAD, 2011).

Most Latin-American countries have substantial endowments of water. The region has over 30 percent of the available global water supply and only 9 percent of the world's population. But there are large disparities between and within countries. More than half the renewable water supply in the region is concentrated in one river – the Amazon. The Caribbean islands, in particular, suffer from fresh water shortages. The distribution of people is also uneven; some 60 percent of the population is concentrated on 20 percent of the land area that has only 5 percent of the renewable water resources.

Agriculture is the main consumer of fresh water even though the irrigated area is modest in comparison to Asia and SSA. Latin America relies extensively on rainfed farming though there are approximately 13.5 million hectares of irrigated agriculture (in 2009) – about 9 percent of the estimated world total. Mexico has by far the largest irrigated area with over 6.5 million hectares; and Brazil is next with 3.2 million hectares, followed by Chile, Argentina, and Bolivia. About 0.5 million hectare in Brazil is in the semi-arid North East region – an area with the lowest social and economic indicators (Oliviera *et al,* 2009). Unlike Asia and Africa, Latin America has a strong tradition of private investment in irrigation with governments acting as regulators and enablers of investment. In recent years investment in water for agriculture has been in decline. The costs of construction have been increasing; government support for large scale irrigation investments has been limited, and there are concerns about the negative social and environmental impacts of irrigation. Existing schemes are generally not well managed.

Population growth and rapid urbanisation are putting considerable pressure on water available for irrigation (Ringler, 2000). As 70-80 percent of the population lives in urban centres, there is pressure to transfer water from agriculture to supply the growing urban populations.

In many areas, water scarcity is made worse by severe water quality problems resulting from poorly treated domestic and industrial sewage and mining wastes. Overall, in Latin America and the Caribbean, about 20 percent of all wastewater is treated while the existing infrastructure can theoretically treat around 35 percent of the wastewater (Mejia, 2010). Furthermore, in Mexico, only 40 percent of wastewater collected in the country's 1,833 plants were treated in 2008 (National Water Commission of Mexico, 2010). Continued population growth and increasing urbanisation will only make matters worse. Runoff from agricultural land containing agricultural chemicals is also a major pollution issue in some countries – including Colombia, Costa Rica, El Salvador – where fertilizer use has increased rapidly over the past 30 years to levels similar to those in the OECD countries.

The lack of effective drainage affects large areas of land and in many cases this is compounded by salinization and water logging. In Argentina, Cuba, Mexico, Peru and Brazil, salinization from irrigation is becoming an increasingly pressing issue. Additionally, water logged valleys cover around 1.2 million hectares in Brazil. However, not all areas in the region are in dire conditions. For instance, Mexico has the largest drainage infrastructure in the region with 2.8 million hectares of irrigated districts and 2.4 million hectares of supplemental irrigation[4] (Mejia, 2010).

Although the region would seem to have plentiful supplies of water overall, the drier regions are a cause for concern and so investment in irrigation to address water logged areas and salinization must be an important part of the region's strategy for both water and food security, and poverty reduction.

5. What is technology's role?

What role have AWM technologies played in getting us to where we are now and, equally important, what options and opportunities does technology offer for the future? The innovative use of technology is not just a feature of water management; it is essential and often provides the catalyst for the broader aspects of agricultural development in LDCs. Decisions about technology are among the first to be made in the development process and it is important for all those involved in AWM to make the right choices.

The large public irrigation schemes depend on technology for major water storage, flow control and measurement, water lifting, and for data collection on which management decisions are based. Without these technologies irrigation water managers cannot begin to properly manage and distribute water. The high costs of large schemes, 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 engineering large irrigation schemes to a focus on smallholder farmers who depend on agriculture for their livelihood. Smallholder farmers make up about 80 percent of Africa's population. They manage rainfall and irrigate small farms and home gardens, often less than 1 hectare in size and are the backbone of African agriculture. A similar situation exists in the poorer regions of Asia. Smallholder farmers usually have direct access to surface or groundwater and make their own decisions about how they 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 water as well as help solve water management problems by simplifying the process of watering crops in an adequate and timely manner. But the 'right' technology must be applied, enabling users to innovate and adapt the technology to their circumstances. Above all it must be simple to construct, reliable to use, easy to maintain, and consider gender specific needs. The focus on the small-scale has also substantially reduced development costs but there is the danger that low-cost technology can become a euphemism for cheap and poor engineering. In SSA there are examples of so-called low-cost irrigation schemes in which canal embankments have not been properly engineered resulting in leaks and requiring substantial and costly maintenance.

Technology must also make effective and sustainable use of ecosystem services. Whereas many services to society come from man-made infrastructure, these come from the 'green infrastructure' – healthy rivers and watersheds that filter out pollution, mitigate floods and droughts, recharge groundwater, and maintain fisheries. Technologies which maintain and enhance such services build resilience into our water delivery systems and water use.

What technology should be adopted? This 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 is introduced and implemented.

Generally, technologies fall into two main categories: those which make better use of available water, that is, water saving options that help to increase water productivity (the benefit derived from each litre of water); and those which make more water available including 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 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 becoming increasingly prohibitive. Decision-makers often respond to water needs by building larger versions of familiar technologies – larger dams, deeper wells, bigger pumps, or water transfer from one catchment to another. Extending existing technologies alone, however, does not address unsustainable water use; rather appropriate technological solutions must be combined with improved water management and efficient water use. Furthermore, in dry areas, water management can go hand in hand with opportunities to capture more green water locally.

Although new water technologies are available, older technologies have a higher potential for immediate application. Some of the more promising technologies are listed below. Whichever technology is used, success will be determined more by the capacity of smallholder farmers to take risks, innovate and adopt them in situations where services are erratic, costs are high, and markets are unpredictable.

