TOPIC GUIDE

Irrigation Infrastructure for Sustainable and Improved Agricultural Productivity

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Executive summary

The purpose of this Topic Guide on **Irrigation Infrastructure for Sustainable and Improved Agricultural Productivity** is to provide basic information and stimulate thinking about: (i) irrigated agricultural systems and interventions to achieve sustainable increases in agricultural productivity, and (ii) how interventions in irrigation infrastructure and services can be designed and implemented to provide foundations for sustainable agricultural productivity and poverty reduction.

The Topic Guide is written for DFID staff, but is relevant to all development professionals interested in agricultural water management. It is intended to be informative for both non-experts and experts interested in irrigated agriculture and related infrastructure. It is not a comprehensive manual, but aims to provide sufficient information to assist development professionals involved in irrigation to take practical steps in their day-to-day work and to inform users where to look for more information.

The Guide focuses on sub Saharan Africa (SSA), and provides an overview of current thinking on how to identify and implement investments in irrigated agriculture that are robust and responsive to the needs of evolving rural communities.

The Topic Guide was written by a team from the International Water Management Institute (IWMI) with contributions from IWMI researchers based in Ethiopia, Egypt, Ghana, India, Nepal, Pakistan, South Africa and Sri Lanka.[1] Issues related to infrastructure are presented; but the Guide stresses that addressing irrigation infrastructure alone is insufficient to achieve the objective of sustainable and improved agricultural productivity; particularly in the light of climate change and other environmental challenges across SSA.

Chapter 1 briefly describes what irrigation is, and its importance globally and in the context of sub-Saharan Africa (SSA). It examines the need for increased investment in improved and optimised agricultural water management in the region, the importance of learning from past mistakes, and understanding the complexity of irrigated agriculture, and not just the technicalities of designing, building, and operating irrigation systems.

Chapter 2 introduces key aspects of the development context in which investments in irrigated agriculture do and will take place in SSA. The evolving rural demographics, rural-urban migration, and climate change make it essential that the renewed interest in irrigation by national governments and development agencies results in better outcomes for rural poor and more sustainable irrigated agricultural systems.

Chapter 3 describes the main characteristics of irrigation systems from water source to the farmers' fields, including infrastructure and institutional arrangements with a focus on smallholder agriculture in SSA.

Chapter 4 addresses the question of what technologies to use on-farm, including brief summaries of the advantages and disadvantages of common technologies.

[1] IWMI researchers who contributed advice, experience and their research findings to this Topic Guide were: Jennie Barron, Everisto Mapedza, Amare Haileslassie, Bedru Balana, Gebrehaweria Gebregziabher, Fitsum Hagos, Ted Horbulyk, Jonathan Lautze, Nicole Lefore, Barbara Van Koppen, David Wiberg, and Tim Williams. See www.iwmi.org for details of IWMI staff research activities.

Chapter 5 explores what institutional and regulatory frameworks are necessary to support sustainable increases in agricultural productivity and effective management of land and water resources. Irrigation depends on implementing a number of inter-related functions, carried out by various parties, often with different interests.

Chapter 6 offers direction to answer the question – how to develop successful irrigation. In general irrigation development, rehabilitation or modernisation of existing irrigation systems involves a wider range of interventions than "just fixing the infrastructure". This chapter includes checklists to assist task managers to navigate the design and implementation of an investment program in irrigated agriculture.

Chapter 7 provides suggested reading - the 5 top reads on irrigation.

Annex 1 – reproduces the checklists from Section 6.

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Abbreviations and Acronyms

ADB	Asian Development Bank
AfDB	African Development Bank
CAADP	Comprehensive Africa Agriculture Development Program
CPWF	Challenge Program on Water and Food
DFID	Department for International Development
FDI	foreign direct investment
IMT	irrigation management transfer
IWMI	International Water Management Institute
MAI	Moisture Availability Index
O&M	operation and maintenance
PIM	participatory irrigation management
SPIS	solar pump irrigation systems
WUA	water user association
WUG	water user groups

Glossary

consumptive use – this refers to the volume of water that evaporates (transpiration) from crops, natural vegetation, and soil surfaces. Consumptive use includes beneficial consumption – transpiration for production of crops; and non-beneficial consumption – water that is evaporated other than for the intended purpose. In many schemes less than 50% of the water withdrawal from rivers and groundwater is consumed.

irrigation modernisation - Process of upgrading infrastructure, operations and management of irrigation systems to sustain the water delivery service requirements of farmers and optimise production and water productivity

irrigation scheme – in this Topic Guide this refers to the combination of the irrigation infrastructure (the irrigation system), its management and farming system

irrigation service fee – charge to farmers for delivery of water. Generally based on the type and area of crop grown with different rates in different seasons. Rarely set at a level sufficient to cover the actual operations and maintenance cost of the infrastructure leading to deterioration of the asset and declining services levels, with subsequent reduction in recovery of irrigation service fees.

irrigation system – in this Topic Guide – irrigation system refers to the physical infrastructure provided to obtain water resources and to deliver, apply, and remove excess, water for agricultural purposes

laser grading/levelling – mechanised field preparation techniques to provide a precise surface gradient for improved field irrigation with surface irrigation techniques

micro irrigation – field application technologies, including drip, trickle and mini-sprinklers

surface irrigation – field application techniques, including basin, furrow and border strip field layouts. High application efficiencies can be achieved when field layout, irrigation stream size, and application times are managed well.

water use – in this Topic Guide refers to the flows in the irrigation system for the purposes of delivering an irrigation to the crop. It is the same as the withdrawal.

water productivity - defined as crop yield per cubic metre of **water** consumption, including 'green' **water** (effective rainfall) for rain-fed areas and both 'green' **water** and 'blue' **water** (diverted **water** from **water** systems) for irrigated areas

withdrawal – this refer to the extraction of water from surface or groundwater resources for use in irrigation. It includes beneficial and non-beneficial consumption and water that is not consumed and which either returns to the river system or recharges groundwater.

wetting front indicator – simple device to improve field application efficiency. The device is buried in field to indicate when irrigation water has infiltrated to a specified depth and therefore irrigation should be stopped

SECTION 1

Irrigated Agriculture in sub-Saharan Africa

1.1 Irrigation is…

Irrigation is one component of Agricultural Water Management (AWM)[2]. It is about applying water to crops from surface and groundwater sources when natural rainfall is not enough to, reliably, produce desired crop yields and quality. Irrigation is an important technology as food, fibre, and bio-energy crops all need water to grow and lots of it. The average European diet consumes 3,500 litres per person per day. To grow wheat in Egypt requires at least 1,000mm of water, usually pumped from the River Nile, and applied at regular intervals over the growing season. In arid regions it is not possible to grow crops without irrigation. In more temperate regions, natural rainfall may not be sufficient or sufficiently reliable to produce acceptable yields and good crop quality and so some farmers practice supplementary irrigation to make up the short-fall. Supplementary irrigation is not essential, rather it is an economic decision based on the costs and benefits of applying more water and improving returns from increased crop yields and quality.

Irrigation is like insurance. It enables farmers to produce good, reliable crop yields, often 2-3 times those of rain-fed crops, provided they have all the other agricultural inputs such as good seed, fertiliser, and pesticides. Irrigation can reduce the impacts of frequent and severe droughts but does not eliminate all the risks of water shortages. During severe droughts, water for irrigation may not always be available as the water source may be just as vulnerable to local rainfall conditions as the cropping.

Irrigated farming systems play an important role in global food security. Some 300 million hectares are irrigated producing over 40 percent of the world's food and natural fibre. What is not always recognised is that 70 percent of the world's freshwater withdrawals are already committed to irrigated agriculture. In developing countries, including some in sub-Saharan Africa (SSA), this figure can reach more than 90 percent of available water nationally.

In SSA estimates suggest that irrigation is only practised on 6 million hectares, 5% of agricultural land, even though the region is well endowed with land and water resources which are largely under-exploited. Unfortunately, they are not evenly spread, though substantial resources do exist even in the drier areas to increase both the area and performance of irrigated agriculture.