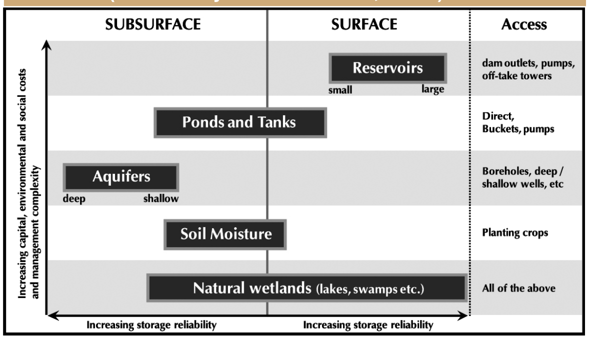
5.1 Water storage

Water storage has perhaps the greatest potential to deliver the improvements in water management. Storage is a (very) old technology and is one that has been exploited throughout history. Water storage is often associated with 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. The IWMI describes storage as a continuum involving both surface and subsurface storage. Surface storage includes natural wetlands and reservoirs and subsurface storage consists of groundwater aquifers and soil water storage that can be accessed by plant roots, tanks, and ponds (Figure 2) (McCartney, 2010).

Storage makes more water available by capturing water when it is plentiful 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 river 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 and reduce water losses. Groundwater storage offers similar benefits and is one of the reasons why 'water scavenger' irrigation using groundwater has been widely applied in Asia. Water 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 2).

Storage options have wide applications and water is accessed and used in a variety of ways. In some cases the storage is managed by small farmer groups and in others by larger more formal institutions. Each has its own niche in terms of technical feasibility, socio-economic sustainability, and institutional requirements (McCartney, 2010).

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



Source: McCartney and Smatkhtin, 2010

The impact of storage on poverty varies considerably. In China and 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. There are examples of storage in reservoirs along canal systems in Nigeria. In Ghana, the storage story is mixed. Some reservoirs have led to more reliable water supplies and have enabled farmers to diversify their crops and have more stable income. But other reservoirs nearby, under similar conditions, have failed to bring about any significant change (McCartney, 2010). This raises the importance of the context in which technology interventions are made.

5.2 Re-thinking canal irrigation

Canal irrigation is synonymous with surface flooding – basins, borders and furrows. On a world scale this is the most dominant irrigation technology. 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 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. Smallholder farmers, who used to depend on the large canal systems for their water, are finding ways around the problem by buying pumps and exploiting local groundwater, often recharged from canal seepage, rather than relying on the uncertainties of canal water. The extensive canal networks cannot be easily abandoned and replaced with small pump schemes. The challenge is to find ways of using existing canal systems 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. Most major canal systems use 'upstream control' technology that not only exacerbates the 'top-ender, tail-ender' problem but is also inflexible to changes in water demand from farmers. This was acceptable in past planned economies when engineers made decisions about how much water was delivered to farmers. But in today's demand driven economies, farmers want much more control over inputs. There are canal control systems, such as 'downstream control', that can improve flexibility and provide on-demand irrigation but such systems would require major re-engineering and would be costly. More local and cheaper options are possible. In the Indian state of Maharashtra a water user association installed pipelines to replace canals in order to distribute water from tertiary canals and to ensure a more equitable share of water. In another scheme, farmers have invested in a storage tank which distributes water through specially designed equal discharge pipelines (Bhamoriya *et al*, 2009). Indeed pipelines, although initially more costly to build than canals, can offer much better control over water supplies, making the system more responsive to farmer demands (Van Bentum, 1994). This is why most domestic water supplies use pipe systems rather than canals – the lack of control over canals would be quite intolerable for most domestic consumers.

Improving canal irrigation is not just a technology fix, but also requires institutional changes. China's public canal irrigation schemes are improving because government irrigation agencies are given incentives

Box 2: 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 in 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 reduce 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, 2010

to align their rewards (for example performance bonuses) with those of the farmers (for example increased crop output) (Johnson III et al, 1998).

There are also options for multi-use canal systems which provide water not just for agriculture but also for domestic, industrial and environmental purposes. Such developments would require significant institutional cooperation across government ministries of water resources, agriculture and the environment.

5.3 Mico-irrigation technologies

'Modern' irrigation technologies, such as sprinklers and micro-irrigation are often seen as one of the keys to increasing food production on smallholder farms which make up a large proportion of the land farmed in LDCs. Sprinklers and micro-irrigation are not suited to the major rice growing areas in South and Southeast Asia, nor are they suited to growing staple grains. But 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. Micro-irrigation can be targeted at selected environments where water costs are high; soil, 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 (Cornish, 1998).

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 by large commercial agri-businesses mainly for high value fruit and vegetable crops. These technologies can improve productivity, raise income through improved crop yields and outputs, and enhance household food security. However, they are not suitable for growing staple cereals.

Although micro-systems 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 realized 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 systems are managed rather than the systems *per se*.

Micro-systems have been extensively marketed in India among smallholder farmers and commercial farmers for over 30 years in line with government policy but with mixed results. The systems were heavily subsidized, at times up to 90 percent of the cost, but the farmers responded moderately. Although the government provided subsidies, other factors were lacking including: groundwater access, crop-specific micro-irrigation technologies, know-how, and access to financing. Additionally micro-systems did not effectively reach the smallholder farmer target group. Rather, the technology was mainly adopted by wealthy commercial 'gentlemen farmers'. Thus greater efforts are needed to promote the technologies to small holder farmers (IWMI, 2006).

Nevertheless, there are some areas in India where smallholder farmers have adopted the technology. Smallholder farmers that employ micro-irrigation tech-nologies tend to intensify their production with multiple crops or switch to higher value crops. For instance in Maharashtra, technology adopters switched from groundnut and oilseed to high water consuming and higher value crops, such as cotton and bananas. Although drip irrigation can increase yields and correspondingly increases income, the economic benefits need to be balanced with higher water demand, which can place greater stress on already scarce water resources (IWMI, 2006). The simple application of technologies is not sufficient to address water scarcity and may at times aggravate the situation; rather micro-irrigation solutions need to consider end-user needs and work within the societal and environmental constraints.

'Affordable' technologies

The investment costs and the inherent risks of modern technologies can be too high for many smallholder farmers, therefore a number of alternative 'affordable' technologies have been developed to fill the gap. These include 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 International Development Enterprises (IDE). They are affordable but often only at a small scale level. A drip kit covering $10m^2$, for example, may cost as little as US$10, which may be affordable. But the same level of investment on a hectare of land would cost US$10,000, which is a very high level of investment and would be difficult to justify on a commercial basis.

Nevertheless, these technologies are characterised by affordable 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. They 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.

Rainwater harvesting is also practised on a small scale around households and home gardens 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 inputs, are simple to manage, and can be built close to households.

5.4 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 fuels, electricity, and renewable energy sources such as sun, wind, and water.

Human powered pumps

Many smallholder farmers still rely on lifting water by hand, using buckets and other similar containers to transport water from source to field. These simple tools, though appropriate for many, are limiting, inefficient, and time consuming. They prevent the poor, particularly women (see section 6.1), from taking up alternative opportunities for income generating tasks.

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 the arms to the legs. They were first developed in Bangladesh in the 1980s for lifting relatively large volumes of water through small lifts of up to 1 m for rice irrigation. Their acceptance among farmers has been described as extraordinary and over 500,000 pumps are now used daily in the country (Kay, 2000). Treadle pumps are seen as a 'stepping stone' between hand lifting and motorized pumping. The initial capital cost is low, between US$50-120, thus investment is modest.

Treadle pumps were introduced into Africa from Bangladesh in the 1990s and are now widely used across the continent. Although the current number of pumps installed is not known, it is estimated that there are many thousands used 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. There are also those who see treadle pumps as yet another means of tying up farmers and their families into yet another form of drudgery.

The transfer of treadle pump technology from Bangladesh to Africa was not without problems. However, commercial companies and NGOs have successfully re-engineered the technology so that it can cope with the different operating conditions that prevail such as undulating land and deeper groundwater sources. Some treadle pumps have now been adapted to sprinkler and drip irrigation systems.

Electric and fossil fuel pumps

A rapid growth in motorized pumping across the world in the past few decades has resulted from the availability of small, cheap petrol, diesel, affordable electric pumps; the development of cheap well drilling technology; rural electrification; and subsidized energy. Pumps provide a level of freedom that smallholder farmers did not have on the larger state-owned schemes. They can irrigate as and when crops need water and when it is convenient to irrigate – usually during the day rather than at night (Snell, 2001).

In places where there is electricity access near farmlands, electric pumps can be an attractive option. However, electric pumps are not a feasible option in areas with an intermittent electricity supply.

Motorised pump costs also tend to benefit large-scale farmers due to economies of scale but tend to be uneconomical for certain smallholder farmers with limited land and revenues (Adeoti, 2009). For instance, in Ghana, the cost of the motorised pump was 5.6 times higher than a treadle pump, a high capital investment for small scale vegetable plots owners (IWMI 2005). Additionally the operational costs of motorised pumps were high compared to the returns. Often users would have to travel long distances for repair support and spare parts. Capabilities in maintenance and repair are important considerations in the adoption of motorised pumps.

Renewable energy powered pumps

Studies on renewable energy sources, such as solar and wind, present mix results regarding technical feasibility and costs. Some studies argue that 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 for irrigation purposes is expensive (Snell, 2001; Fraenkel, 2006). However, other studies have found that some renewable sources are more cost competitive than traditional sources of energy in rural areas and for small scale applications, such as micro-irrigation (ESMAP, 2007; Burney *et al*. 2010).

Box 3: Micro-irrigation examples

KickStart, an international NGO, 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 to not depend solely on seasonal rainfall.

Irrigating 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

Box 4: Labour for lifting water is not always a cheap option

A healthy farmer expends about 250 Watt-hours of energy each day and will use 1 kWatt-hour in four days. At an income of US$1 per day this would be valued at US$4. 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 per litre. If the labourer has access to alternative wage earning work then investing in a petrol driven pump can pay dividends.

Source: Fraenkel, 2006

Box 5: Pumped irrigation in Nigeria

Farmers in northern Nigeria lost their traditional use of the fadamas (wetlands) 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 (hand lifting devices) 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 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 farmers have confidence in the technology. External monitoring helped avoid depletion of the aquifer.

Source: Kay, 2001

Solar power is 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. Both the solar energy devices 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, although this problem can also apply for conventional energy technologies (ESMAP, 2007; Burney *et al,* 2010). A study regarding solar-powered agricultural irrigation found that photovoltaic (PV) pumping irrigation systems are technically and economically feasible, but the main constraint is land availability for the solar array (Kelley, 2010). At present, solar-powered devices are only cost-effective in low-powered and specialised applications. Nevertheless, they should be considered on the list of potential technologies, and future improvements in cost and robustness should improve their competitiveness.

Wind power has been used extensively for lifting water, usually for draining low-lying land where there are persistent strong 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 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 year. Nevertheless, some experiences have shown that wind energy resources can be successfully used for abstracting groundwater and irrigating crops (Al Suleimani & Rao, 2000). In India, wind power pumps hold great potential for smallholder irrigation provided that certain conditions are met such as wind resources, farmer income, etc. (Kumar *et al,* 2007).

The decision to use renewable energy technologies rather than conventional energy sources depends on number of factors: availability of renewable resources on the site, the power needed and type of utilization, among others. Notable examples of application of renewable energy technologies in rural areas are wind pumps for irrigation in South Africa and Namibia. Other applications include small biomass plants for water pumps, micro-hydroelectric plants and solar energy for micro-irrigation (UNCTAD, 2010).