In 2002, the Comprehensive Africa Agriculture Development Programme (CAADP) prepared under the New Partnership for Africa's Development (NEPAD) adopted land and water management as the first of its four pillars for priority investment. Pillar 1 aimed to extend the area under sustainable land management and reliable water control systems to 20 million hectares by 2015 (NEPAD, 2003). This target has not been met. However, there is no indication and no way of verifying this due to lack of baseline and current data on areas

[2] Agricultural water management (AWM) is about providing crops and animals with the water they need, enhancing productivity, and conserving natural resources for the benefit of downstream users and ecosystem services. AWM includes irrigation, but is broader than applying water to crops. It includes soil, land, and ecosystem conservation practices, such as drainage and watershed management; fisheries management; and technologies for lifting, storing, and conveying water.

irrigated. This plan has now been significantly scaled back to a more realistic target of increasing the area under irrigation by at least 5 million hectares by 2025 (NEPAD, 2016).

Agriculture remains the mainstay of most economies in the region and smallholder farmers are the backbone of agriculture, producing most of the region's food. Some 70% of the region's estimated 400 million poor people live in rural areas and practise rain-fed farming during the unreliable and drought-prone wet season on small plots of 1-2 hectares. This is subsistence farming where low yields and crop failures are the norm and food aid is often needed to avoid widespread hunger and malnutrition.

In spite of the recent growth in agricultural GDP, hunger, malnutrition, and poverty still persist. Agricultural productivity is the lowest in the world, with per capita output only 56% of the world average. Additional challenges are posed by climate change, the impact of conflict and continuing volatility in food prices.

Most existing irrigation involves smallholders working individually or in small groups growing crops for home consumption and local markets, although some grow for export. There is a growing number of larger, more formal government-funded and run irrigation schemes, but many of these face difficulties in terms of investment, effective operation and maintenance, and reliable support services. Essential support services include the supply and management of agricultural inputs, such as seeds, fertiliser, machinery, irrigation and management of outputs including effective marketing for produce. There are some successful commercial irrigated estates growing tea, coffee, and sugar, mainly for export. Smallholders are often encouraged to practise irrigation farming alongside the estates as out-growers. Some estates then provide smallholders with the support services they need.

Well-managed irrigation systems, both smallholder-led and government-led, can reduce the risks associated with crop production, and enable farmers to, more confidently, commit more investment in their crops, raising yields, crop quality, and income. Although farmers recognise that irrigation is a highly desired agricultural input, the history of poor performance of many schemes also makes farmers cautious. Irrigation is likely to be an important means of adapting to climate change to enable food security, making it essential that irrigation services are made more reliable (Grist, 2015).

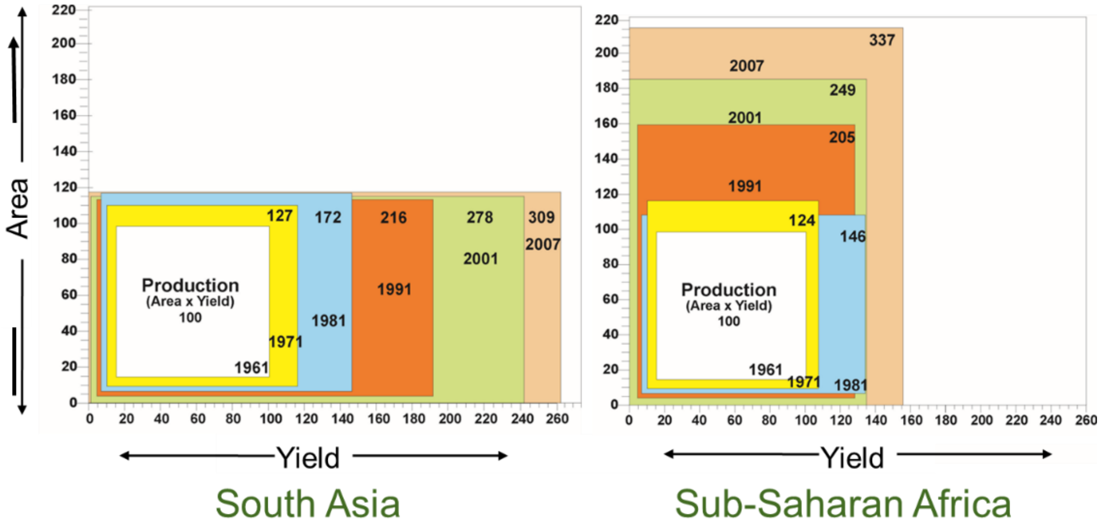
1.2 Learning from past mistakes

Investments in irrigation over the past 50 years have often failed to meet expectations and so it is important to understand why this occurred so that mistakes are not repeated.

Both Asia and SSA have irrigation potential but it may be helpful to compare their different approaches to increasing irrigated production. The development trajectory in SSA has largely been based on expanding the irrigated area, whereas in Asia the emphasis was on intensifying production on existing land (Figure 1.1). In both regions, investments in irrigated agriculture have been plagued by a history of cost-overruns, poorly performing systems, and concerns regarding sustainability, governance, and equity of investments in the sector.

Figure 1.1 Development trajectories of agriculture in South Asia and Sub Saharan Africa (1961-2007)

Notes: X and Y axis are dimensionless – 1961 = 100.
Source: Henao J. and Baanante, C. 2006.



During the 1970s and 1980s much of the global development focus was on building large government-managed irrigation schemes. But poor performance in terms of project implementation, and subsequent water management and food production left the persistent perception, particularly in SSA, that irrigation failed to live up to expectations even though governments formulated and implemented numerous policies over the last 50 years to address the problem. Furthermore, doubling the area under large-scale irrigation, the normal focus of government-led investments, would only increase the contribution of irrigated agriculture to food supply in SSA from 5% at present to 11% by 2050 (Molden 2007). Governments and their development partners often see large-scale irrigation as an attractive focus for investment and as such they pay less attention to the potential of micro, small and medium scale irrigation which, as history shows, has greater potential to reach the rural poor. In addition, large-scale investments are expensive (Inocencio et al. 2007), take a relatively long-period to mature, and only reach smallholders who farm close to where the systems operate.

The perception of failing irrigation services in SSA is derived mainly from experience with government-run large-scale schemes, which were costly to build in comparison to other parts of the world. Most failed to achieve predicted service areas and/or expected agricultural production. This occurred at the time when world food prices were falling through the latter part of the 20th Century (Field and Collier, 1998). What has become clear is that too much attention was focused on infrastructure – designing and building irrigation schemes – with little thought given as to how they would be managed and maintained to produce marketable food and fibre crops. Little thought was given to the wider socio-economic implications of irrigation development. Furthermore, in attempts to reform irrigation management in the 1990s, too little attention was given to recognising the role of power and politics in shaping reform outcomes – for instance, focusing mainly on the need to transfer irrigation system management from government to farmer groups (Water User Associations (WUAs)). In many countries this was seen as a means of reducing government costs and responsibilities, and reform efforts continued to overlook the existing power relationships between farmers, the rural elites, and the irrigation bureaucracy, and how this influences actual transfer. Global experience in irrigation reform also indicates that irrigation bureaucracy staff often have different interests, objectives, and policy preferences

(Oorthuizen, 2003; Suhardiman, 2008; Yalcin and Mollinga, 2007) to those planning reform and as such they tend to frustrate the process of change. It is like asking 'turkeys to vote for Christmas'.

The disappointing experience of under-performing irrigation triggered a shift in development thinking towards small-scale irrigation in which smallholders, both individually and in groups, had greater control. Individual farmers and communities began investing in water-lifting devices, such as shadufs, treadle and petrol driven pumps to grow marketable crops and exploiting local streams and shallow groundwater resources (Box 1.1). This was grass-roots driven and independent of government funding and management. It has been largely successful and accounts for a large portion of the 6 million hectares irrigated. Irrigation opinion from the 1980s was that any attempt from government to invest in this approach would probably kill it.