5.5 ICT in water management

ICTs are growing in importance in most LDCs and although they have yet to make a significant impact on agriculture and AWM, there are positive signs. In Ugandan villages, for example, farmers have access to a wealth of information on the Internet and can call 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. An IWMI study indentified more than

6,000 traditional water tanks (small reservoirs to capture rainfall or runoff) in a single sub-watershed in the Krishna basin using Landsat data (Thenkabail *et al*, 2008). If these traditional tanks, built 1500 years ago, were restored to capture just 15 - 20 percent of local rainfall, they could hold some 1.74 cubic kilometres of water – 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 (Pittock *et al*, 2009).

5.6 Common and unconventional water sources

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. When discharged into the sea or into the desert, it is beyond economical recovery. Wastewater is a resource that can be re-used, particularly for agriculture. 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.

Wastewater reuse is high on the agenda in countries across North Africa and the Middle East where water is already scarce. In the Syrian Arab Republic, 67 percent of sewage effluent is reused; in Egypt, 79 percent; and in Israel, 67 percent, mostly for irrigation and for environmental purposes (FAO, 2010a). 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 readably available for total usage. Egypt's water strategy for 2017, which shows more water being used than is available from the country's water allocation from the Nile River, suggests that this entire amount of water reuse is already accounted for in Egypt's water balance (FAO, 2010a).

Wastewater for agricultural uses is also becoming an important issue in Latin America and the Caribbean. Large cities use treated wastewater in local fruit, vegetable, dairy and poultry markets. In Mexico, for instance, approximately 25 percent of municipal wastewater is reused to irrigate 300,000 hectares of land (Mejia, 2010). On the other hand, in some countries, culture and concerns about the quality of treatment are barriers to resuing wastewater. Using effluent to grow crops such as fruit and vegetables is not an accepted practice. However, treated water used to grow processed crops such as grains, root crops and biofuels may be less contentious.

Large scale wastewater treatment for agricultural purposes can involve substantial additional costs compared to freshwater. Wastewater requires treatment to avoid health risks even when the crops are not directly consumed. Municipal wastewater comes mainly from cities and larger towns where there is a high 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 the treated water can be used for agricultural purposes and so canals and/or pipelines are required 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); therefore some means of water storage is essential if all the water is to be effectively used. All this can add considerably to the costs of re-using water for agriculture.

Wastewater usage in agriculture on an informal and unregulated basis is a pressing issue in developing countries which deserves more attention. Globally around 3-3.5 million hectares of land are irrigated with raw or diluted wastewater – double the size of Africa's total formal vegetable irrigation schemes. In many low-income countries, fresh water is not readily available and municipal wastewater treatment facilities hardly exist; thus untreated wastewater is the only affordable option for irrigation in many cases. Additionally, nutrient value in wastewater has lead to increased yields, at lower costs. For instance, farmers in Pakistan on average earn 30-40 percent more per annum when using wastewater for irrigation compared to regular water. Additionally wastewater irrigation employs local suppliers, traders, and others in related services. Women also benefit in SSA, as they make up over 95 percent of vegetable vendors in the region (IWMI, 2006b). On the other hand, the health risks could be extremely high. This connects the issues of food security with the major challenges facing domestic water supply and sanitation, especially in LDCs.

The issue is not whether wastewater should or should not be used in agriculture; rather, how can wastewater be used safely for irrigation with affordable treatment technologies? The policy challenge is to maximise benefits while minimising risks in wastewater use. This would entail the adoption of safety guidelines which are appropriate to the local context, and the diffusion of simple technologies. These technologies include: localised drip irrigation, construction of shallow wells, as well as water collection and application methods which reduce contamination. Many innovative local solutions exist for wastewater treatment. In India's Kikwari village, for example, farmers constructed a wastewater system using pipes to connect the drainage water into settling tanks. The water was then filtered and used for irrigation in school and community gardens (Mikhail *et al,* 2008). It has been observed that farmer field schools can contribute to disseminating good practices and linking research with extension services (IWMI, 2006b).

Desalination

Desalination is a process that removes salt from saline water to produce fresh water. Desalination processes have evolved 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. Desalination 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 (FAO, 2006b).

Since the late 1970s, seawater desalination costs have decreased by nearly 14 times due to economies of scale and continued developments in membrane technology; but costs for deployable technologies have remained largely unchanged (AMTA, 2007). Desalination could be a potential source of water for irrigation but at its current cost of around $0.5-1.5 per cubic metre, the technology is still considered too costly. Some firms, however, are developing new systems that could potentially cut desalination costs by half (Hurst, 2009). There are also concerns about the water being too pure and lacking micro-nutrients for irrigation (FAO, 2006b).

Planners and policy makers still look at desalination as a 'silver-bullet' solution to water shortages. Unless desalination is powered by clean energy sources, desalination will likely worsen the problem they are trying to solve by burning more fossil fuels, 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. However, yields are low averaging only 2-5 litres/day and depend on sun-hours. Solar stills are a useful option for providing basic energy and domestic 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 impacts.

5.7 Improved rain-fed agriculture

Substantial improvements are possible in rainfed agriculture and the technologies are not new. 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 those areas that face the greatest water challenges and where most of the hunger and poverty exists.

Innovative strategies are required to manage the sudden excesses of water and frequent dry spells. For instance, 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. The challenge for the poor is to identify pragmatic options for gradual improvement which are manageable by part-time farmers with limited skills and without access to regular extension advice.

Because the majority of the world's poor and hungry live on rainfed farms in South Asia and SSA, raising farm productivity using these techniques would directly boost food security and incomes. So it is both disappointing and of great concern that these technologies, though widely known, are not being extensively promoted, implemented, and practised (UNCTAD, 2011).

5.8 Conservation agriculture

Conservation agriculture is not directly a water technology but improved water management is one of the benefits. The rainfed farming system is practised on 95 million hectares worldwide, primarily in North America, Brazil, and Argentina, though to a much a lesser extent in Africa and Asia. Conservation agriculture utilises soil and agro-ecosystem resources in a sustainable manner in order to optimise crop yields rather than exploit natural resources to maximise output. Soil cover is permanently maintained with minimal soil disturbance using 'zero-tillage' systems. Crop 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 only beginning to spread in Kenya, the United Republic of Tanzania, and Zambia, where some farmers have doubled or even tripled grain yields. In Zambia, conservation agriculture has helped vulnerable households to survive drought and livestock epidemics. More than 200,000 farmers are now using this technique. In the 2000–2001 drought, Zambian 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 use conservation agriculture (IFAD, 2008).

6. What needs to be done?

Existing AWM technologies are available to help meet the challenge of food security. But history has shown that exploiting the endowed potential of water and land will be challenging 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 their livelihoods. When taking these factors into account, food security becomes an extremely complex issue. Indeed this complexity was one of the reasons why the development community pulled out of irrigated agriculture in SSA in the 1960s and 1970s following disappointing investments in irrigation infrastructure.

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 security have not been high on the international and political agenda. Additionally, water management has not featured high in the agriculture agenda. Farmers and professionals in LDCs lack the capacity to plan, manage, and implement AWM and there are few supporting institutional structures. Furthermore 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 initiated their green revolution in the 1970s by spending 15 percent of their annual budgets on agriculture. The World Bank estimates that a 1 percent increase in agricultural GDP in Africa will reduce poverty by 3 or 4 times as much as a 1 percent increase in non-agricultural GDP. Yet donor countries spend less than 5 percent of their development aid on agriculture in the region (HOC, 2009).

On the positive note, agriculture is now returning to the world agenda and the international community is beginning to re-engage in agricultural investment. There is now a growing recognition that integrating resource management, production, marketing, and consumption is essential for sustainable and profitable agricultural growth. But 'more of the same' will not be enough and the pitfalls of the past must be avoided.

6.1 Focus more on women

Given the important role women play in agricultural production in LDCs, focusing on the unique challenges women face and their lack of access to resources is an important key to increasing overall agricultural productivity (Meinzen-Dick, 2010). Women are often excluded from decision-making and have little choice over the services they receive. They have limited access to water and this is often coupled with their limited access to land. Securing access to land among poor farmers, particularly women, can lead to secure access to water rights (IFAD, 2001).

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. Thus a broader understanding of their needs is essential in order to remove the obstacles that women face. If the

Box 6: Water harvesting in the United Republic of Tanzania

Micro water harvesting systems were introduced into the drier regions of the United Republic of Tanzania to improve maize production giving smallholder farmers 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 water. The need for cooperative group action can also give rise to disputes over water sharing. Whether farmers will continue to prefer macro-systems over 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 the United Republic of Tanzania Government sees runoff as a beneficial resource rather than just a hazard which causes soil erosion. Development of rainwater harvesting is included in the United Republic of Tanzania National Water Resources Management Policy.

Source: Hatibu, 1999

resources accessible to men were made equally available to women, they would increase their farm output by 20-30 percent. On the global scale, agricultural production would rise by 2.5-4 percent. As both research and extension in LDCs are dominated by men, more resources need to be directed towards women in order to narrow the gender gap in AWM (FAO, 2011).

Whilst women's role in agriculture is becoming more recognised, many AWM activities are still associated with men. For instance, the opening and closing of gates and the physical application of water in the fields are viewed as masculine tasks even in situations where women provide most of the labour in the irrigated fields (IFAD, 2007). Furthermore, men often attend to cash crops and livestock while women are associated with tending staple crops, vegetables and kitchen gardens. Thus garden irrigation has become an important focus for women who farm vegetables for home consumption and the local markets. Studies in Nepal (Upadhyay, 2005) show that women play a predominant role in drip-irrigated vegetable production. They contribute almost 90 percent of the total labour and yet the extension and adoption system focuses largely on male farmers and cash crops. Women have received little or no information on improved agriculture and technology. If irrigation is to address the concerns of both men and women, then women should be included in the management of local water resources through Water User Associations (WUA).

IFAD (2007) also recommends new ways of doing business that enable women to benefit from water projects. This includes fixing minimum quotas for land allocation to women and ensuring equal plot sizes for men and women, improving women's access to financial services, providing additional water infrastructure such as wells and handpumps, opening up membership to users of water other than for irrigation, and establishing a minimum quota for women's membership of WUAs.

Multiple-use schemes offer opportunities for women to improve their overall wellbeing and that of society by providing additional uses for water rather than single uses. The public sector was responsible for artificially creating these sub-sectors and categorising water uses for single purposes (IRC and IWMI, 2009), when in practice communities naturally use water for a variety of purposes. Multiple-use schemes recognize that water has many applications and priorities such as domestic use, kitchen gardens, livestock watering, and fisheries, many of which are traditionally the responsibility of women.

Add-ons to irrigation schemes can include steps to irrigation canals to enable access to water for drinking, laundry and other domestic activities, or simply maintaining water in seasonal irrigation canals throughout the year for domestic uses. Similarly, schemes primarily designed for domestic uses can become multiple-use schemes (or 'domestic-plus' schemes). For instance, if 50–100 litres per capita per day are provided, 3 litres per capita per day is designated for drinking and cooking. The water in excess of domestic needs is used for horticulture, livestock, or small-scale enterprise. Additionally multiple-use schemes recognize women's concurrent roles as farmers, housekeepers, livestock keepers, and entrepreneurs. Hence by their very nature multiple-use schemes should be participatory and community-driven. Planners look at *all* users' priorities for *all* water applications and sources instead of the single-use public sector mandate. Moving beyond the sectoral boundaries of the single-use water subsectors, this 'inclusive community-based participatory planning' approach involves men and women alike, leading to a more 'gender-balanced water intervention' (IWMI, 2006).