Box 1.1 Small-scale irrigation could change the lives of millions of people

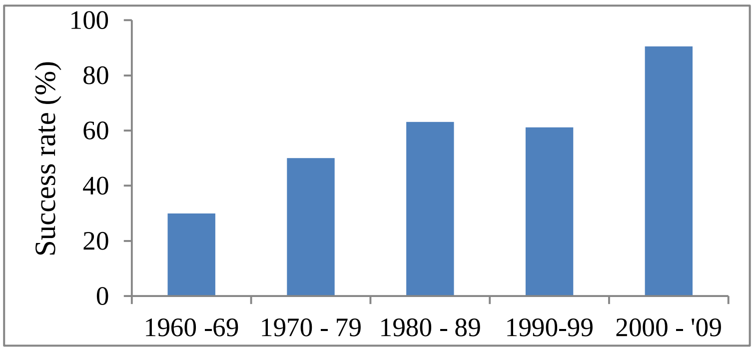
Smallholder farmers in SSA are increasingly using small-scale irrigation to cultivate their land. Individually owned and operated irrigation technologies improve yields, reduce risks associated with climate variability, and increase incomes, allowing farmers to purchase food, health care, and education. There is great potential for many more farmers to benefit from small-scale irrigation. The AgWater Solutions Project examined AWM in practice and provides governments, donors, lending institutions, the private sector, and farmers with information to make well-informed decisions about investments that could change the lives of millions of rural people. Source*: Giordano et al (2012)*

1.3 Why is there renewed interest in irrigation?

In spite of past failures, irrigation still has significant potential for economic growth, food security, and poverty reduction. Against this backdrop, the need to tap the potential of irrigation in all its forms, for improved food and nutrition security, poverty reduction, and environmental stability has never been greater.

Mutiro and Lautze (2015) show that the success rate[3] of investments in irrigated agriculture has improved since 1960 (Figure 1.2).

Figure 1.2 Irrigation scheme success rate (by decade) Mutiro and Lautze



[3] Mutiro and Lautze (2015) classified success or failure by analysis of five criteria applied successively until a clear result of success or failure could be determined. The criteria were: (i) EIRR or ERR >10% - success; (ii) Gross margin positive – success; (iii) Net income per ha positive – success; (iv) Yield >50% of local potential – success; and (v) Actual area irrigation divided by area equipped for irrigation >50% - success.

1.4 What has changed to suggest improved outcomes?

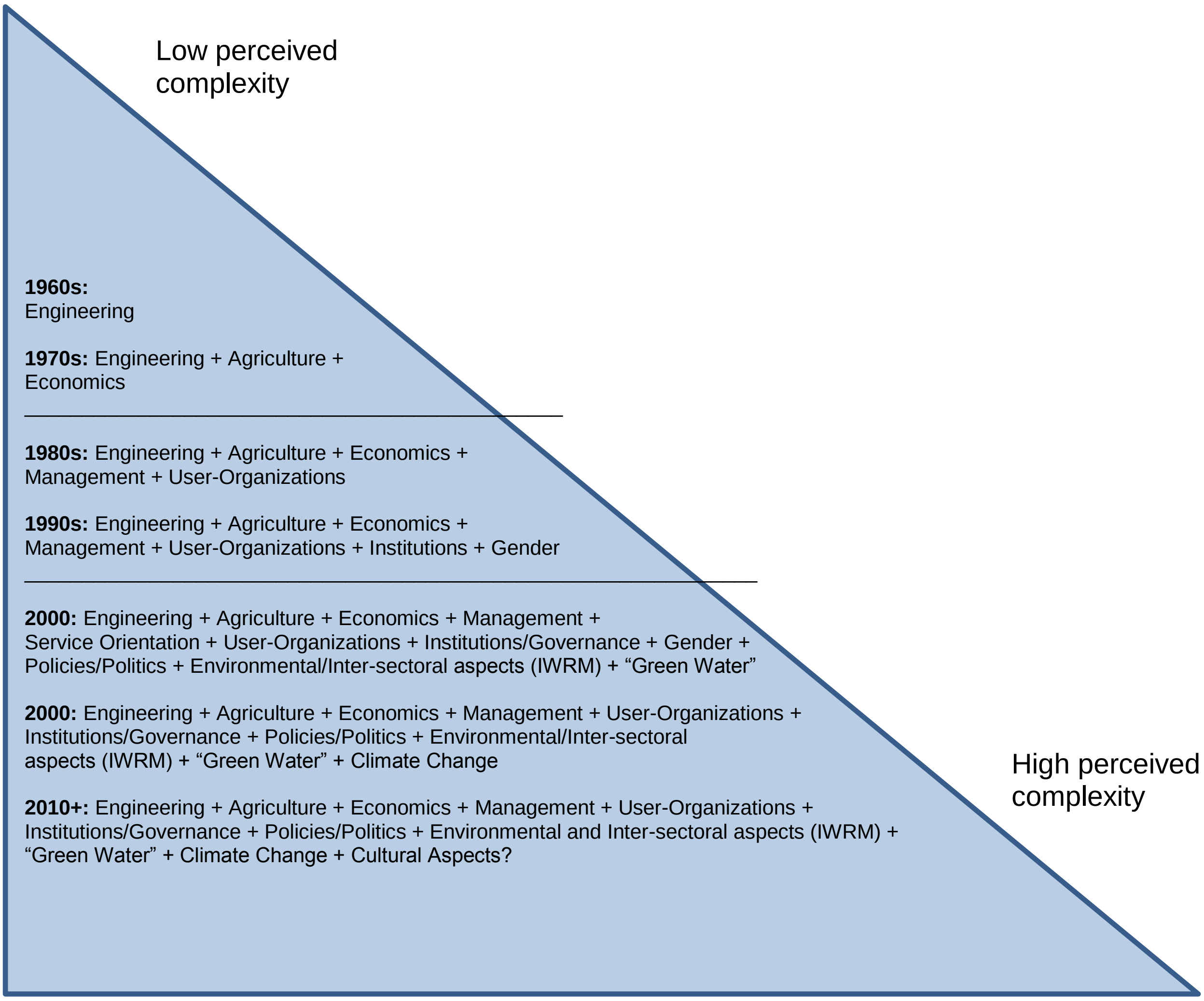
At the 23rd African Union Summit in Malabo, Equatorial Guinea (June 2014), Africa's Heads of State and Government signed up to the Malabo Declaration for transforming Africa's agriculture. The declaration marked the continent's renewed commitment to clear, measurable agricultural transformation and growth targets – realising the value and impact of agriculture on broad socio-economic growth and development indicators. The targets include sustainable increases in agricultural productivity and production with growth of irrigated agriculture explicitly identified as a key requirement. The focus is expected to be mainly on expanding the area under irrigation, but recognises the need to improve the quality and appropriateness of irrigation technologies.

Many governments (e.g. Ethiopia, Kenya, Ghana, Malawi, Mozambique, Nigeria and Tanzania) have significantly renewed their interest in irrigation. Development partners (e.g. EU, JICA, USAID, and World Bank) are also renewing their interest as well as foreign and domestic investors (e.g. in Ethiopia, Ghana, Nigeria, Tanzania and Zambia). This all reflects growing global concerns about water security (UN Water, 2013), the link to food security and a realisation that sustainable irrigation has an important part to play in driving a 'green revolution' in the region after decades of under-investment in AWM.

The NEPAD Agency, with partners, is developing a private sector-led initiative to catalyse accelerated expansion of area under irrigation by at least 5 million hectares by 2025. This will address aspects ranging from skills development (technical and management) through to ensuring access to irrigation technologies appropriate in the local ecosystem and business environment.