Overall, gender perspectives need to be mainstreamed in planning processes to ensure the specific needs and concerns of women and men from all social groups are taken into account in the development, use, and management of water.

This is not a new theme, rather it was promoted in the 1980s to improve irrigation performance and it is still highly relevant today. There are still many examples of designs inappropriate for users' context. Canal systems, for example, are often designed with flexibility in mind and have moveable gates so that canal flows can be adjusted to meet crop water requirements. But such systems may not necessarily match the farmers' preference for more user-friendly irrigation technologies. In such cases, fixed water control structures may be a more suitable option, as they offer a more easily managed distribution system (Horst, 1983).

Women in WUAs in Ghana

In Ghana an IFAD-supported water management project established a WUA in which 40 percent of the participating farmers were women. They were allocated 40 percent of the land with plots the same size as those allocated to men even though women were not traditional land owners in the region. Women now play a much greater role in irrigation management, they have direct access to irrigated land, equal time to speak up and present their views, and they generate crops and cash which contribute to family food security and improved nutrition.

Source: IFAD, 2007

Adding domestic water use to an irrigation scheme in Nepal

The Nepal Smallholder Market Initiative, a multiple-use scheme, was introduced in Nepal from 2004-2008. Small stream diversions and water collection tanks were installed to provide a gravity water supply to surrounding village reservoirs for 10-40 households for homestead horticulture and domestic uses. Some households began using drip irrigation. The cost of this multiple-use system was approximately US$50/year per household while the benefits from yielding high-value crops increased income by more than US$180/year on 0.5 hectare plots of land.

Source: Winrock; IWMI, 2006; Mikhail et al 2008

6.2 Focus on existing technologies

Benefits can come from promoting and using existing technologies and adapting them to new circumstances. This is true for both irrigation and drainage technologies. Adapting existing technologies should embrace 'design for management' as many technologies are designed and developed with little thought given to who will manage them, and how they will be managed and maintained.

Design for management also needs to be gender sensitive to enable rural women to fully benefit from schemes. Examples include preferences for irrigation schedules that fit better with family duties and avoiding night irrigation because of gender-based violence or harassment.

In Zimbabwe, although women were the main irrigators, only men were made responsible for and trained to operate and maintain the diesel pumps for

Box 7: Women farmers innovate to solve their irrigation problems in Ghana

A small-scale irrigation project was established on the outskirts of Khumasi for a group of women growing vegetables for local markets. The scheme uses open irrigation channels supplying many plots, each less than 0.1 hectare and 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 other household and family duties that took priority over irrigation. They solved the problem by innovatively 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

water supplies. This lack of control over the supply often meant that women experienced the additional burden of carrying water to ensure their crops were irrigated. Designing schemes using existing technologies for multiple uses can also reduce drudgery and provide women with more time for other productive activities (IFAD, 2007).

6.3 More research for development and better dissemination

There is often a disconnect between AWM research in LDCs and its practical implementation for farmers. Some research topics may not be relevant for farmers while other research outputs may be beneficial but do not necessarily reach their intended audience. New ways of disseminating this information are needed which take into account the needs of end-users. The information should not only be intended for farmers but also presented in an appropriate manner for policy-makers, agro-entrepreneurs, extension staff, and the general public. For instance, researchers in East Africa, are promoting research uptake. Their approach is to build a 'community of champions', now over 800 whose role is to promote AWM with a carefully prepared uptake promotion strategy (NRSP, 2006a). Researchers in natural resources also need to bring social scientists into the team so that their efforts are more end-user and gender responsive.

NGOs also have a vital role to play in linking research with practice. They have the advantage of directly interacting with the local community. Researchers should engage more directly with NGOs to better understand local needs, gain feedback and share information.

6.4 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 mobile phones. These may seem hi-tech options but in view of the rapidly expanding use of mobile phones in LDCs there is scope to provide valuable information and advice to farmers in remote places who do not have access to extension services.

Areas in which ICTs can play an important role in water management are shown in Figure 3.

Special efforts should be made to reduce the gender gap in ICT access and use, particularly in view of the significant role that women play in agriculture (Melhem *et al,* 2009) (see section 6.1).

6.5 Build new institutions

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

At a national level, monitoring, collecting, and synthesising data on water resources is an essential part of managing and regulating water resources. So too is communication across government departments with water management responsibilities. Bridges need to be built between the various ministries that deal with water, food, agriculture, environment and finance. In many countries, responsibility for water in agriculture falls between the Ministry of Agriculture, which deals with AWM 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 is an essential ingredient in integrated water resources management.

Decentralisation is a key policy for many LDC govern-

Box 8: 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, 2011

In 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, [higher] school enrolment 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

Figure 3. Major areas for ICTs in water management (ITU, 2010)

Mapping of Water Resources and Weather Forecasting	Asset Management for the Water Distribution Network
Remote sensing from satellites In-situ terrestrial sensing systems Geographical Information Systems Sensor networks and the Internet	Buried asset identification and electronic tagging Smart pipes Just in time repairs / real time risk assessment
Setting up Early Warning Systems and Meeting Water Demand in Cities of the Future	**Just in Time Irrigation in Agriculture and Landscaping**
Rain/storm water harvesting Flood management Managed aquifer recharge Smart metering Process Knowledge Systems	Geographical Information Systems Sensor networks and the Internet

Source: ITU, 2010

ments but local management relies on sustainable local institutions capable of engaging local communities and articulating their needs as well as analysing, designing and implementing policies and innovations. The essence of such organisations is social capital, which will need strengthening if decentralisation is to succeed.

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

6.6 Develop AWM capacity

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

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 institutional structures, such as water abstractor groups and extension support services, and providing a favourable environment condusive to increased food production and agricultural water investment. For example, reducing tariffs on imported pump sets or other irrigation and soil improvement technologies would help to lower costs and make agriculture more profitable (FAO, 2004).

6.7 Support Public-Private-Partnership

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 traditionally government/aid funded activities. These need not be two separate sectors of the economy. Rather there are opportunities for cooperation between the two and for smallholder farmers to join with commercial farmers for a potential 'win-win' situation.

In Zambia, smallholder farmers and emerging commercial farmers are encouraged to cooperate (Tardieu, 2009). Smallholder farmers can benefit from accessing the value chain and acquiring more knowledge on modern farming techniques and management skills. Commercial farmers benefit from economies of scale, being able to purchase crops from neighbouring smallholder farmers, and adding value such as maize milling and bio-fuel processing. Including smallholder farmers in commercial irrigation schemes can also reduce unit water costs. The approach is based on three principles: irrigation

Box 9: Strong social capital supports traditional rice irrigation

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

Source: NRSP, 2003

schemes must be financially sustainable – with an emphasis on smallholder schemes; they must be professionally managed; and there must be inclusive business opportunities for both input supply and for marketing produce.

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

6.8 Encourage the private sector

Many AWM developments around poverty are based on aid. But there are considerable opportunities for the private sector to engage commercially in the supply of water management technologies (See Box 3 for examples in India and Nepal). African AWM decision makers and farmers can learn from this as there are considerable opportunities to introduce affordable, appropriate pumps manufactured or assembled locally. Similar opportunities exist for the supply of drip kits and treadle pumps and the development of supply chains that offer support and spare parts.

To be commercially successful, products must make a significant positive contribution to the income and productivity of the customers who purchase them; they should be affordable; have a very short payback period; and match specific customer requirements such as fitting the small plots typically managed by smallholders farmers.

6.9 Focus more on youth

Over 25 percent of the world's population is between 10 to 24 years old and in some African countries it is 35 percent – many are born into poor rural families. Youth are 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, 2006b).

6.10 Increase water-food trade

Some 85 percent of the water used by the world's half billion farms produces food commodities that remain within the producer economies. Only 15 percent of farm output in terms of embedded water is traded internationally. This trade in water embedded in food-products, known as 'virtual water', between water-rich and water-short nations may 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 versus self-sufficiency will not be easy to resolve. Poorer countries may wish to continue over-exploiting water resources to feed their populations. Industrialising the economies of water-scarce countries is seen as a long term means of raising GDP in preference to a continuing dependency on agriculture and particularly low-value food and fodder crops (World Bank, 2007).

6.11 Strategy in Asia

In Asia, new strategies for improving AWM are being established. A useful five point strategy is outlined as follows (Mukherji, 2009):

- 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.

6.12 Strategy in Africa

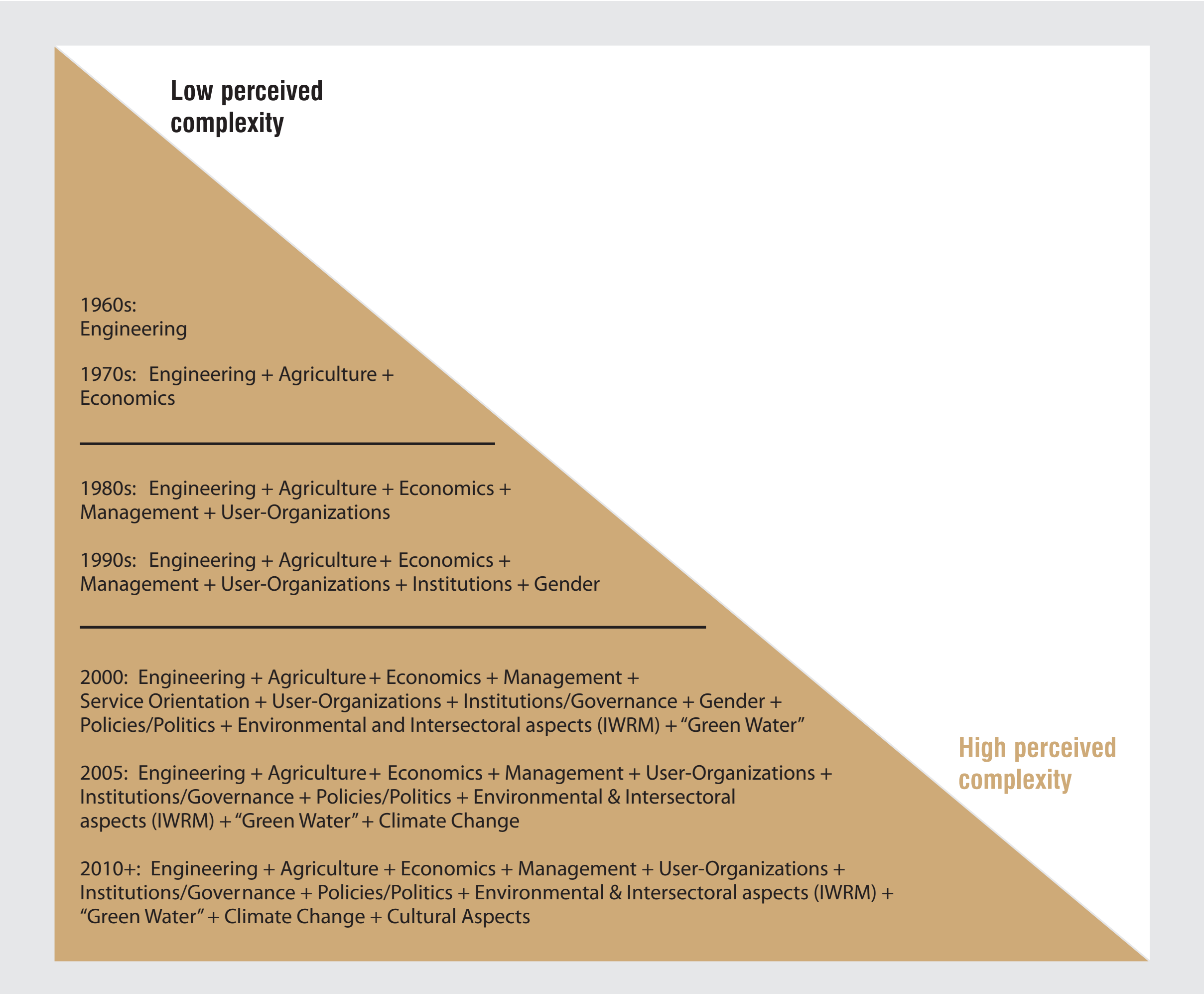
In SSA the 'Comprehensive Africa Agriculture Development Programme' (CAADP) established by the New Partnership for Africa's Development (NEPAD) in 2002 has set the agricultural development agenda for the whole region with a pillar focusing on land and water development. A group of key donor agencies 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*, 2007):