The renewed emphasis on irrigation coincides with a growing recognition that providing irrigation services is not simply a technical engineering under-taking but involves addressing the complex interaction of multiple disciplines. Huppert (2009) examined how perceptions of irrigation systems and services have evolved over the past 50 years from a relatively simple engineering and technology issue to one that now involves almost everything including the proverbial 'kitchen sink' (Figure 1.3). Huppert suggests that for investments to perform substantially better when creating new irrigation systems or rehabilitating and reforming existing irrigated agriculture, it is important to understand and influence how the sector actually works in practice, and how irrigation services and change processes must be shaped not only by the bio-physical constraints but also by political, social and cultural considerations. Focusing on the interests, perceptions and strategies of policy actors (irrigation bureaucracy, farmers, WUAs, the rural elite, politicians) in relation to defined policies and how these shape and reshape negotiation processes, resource allocations and the formation of alliances in policy processes is crucial to unpacking how existing power relationships shape outcomes.

Figure 1.3 Chronology of perceived complexity of irrigation systems (Huppert, 2009)



1.5 Summary

Ask any farmer what they want and the answer will often include irrigation. Done well, irrigation can remove much of the uncertainty from crop production, giving the farmer confidence to invest in better seeds and other inputs. However, irrigation sector projects fail when they do not adequately take into account the development context in which investments are being made. Creating an improved irrigation service requires the consideration of a wide range of bio-physical, socio-economic, cultural and political economy issues. Investments in irrigated agriculture can be derailed if they do not address the multiple stakeholders within the irrigation community. It is critically important to consider how individuals might perceive the planned investments and reforms in relation to their own roles and responsibilities. This is a particular issue in efforts to reform irrigation agencies – both formal and informal. These issues are explored further in the following sections.

SECTION 2

Why Irrigate?

This is a key question given past experiences in irrigation in SSA and the renewed enthusiasm both from governments and funding agencies. Deciding to irrigate can help to solve some important problems facing individuals and nations, but it does bring a whole new set of problems as well.

2.1 Irrigation as a pro-poor investment

Food and water security are critical issues in pro-poor development strategies. Food production is fundamental to reducing hunger, and water is essential for food production (Rauch, 2009). While demands for food continue to increase, water availability for food production is becoming more constrained due to increased use by other sectors and to climate change. The ability of farmers to access and control water has a direct impact on potential crop yields and income. Lack of access has indirect impacts by reducing potential payoffs from investments in fertilisers, improved seed varieties, and in learning technical skills (Box 2.1). Not only does this cause agricultural productivity growth to stall, it leaves farmers and nations reliant on the vagaries of weather for their well-being. Interventions to improve AWM in rain-fed and irrigated agricultural systems seek to reduce the risks associated with crop production and food security, and contribute to poverty reduction.

Box 2.1 Irrigation is not without risks

A note of caution. Irrigation tends to move smallholders from subsistence farming and into the market place and this can be a high risk venture for the unwary and impoverished. When a few farmers take the risk and invest to produce vegetables for a local market it can bring good profits but when lots of farmers get involved, unsophisticated markets can quickly become saturated with produce and prices fall. With little or no effective market structures in most of the region and no effective storage facilities, smallholders may experience serious losses which they can ill afford. Research indicates that it is the younger farmers who are more willing to invest and take risk, rather than the older more established farmers (Mahoo et al, 2006)

2.2 Feeding a rapidly growing population

From 2000 to 2013, SSA's average annual population growth rate was 3%, while urban population grew at 4.1% (World Bank, World Development Indicators, 2015). Over the next 30 years most of the world's population growth is expected to be in Africa and South Asia, in areas least able to deal with the problems of water and food scarcity. Increasing population pressure and low agricultural productivity have led to persistent hunger and made food security a key priority for African governments. These pressures have led to a many large-scale government-run irrigation schemes, which were designed to produce cotton fibre for exports, focusing instead on staple food production in a bid to ensure food self-sufficiency.

2.3 Growing and changing demands for food

As a result of urbanisation and income growth, diets are changing and increasing the demand for horticulture products – vegetables, fruits, and spices. This growth in demand, both domestically and externally, is promoting new opportunities for horticulture in irrigated farming systems in several African countries including Kenya, Ethiopia, Zambia, Ghana, and Nigeria. Irrigation has become an essential input in meeting the quality and market timeliness required in sophisticated urban and international markets.

In some countries, for example in Ghana, informal irrigation in the rural-urban interface covers an area greater than the area under formal government-run irrigation (Dreschel et al, 2006). Irrigation in urban and peri-urban areas enables producers to take advantage of expanding urban markets and overcome the lack of market infrastructure, such as refrigerated transportation and storage. This complements traditional rural agriculture sources which also feed cities with fresh vegetables (ibid).

Rural-urban migration is drawing family labour away from irrigated farming. The past few decades have seen an unprecedented rise in out-migration across rural Africa and Asia, brought about by the combined pressures of climate change, demographic pressure and rising living costs (FAO, 2012). With growing movement between cities and rural areas, and between countries, there are both opportunities as well as threats to sustainable irrigated agriculture and water management. International and internal labour migration has provided an opportunity for diversification and remittances can provide income which can flow back into agriculture (Paris et al., 2005, Singh et al., 2013).

But out-migration can have unforeseen consequences on the management of land, wetlands, and communal irrigation resources. Firstly, out-migration and the associated livelihood transitions between generations are affecting how ecosystems are used and the demand for water for different purposes. Research in China (see Sugden and Punch, 2013, Liu et al., 2011) and in Nepal (Sugden et al., 2013b, Sugden et al., 2014) showed how out-migration is reconfiguring the way aquatic ecosystems are used, with marginal uses such as fishing becoming less important, while demand for irrigation water remains high. Secondly, the loss of labour due to migration can also lead to the breakdown of irrigation schemes and other communal resources (Sugden et al., 2016). Changing patterns of consumption mean that remittances are not always channelled into productive uses, such as investments in irrigation or farm inputs, and are often used for consumer goods, and for vital household expenses such as education, health costs, and home improvement.

2.4 Gender impacts

Since the 1980s efforts to establish gender-equal practices have accelerated. These include recognising female-headed households; targeting landless women and men in irrigated plot allocation; joint titling of irrigated land; joint membership of irrigators' organisations; women's representation in committees; or targeting small schemes to women-only groups. The sustainability and livelihoods outcomes of these gender-equal interventions are positive (van Koppen, 2002). However, the recent surge of large-scale land-based investments may increase the risk of mainly male elites capturing benefits at the expense of women and marginalised men (Mehta et al, 2013, Locke and Henley 2014).

Out-migration can have positive gender impacts, giving the stay-behind female population greater control over finances and decision-making (Singh et al., 2013, Masika, 2002). However, there are also negative consequences which have implications not just for gender empowerment but the long-term sustainability and productivity of irrigated agriculture.[4] Women often face an increased workload when men migrate, and in monsoonal climates, this can discourage farmers from planting an irrigated second or third crop (Paris et al., 2005, Sugden et al., 2013a, Zahur, 2009). Women who stay behind often have more limited access to capital and resources, making on-farm investments more challenging (Song et al., 2009, Raihan et al., 2010). In some regions, irrigation has traditionally been a male domain, and women lacked access to social networks to access water through pump rental markets (Sugden et al., 2014). Giordano and de Fraiture (2014) argue that women and resource poor farmers face challenges accessing affordable technologies. Smallholder irrigation offers greater equity in access than large-scale systems; however, women are generally under-represented in the use and ownership of small-scale irrigation equipment (van Koppen et al., 2012).

2.5 Trade and markets

Changes in domestic, regional, and international markets are creating new opportunities for production and trade in horticulture commodities. These changes, driven by rising incomes, faster urbanisation and technological advances are increasing demand for high-value horticulture products such as fruits, vegetables and spices. There is evidence that high-value markets catering for domestic consumption are the fastest growing in many SSA countries. Williams (2011) estimated that Africa’s export of horticultural products grew at an average annual rate of 10.7% between 1990 and 2008, double the average annual growth rate of traditional African agricultural exports during the same period. This growth in markets for horticultural products is adding a new dimension to irrigated farming systems, promoting a range of small- to large-scale irrigated horticulture systems across Africa.

Market and institutional reforms initiated in many African countries since the mid-1980s have created opportunities for farmers, especially on large-scale public irrigation systems. Greater freedom of crop choice, removal of price controls, and liberalization of marketing arrangements for produce are enabling farmers to diversify to grow a range of new crops.

Free trade has allowed the import of pumps for irrigation that have, in turn, enabled the growth of small-scale, farmer-managed irrigated farming systems across Africa. Thus increasing numbers of smallholder farmers, including women and youths, that previously relied on rain-fed farming are able to develop small-scale irrigation, drawing water from rivers, lakes, reservoirs and shallow groundwater, reducing the risk of crop failure and encouraging increased investment in crop inputs and diversification to crops for market. Nevertheless, many of the poorest in society are unable to do this because they do not have the investment capacity and also cannot take the risk of engaging in relatively sophisticated marketing. The risk of failure is too high and so many are trapped in their subsistence life style.

For many smallholder irrigators, and indeed smallholders in general, marketing is a major constraint. Most smallholders have limited access to serious markets[5] and so they tend to grow for their immediate family and for local sales. Thus there is little incentive to produce more than is required for immediate family needs. In such situations there is little point in ‘pushing’ production. Also the risks of entering a market economy can be high. Most irrigated crops are perishable, market prices can fluctuate widely, and the lack of appropriate storage facilities means that farmers must often sell at low prices shortly after harvest when

[4] *Empowerment is the process through which individuals feel they can influence, control and take decisions over issues that affect their lives, assuming alternatives exist. Supporting women’s empowerment requires an understanding of underlying culture, as well as an understanding of control and power dimensions (Murray, 2015)*

[5] Linking rural and peri-urban agricultural production systems with urban markets will help create larger markets with additional ‘pull’ for quality agricultural products. Allen et al 2015.

gluts are more common. In the absence of organised markets, traders are able to take advantage of resource poor farmers (Giordano and de Fraiture 2014). Pro-market NGOs, such as Kilimo Trust[6] in Kampala, suggest that more market 'pull' is needed to incentivise smallholders to produce more quality products. Improving existing, and/or creating new, markets and value chains can benefit the poor and should be considered for inclusion in most investments in irrigated agricultural systems in SSA.

2.6 Water resources, climate change, and irrigation

Africa is often considered to have abundant water and land resources that should allow the expansion of agricultural areas and increased food production, enabling food security in the continent. This may be true at continental scale but large differences exist in the availability of water resources for agriculture at sub-regional scale as the result of socio-economic and natural conditions (Zwart, 2013).

Across SSA, surface and groundwater resources are highly variable and uncertain (You et al., 2011; Xie et al., 2014; Altchenko and Villholth, 2015) and this is likely to worsen under the latest climate scenarios (Vörösmarty et al., 2005; Gan et al., 2016). According to Arnell et al. (2016), under the A1B emission scenario,[7] 127 million people in SSA will be exposed to a decrease in water resources whereas only 28 million will benefit from increased water resources. As demand increases for resilient agricultural solutions which are able to ensure food security, and as irrigated agriculture is promoted throughout SSA, irrigation technologies will be needed that complement 'climate-smart' agriculture. Climate-smart agriculture is based on three specific objectives: (i) sustainably increasing productivity and income, (ii) increasing adaptation and (iii) reducing greenhouse gas emissions below "business as usual" (Campbell et al, 2014).

Physical water shortage already exists in many river basins in Africa (e.g. the basins of the Volta, Orange, and Limpopo rivers, and many smaller basins in North Africa) and the situation is likely to get worse (Arnell, 2004; Smakhtin et al., 2004; De Wit and Stankiewicz, 2006). Climate change predictions show that in several regions the physical water availability will decrease significantly due to changes in rainfall, runoff, and evapotranspiration. It is estimated that 23 countries in SSA will become water-stressed or water scarce by 2025 as a result of the combined effects of population pressure and climate change. Projected water scarce or stressed countries by 2025 include the major rice-producing countries in Africa – Nigeria, Egypt, and Madagascar (UNEP, 2008). Irrigation is the driver for the majority of water withdrawal from surface and groundwater sources in many developing countries (see Box 2.2).

6 www.kilimotrust.com

7 The Intergovernmental Panel on Climate Change (IPCC) defines a range of emission scenarios. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).See: https://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya1 (accessed 9 September 2016)

Box 2.2 Beware of unintended impacts on surface and groundwater resources

Irrigated agriculture has potential for positive and negative impacts on water resources.

Diversion of water from surface water resources and excessive irrigation application can result in increased groundwater recharge. This provides the potential to increase the available water resources by storing water from the wet season for use in the dry season, but at the cost of decreasing wet season flows in the river. The change to the downstream flow regime may disrupt fisheries and flood recession agriculture.

Conversely, where surface supplies are limited or irrigation deliveries unreliable, farmers often decide to sink individual wells to access groundwater to secure their crops. Where use of groundwater is unregulated, over-extraction for agricultural use has happened. The North China Plain and the irrigated plains of the Indus river in India and Pakistan are salutary lessons of the impact of irrigation on groundwater resources.

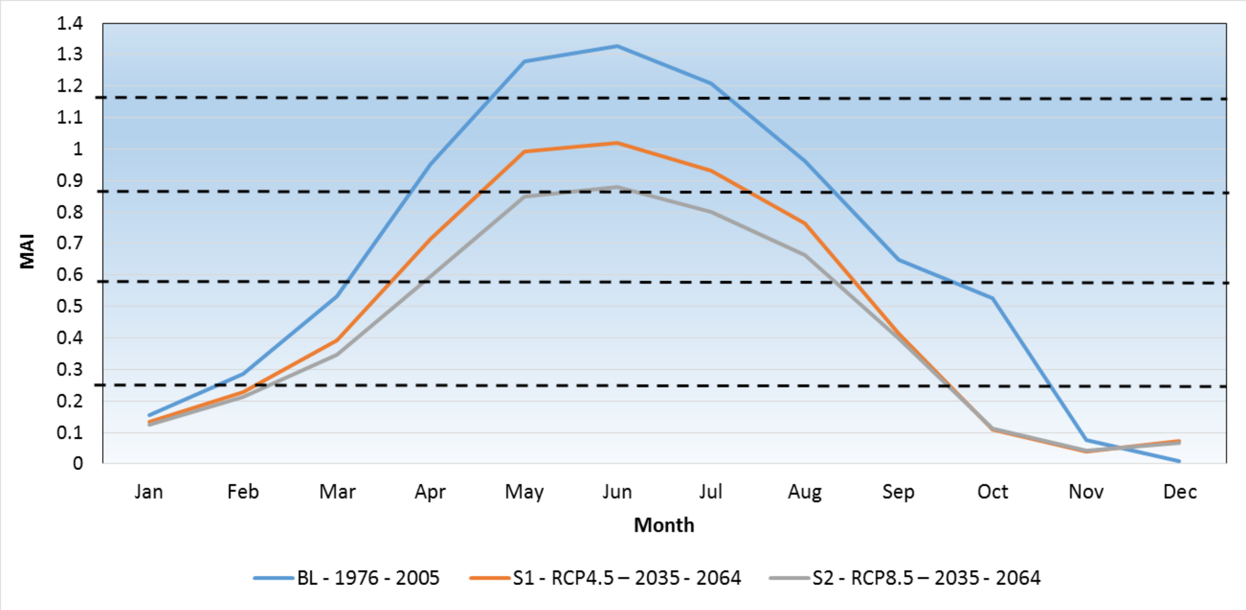
Climate change and its associated impacts will affect agricultural systems in both the short and long term (Grist, 2015) through:

- Increased frequency and/or severity of extreme events and increasing climate variability.
- Increases in global average temperatures and temperature extremes, and long-term changes in rainfall (regionally-dependent increases and decreases) and related sea level rise.
- Emissions-related impacts (increased atmospheric concentrations of ozone and CO_2).
- Increasing incidence and shifting range of plant pests and diseases and their negative impact on crops and yields.