- Advocacy – AWM needs to convey a strong positive message such as water for food, water for wealth, and 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 investment 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.

6.13 Strategy in Latin America and the Caribbean

Whilst Latin America and the Caribbean is one of the

Figure 4. The growing complexity of managing irrigation systems (Huppert, 2009)



Source: Huppert, 2009

Box 10: 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 by qualified staff to meet the diverse cropping patterns in the valley. Because of staff constraints this proved difficult to manage and the unpredictability of the water supply due to unforeseen water scarcity added to the problems of managing the supply. Since there was little or no interaction with farmers throughout the process, some farmers would break the boxes and open valves to access the water. JVA rebuilt the boxes and tried to prevent farmers from illegally opening valves but this was unsuccessful.

In recent years JVA has realized that water delivery under conditions of diverse cropping patterns and unpredictable water supplies is a complex service requiring 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

few regions in the world with sufficient land and/or water available to increase agricultural production, this potential is jeopardized by high rates of natural resource degradation (FAO, 2010b). From an AWM perspective the key regional issues identified include:

- Improving agricultural productivity in parts of the region.
- Developing less water intensive and more drought tolerant crops.
- Optimising water storage and distribution of water using on-demand water supply systems.
- Protecting irrigated areas from flood damage and maintaining drainage systems.
- Introducing more water-efficient growing practices.
- Improving water governance and institutional capacities to ensure that existing plans function properly.

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, less on *where* and with *whom* and most importantly *how* to implement it. The question of how to implement AWM schemes is largely ignored as decision-makers and donor agencies rarely address the full complex interactions between individuals, the state, and service providers, and the limited absorptive capacity to translate plans into practice.

There are no simple universal 'blue print' solutions as technology choices depend on local people and circumstances. But having selected appropriate interventions for specific locations and target groups, how can governments and agencies successfully intervene in complex and changing AWM systems with specific technical, environmental, socio-economic, and institutional challenges? Recognising that AWM systems are complex is an important step as well as realising that AWM is also embedded in the wider political and socio-economic fabric of society (Figure 4). These factors can make intervention complicated to implement but ignoring them can lead to rigid systems that cannot respond to change.

Some interventions are relatively straightforward, such as canal maintenance. Changing agricultural production from rainfed to irrigated agriculture is much more complex and requires a great deal of interaction between individuals and between organisations. These more complex interventions will place new demands 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, and citizens (Huppert, 2009).

Improving AWM in LDCs is usually based on the assumption there is good governance and a supportive institutional framework. This is not usually the case. Introducing new formal institutions such as Water User Groups within local social structures can be challenging 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 scaling up of successful experiences are not within the fiscal realm of LDCs.

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 strengths and engaged with local farmers and communities using indigenous knowledge and recognizing local water rights (Huppert 2009) (see Box 10).

8. Conclusion

This paper sets out the water and food security challenges in LDCs and developing countries. The general consensus is that there is sufficient water to meet global needs. Carrying on with the 'business as usual' model is not an option. It is up to stakeholders, smallholder farmers, researchers, policy-makers, and governments to innovatively use AWM technologies in addressing the growing food demands with finite water resources.

Some key messages:

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

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

These facts about water for agriculture are not well understood by the general public and indeed many development professionals. AWM 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 smallholder farmers, many of whom are women. Water technologies appropriate to their needs will play a crucial role in meeting the food security challenge. Women have only limited access to a wide range of physical assets such as agricultural inputs, technological resources, land and water. As a participatory and community-driven approach, multiple-use schemes provide greater opportunities for women by recognizing their concurrent roles in the agricultural sector and addressing their needs in water allocation and management.

Many benefits will come from using existing technologies and adapting them to new situations so they are appropriate in terms of location, people, and purpose. Investment in water technologies must also form part of a comprehensive investment in a range of farming and value chain market-orient services.

Research must focus on this process of adaption and innovation. Researchers must also focus more on uptake and dissemination of information and knowledge and tailor it for different audiences including farmers, policy-makers, 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 smallholder farmers.

Many LDCs have a severe shortage of capacity for AWM. To address this shortage would not only entail training individuals but also institutional building and the creation of an enabling environment in which agriculture can flourish.

Public Private Partnerships offer new opportunities to improve AWM as well as the prosperity of small-holder farmers.

Institutional structures and technologies that recognise the key role that women play 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 an abundance of good advice 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.

NOTES

[1] FAO (1992) defined safe food as follows: "food supply must have an appropriate nutrient content and it must be available in sufficient variety and quantity. It must not endanger consumer health through chemical, biological and other contaminants and it must be presented honestly."

[2] Bruinsma (2009) produced similar predictions for 2050

[3] South Asia: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

East Asia: China, Democratic People's Republic of Korea and Republic of Korea, Japan, and Mongolia.

Southeast Asia: Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Thailand, and Viet Nam.

Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

[4] IFAD defines supplemental irrigation as "the addition of small amounts of water to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields".

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