A recent study in Ghana examined the potential impact of climate change on AWM systems in the northern regions of the country. Figure 2.1 illustrates the projected change in the Moisture Availability Index (MAI)[8] between the current climate (1990-2010) and the predicted future climate (2040-2060). This suggests that although rain-fed agriculture is currently possible for crops planted in March through to August, by about 2050 rain-fed cultivation is likely to be marginal and irrigation will be required to enable stable production.

[8] The Moisture Availability Index is defined as the ratio of the P75 (the rainfall exceeded 75% of the time) over reference evaporation (ET_o). Hargreaves, 1972. At a MAI of below about 0.34 crops effectively have no usable yield. At MAI above about 0.60 rain-fed cultivation is possible but yields may be well below optimum.

Figure 2.1 Predicted impact of climate change on Moisture Availability Index (MAI) in Northern Ghana (Mutuwatte, 2016)



Notes: S1 and S2 scenario results from Canadian Centre for Climate Modelling and Analysis for specified Representative Concentration Pathways (RCPs) adopted by the IPCC for its 5th Assessment Report (AR5) in 2014.

2.7 Governance, corruption and irrigation

The irrigation subsector is recognised as being vulnerable to governance risks due to several factors, including: (i) capitally intense works with opportunities for large-scale procurement, particularly in surface irrigation; (ii) poor regulation and monitoring; (iii) weak business processes and control systems; (iv) an increasingly blurred interface between the public and private sectors; (v) lack of capacity for managing water resources, given uncertain water levels and climate change; (vi) fragmented water institutions; and (vii) political interference (ADB, 2015). Vulnerabilities exist in policy-making, regulation, organisational arrangements, and subsector operations. Reducing risks from poor governance and institutional weaknesses requires an understanding of where they occur and what arrangements sustain them (Box 2.3). Familiarity with specific dynamics affecting

Box 2.3 Governance challenges in irrigation development

Corruption is a significant challenge in the irrigation subsector. In surface irrigation systems, corrupt practices can be seen in contracting for the construction of large irrigation infrastructure or for maintenance work (e.g. desilting of canals). Corruption is linked to the award of contracts to preferred contractors. Technical and commercial requirements may be tailored to accommodate a particular bidder, invitations to bid may not be published, confidentiality of suppliers' offers may be breached, and the bidding process and contract execution may not be transparent. Very short deadlines may be imposed to make it difficult for bidders who have no prior knowledge of the contract. Collusion with favoured contractors to inflate the costs to make room for subsequent kickbacks can occur. Contractors or suppliers may try to cover the costs of corruption by providing substandard materials or workmanship, and/or bribe inspectors to obtain false certifications of quality and delivery. In turn, these can lead to poorly functioning irrigation systems and failure to service farmers that need these systems most. Weak supervision, absence of third-party monitoring, and lax quality control enable contractors to get away with such corrupt practices. *Source ADB, 2015* governance arrangements in the subsector is vital. In addition, assessing which systems and stakeholders can be strengthened to create an effective, systemic movement toward accountability and integrity in the subsector is fundamental. Corrupt practices can be pervasive, adding significantly to the cost and delaying development of infrastructure (AfDB, 2010).

2.8 Capacity for irrigation development

The identification, design and operation of irrigated agriculture requires the consideration of multiple options and challenges. Addressing these challenges calls for coordinated inputs from multiple disciplines and often requires collaborations that cross boundaries between agencies and ministries. The increasing involvement of private sector entities in irrigation and agriculture is creating new demands for more responsive agencies. It must be recognised that the availability of the range of skilled and experienced irrigation and related specialists in SSA is limited. The need for comprehensive capacity building programmes to create cadres of specialists to develop and operate irrigation and drainage systems is well recognised (see Box 2.4). Investments to establish the required technical and academic skills will help ensure the current interest in irrigated agriculture results in better performing schemes than recent history.

Box 2.4 Capacity building for irrigated agriculture in Africa

It is well documented that Africa faces multiple stresses including food insecurity, malnutrition, poverty, extreme climatic events, climate variability and change. Africa needs to develop its own strategies that address challenges and constraints faced by people on the ground including the farming community. It has been highlighted in different international forums that Africa has low adaptive capacity, lack of human, financial and technological resources, therefore any strategies or plans that address Africa's needs and challenges would be welcome across the regions. The ICID capacity building strategy for Africa will contribute to enabling African countries to be able to manage their natural resources in effective and efficient ways.

Source: ICID African Regional Working Group - Capacity Building Strategy for Africa, 2015

See also FAO, (2006) Capacity Development in Irrigation and Drainage Water Report 26

2.9 Summary

This section reviews the reasons for irrigating and the range of challenges to be faced when considering interventions in irrigated agriculture. It is critically important that investment decisions take into account the impacts of the changing demography of rural areas, changing climate and water resources, and the challenges of creating sustainable and equitable markets for produce from new or improved irrigation services. Important aspects that have received inadequate attention in the past are the political economy and governance risks that, although common to most public sector infrastructure investments, are particularly prominent in irrigation. The need for a renewed focus on capacity building to establish a cadre of professionals able to undertake irrigation and drainage development and operations should not be under-estimated.

SECTION 3

Irrigation system characteristics

Irrigation schemes are often described as small, medium, or large scale. But there is no universal understanding of what these terms mean. In SSA irrigation schemes are often classified on the basis of scheme area but the boundaries between classes varies across countries (see Box 3.1). For example, small scale irrigation in Ethiopia is less than 200 hectares, but this would be considered as medium or large in Mozambique (Awulachew et al. 2007, Girma, M. M.; Awulachew, S. B. 2007). This poses difficulties in developing generic irrigation typologies for targeting appropriate technologies.

Box 3.1 Irrigation System Classification

Definitions of scheme sizes vary considerably from one country to the next. Many countries, including Mozambique, classify anything over 500ha as large-scale. Surface (gravity) and pressurised irrigation schemes of more than 1,000ha exist in about two-thirds of African countries, while schemes of more than 10,000ha exist in nearly a quarter. The largest scheme in Africa is the Gezira-Managil scheme in Sudan with an area of about 870,000ha. Several schemes of more than 100,000ha also exist in Egypt, Morocco and Sudan.

'Small' is often used to describe individual smallholder irrigation systems which are run entirely by farmers, which tend to be successful, but are quite different in character to small schemes run by government agencies. Medium and large schemes are mostly owned and managed by government agencies, although public private partnership (PPP) arrangements are being tested, notably in Morocco and South America. And private irrigated plantations for sugar and other commercial crops can range from a few hundred to thousands of hectares. All this can cause endless confusion.

To try to avoid confusion, this section provides a distinction in terms of how schemes are owned and managed. The term 'formal irrigation schemes' is often used to describe schemes of all sizes which are owned and managed by government agencies. 'Informal schemes' on the other hand are generally small, privately owned, run by individual or groups of farmers, and are operated independently of government support. Nevertheless, this is not a perfect distinction as there are some formally managed schemes that rely on informal farmer arrangements for local water management through WUAs. There are also informal irrigation schemes that rely on government funding to support them, such as small dam and reservoir construction in Ethiopia and the supply of treadle pumps to smallholders in Malawi.

An important characteristic of irrigation schemes in SSA (Haileslassie et al., 2016) is that - although they may be classified as large, medium or small in terms of total area - most schemes, with the exception of commercial estates, are operated to provide water to many small farms with individual irrigators operating less than 2 ha (FAO 2002). This makes provision of responsive or flexible irrigation services particularly challenging (Box 3.2).

Box 3.2 Why is providing a reliable irrigation service difficult?

Providing an irrigation service that is responsive to the day to day irrigation requirements of individual farmers is a practical impossibility in schemes over a few hundred hectares. The information and control systems are simply inadequate for the manual control of the infrastructure to meet farmers' expectations. This provides the impetus for farmers to invest in more independent means to obtain water as and when required. Such independent means may involve "informal operation" of control structures, creation of barriers to increase water levels to increase flows to specific areas of scheme, or investment in pumps to lift supplies from canals, drains and other water sources. While these actions provide improved services to the individual, the overall impact is to degrade the overall service provided to other farmers.

3.1 The physical components of irrigation systems

Irrigation systems (Box 3.3) are a means of delivering water from the source (surface and/or groundwater resources) to the farmers' fields. They are designed to deliver the right amount of water to the right place at the right time. Most systems rely on a network of open channels and hydraulic regulating structures to control and distribute water. Some irrigation application techniques (e.g. sprinklers, trickle and drip) require pressurised systems and so use pipes for distribution. In addition to the physical components of the irrigation system, successful irrigation requires institutional systems to manage and deliver water to the farms.

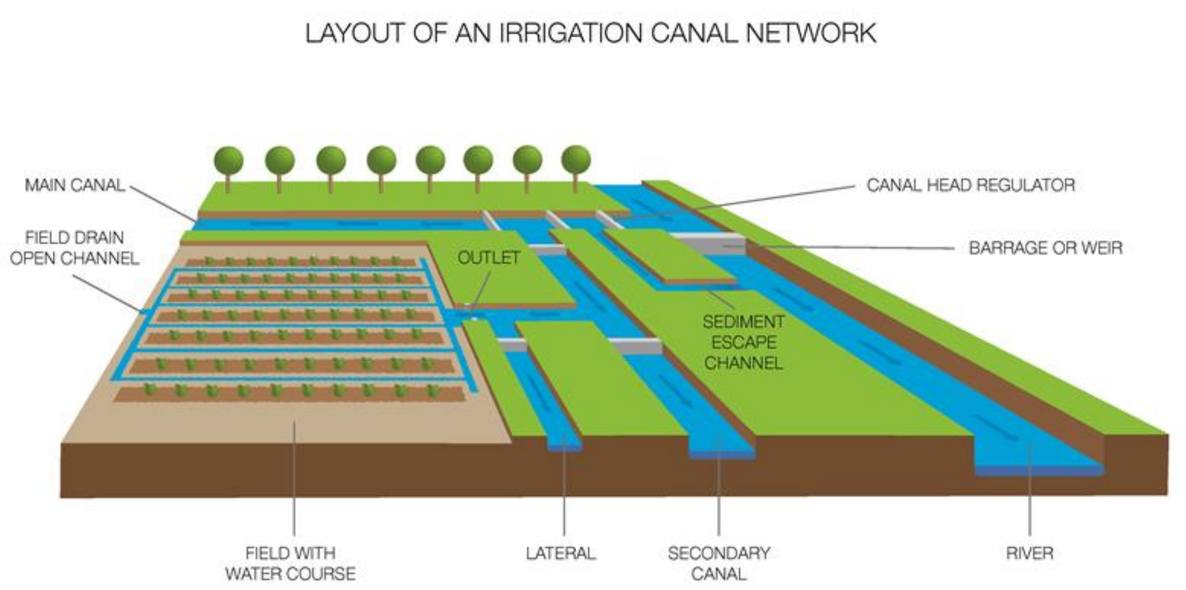
Box 3.3 Irrigation Systems, Projects, and Schemes – what's the difference?

In discussions about irrigation it is common to hear references variously to irrigation systems, irrigation projects, and irrigation schemes. Unfortunately these terms are often used interchangeably. For clarity, this topic guide adopts the following definitions:

Systems –	the components and sub-components of the physical infrastructure; the methods of control of the infrastructure components; and the institutional arrangements for the management of the systems.
Projects –	a defined set of time-bound activities to achieve a specified objective – in this case the construction or rehabilitation of irrigation infrastructure, management arrangements, etc.
Schemes -	combination of infrastructure, management and institutional arrangements, and farming systems serviced by an irrigation system.

Although irrigation systems can have a wide range of command area, from a few hectares of irrigated land created and managed by an individual farm household through to many thousands of hectares of government agency constructed and operated systems serving many thousands of famer households, each has some common components. Typically the physical infrastructure of an irrigation system will include some or all of the following components (Figure 3.1).

Figure 3.1 Schematic of major components of an irrigation system



Source: Authors

Most of the physical components found in large or small schemes are similar; the main difference being one of scale. Headworks to a small scheme, for example, may be a small petrol or treadle pump; the distribution system may comprise only one small canal or pipeline with small diversion structures to distribute water around the farm.

- **Headworks—**arrangements for raising the water level and diverting water from rivers, lakes, streams, storage dams or reservoirs, or by extraction from groundwater aquifers and for releasing controlled discharges to the irrigation conveyance system.

- The **conveyance system** delivers water from the headworks to the farm gates or field outlet. In small systems conveyance may be through a network of pipes and control valves. In very small systems, the conveyance system may be manually transported watering-cans directly for application to the crop. In general conveyance systems consist of a network of branching canals, often referred to as primary, secondary and tertiary systems. Division of water at each branch is controlled by a variety of structures that may be a fixed proportional division, or manually or remotely operated, depending on the scale and sophistication of the operational control system.

  Many irrigation canals are earth channels often referred to as un-lined. While the canal is operating, water is 'lost' through seepage to groundwater, drains or fields alongside the canal. Irrigation system owners and their development partners have invested huge amounts of money in canal lining in efforts to reduce these losses, generally expressed as improved canal conveyance efficiency. There are good reasons to line irrigation canals, including reducing land required for the canal due to improved hydraulic performance of the channel and, possibly, improved maintenance. However, until the advent of impermeable membranes for lining, it is an inconvenient truth that in many cases these investments were misplaced as the structural integrity of traditional concrete and masonry lining failed rapidly with the resources realistically available for maintenance (Goldsmith and Makin, 1989). And unfortunately in water scarce, or closed (see Box 3.4) river basins, even using the latest membranes to reduce seepage losses to zero, canal lining alone will not result in water being released for increased areas of crop production or diversion to other users in cities, industry or the environment.

- **Primary system** – system of main canals and control structures or pipelines to convey water from headworks to the secondary systems. Ideally no farms are directly connected to the primary system, to enable effective control of water supplies to the secondary network.

- **Secondary and tertiary system** – networks of canals and control structures or pipelines to deliver water from the primary system to farm outlets. The delivery, or irrigation schedule, is based on crop water requirement, predefined water rights or predefined share of available water, or other arrangements.

  In formal irrigation schemes, where the headworks and conveyance system is owned and operated by, or on behalf of, a government department, control of the water distribution transfers from the agency to farmers or water user groups. The need for system operator and user/user groups to agree on the service to be provided at the point of transfer is discussed in Section 3.2 below.

  Downstream of the point of transfer to water user control often includes responsibility for operations and maintenance of some proportion of the conveyance system, typically the tertiary canal serving a small group of farmers. Individual farmers are responsible for management of the on-field application of irrigation to their crops; however the degree of independent control is dependent on the scale of the system and, in larger systems, the irrigation schedule and the operations of farmers sharing the same tertiary canal systems.

Box 3.4 Open and Closed Basins

As population and economic activity increase in river basins, the basin evolves from an "open" to a "closed" state. In the open state there is sufficient water to satisfy demands even in the dry season, and fresh water flows out of the basin. As growth continues, water supplies progressively tighten. Most of the water is diverted to meet demands, and an increasingly large percentage of the drainage water is captured and reused. A progressively smaller quantity of water, of diminishing quality, flows out of the basin in the dry season. Eventually, either all of the water is evaporated upstream leaving no dry-season flow out of the basin, or the flow is so polluted that the water is not usable. The basin becomes completely "closed"—i.e., there is no usable water leaving the basin. *Source Seckler 1996.*

- **On-farm water management systems** – networks of small field channels, pipes and associated structures that distribute the water among farmers' fields. The most common form of on-farm irrigation is by some type of surface irrigation. Increasingly, often in response to poor irrigation services, farmers are investing in "high-tech" on-farm systems which include sprinklers and drip-irrigation systems. Use of these high-tech systems often requires local on-farm storage or groundwater extraction. Operation of the on-field systems involves pressurisation of the on-farm distribution system, generally by pumps energised by small diesel engines, wind turbines and most recently by solar power; increasing the farmer's cost of irrigation. The overwhelming majority of irrigation application is through surface irrigation methods (Table 3.1). Advances in precision surface irrigation can provide high on-farm application efficiencies (Box 3.5). On-farm technology is discussed further in Section 4.1.

Table 3.1 Regional Summary of irrigation technology use

Region	TOTAL	GRAVITY	SPRINKLER	DRIP	Undefined
	Ha	Ha	Ha	Ha	Ha
Africa	9,342,237	7,126,919	1,620,545	594,773	
Central Asia	12,360,331	12,161,394	183,714	15,223	-
Middle East	19,207,142	16,339,334	1,950,727	917,081	-
South America and Caribbean	17,752,097	12,948,558	3,782,241	1,021,298	-
South and East Asia	180,480,311	171,229,276	4,335,757	1,348,729	3,566,549
Total	**239,142,118**	**219,805,481**	**11,872,984**	**3,897,104**	**3,566,549**
		GRAVITY	**SPRINKLER**	**DRIP**	**Undefined**
As % of irrigated area		**%**	**%**	**%**	**%**
Africa		76.3%	17.3%	6.4%	0.0%
Central Asia		98.4%	1.5%	0.1%	0.0%
Middle East		85.1%	10.2%	4.8%	0.0%
South America and Caribbean		72.9%	21.3%	5.8%	0.0%
South and East Asia		94.9%	2.4%	0.7%	2.0%
Total		**91.9%**	**5.0%**	**1.6%**	**1.5%**

Source: Area equipped for controlled irrigation, latest available data - FAO Aquastat - http://www.fao.org/nr/water/aquastat/tables/index.stm (accessed March 2015)

Box 3.5 Precision surface irrigation compared to high-tech field application technologies

A review of technological change in the Australian irrigation industry found a large range in actual irrigation application efficiencies: drip and micro (75-95%), sprinkler (60-90%) and surface (60-85%). The highest surface efficiency (85%), achieved through laser graded fields with matched irrigation stream flow rates, is much higher than the lowest sprinkler efficiency (60%) and still appreciably higher than the lowest drip efficiency (75%).

Field trials in Pakistan of precision surface irrigation have achieved similar high field application efficiencies, using locally manufactured levellers and standard 40 horsepower tractors, in plots of less than 0.4 ha. *Sources: CRC WATERpak (http://www.cottoncrc.org.au/industry/Publications/Water/WATERpak) and CRDC. 2014. Australian Cotton Production Manual (http://crdc.com.au/publications/australian-cotton-production-manual).*

- **Drainage systems** – irrigation also requires drainage systems to take away excess water (unwanted rainfall, excess irrigation water) from fields and to control water-tables to prevent salinisation[9] and waterlogging.

  It may seem strange that, having spent considerable financial and physical resources to deliver water to the field to grow crops, irrigation system operators are also concerned about drainage. However, even the freshest water contains some dissolved mineral salts and over time, if not managed correctly, the process of

[9] *Salinization is the process by which water-soluble salts accumulate in the soil. Salinization is a concern in agriculture as excess salts hinder the growth of crops by limiting the take up of water. Irrigation water generally contains some soluble salts that becomes concentrated in the soil profile by evapotranspiration. By applying water, in excess of the crop water requirement, soluble salts can be leached from the root zone into the drainage system for disposal. The concentration of salts drained from upstream irrigation systems can affect the use and quality of water downstream.*

evaporation and transpiration will result in these salts becoming increasingly concentrated in the soil. Depending on the sensitivity of the crop, at some point the concentration of salt in the root zone will limit the capacity of the plant to extract water resulting in water stress. As stress increases, the crop yield and the farm household food security or income will be reduced.

Management of salinity in irrigated areas involves applying more water than the crop can transpire so that excess water, referred to as the leaching fraction, percolates through the root zone, dissolving the salts and transporting them to the drainage system for discharge to a river. The drainage water will generally have a higher salt concentration than the ambient concentration of the receiving water, with potential negative impacts on downstream users. In addition, the leaching water may also contain concentrations of agrochemicals mobilised from the upstream fields, with potential impacts on aquatic ecosystems.

In general, it is not economic to design irrigation systems for the most extreme years and so designs are often based on providing adequate water for a given area and cropping in say 8 years in 10. Thus, on average and by design, irrigation systems will "fail" to some degree about one year in four or five (Box 3.6).

Box 3.6: Irrigation reduces the risks of crop failures

Irrigation systems are designed to supply a defined irrigation service. However, when the water available at the headworks is less than the design assumptions, often specified in hydrological terms as the 75% or 80% probability of exceedance, the system cannot supply the designed service. These failures may be minor and the system operators can provide lower flow rates or apply slightly longer irrigation intervals; effectively sharing the shortage among farmers. But when more severe water shortages or drought conditions occur during the irrigation season after crops are established, it may be impossible to supply some farms, often resulting in substantial losses for individual farmers. Irrigation schemes are designed to reduce the risk of crop failure but they do not remove such risks entirely.

Prediction of seasonal droughts would enable agencies to advise farmers of likely availability of irrigation, enabling better informed planting decisions. Alternatively, provision of index based crop insurance would enable the more commercial farmers to reduce their exposure to risk of crop failure.

3.2 Institutions and organisations

The success of infrastructure and irrigation technologies depends on institutional arrangements and the organisations that manage the irrigation scheme. The institutions are the rules, incentives and controls, agreement and rights, and finance, which determine the services provided (Rauch, 2009). Medium and large scale irrigation systems need formal institutions and organisations for system operations, maintenance, and repair. These will include arrangements for:

- Managing water allocations (assessing water demand and availability, managing water scarcity, and delivering agreed water in terms of quantity, timeliness, and quality);
- water services (canal operation, water monitoring, operation of farm gates and hydraulic devices, billing and collecting service fees, and contract management);
- system maintenance (preventive, reactive, and daily upkeep);

- repair and asset management (replacement/repair of structures, pumps and motors, control valves, gated outlets, and other facilities to restore system functions);
- resolving disputes about water allocation and services; and
- recovering costs of providing irrigation services (from users of community and privately operated schemes, but frequently through some form of subsidy in government managed schemes)

Small community schemes can largely be self-managed with informal institutional arrangements and often with informal operational procedures. A small scheme operated by a few farmers from the same community, who have invested resources to develop the system, is less complex to manage and generally may have characteristics much like an individual farm irrigation system. However, in some cases an irrigation scheme serves only a small command area, but the water source, diversion structures and distribution system are formally owned and managed by a government irrigation service. In this situation the management arrangements may be more typical of a medium or large scale system (Table 3.2). If these characteristics are not adequately appreciated and resourced it can lead to inadequate O&M investments and quite rapid deterioration of infrastructure and irrigation services.

Table 3.2 Management complexity of irrigation schemes

Command area	Ownership and Management Arrangements		
	Individual	Communal	Agency
Small	*	**	***
Medium		**	***
Large	**		****

Notes: Management complexity increases from * to ****.

Informal smallholder irrigation can take many different forms (Table 3.3). Each has distinctive characteristics and, in general, can be improved with careful selection of appropriate investments in infrastructure and/or capacity development of managers and users.

Table 3.3 Classification of informal smallholder irrigation in SSA

Classification	Description	Examples
Water harvesting.	Involves making better use of natural run-off. Many approaches. Collecting run-off from a catchment and concentrating water in a smaller cultivated area. Large schemes – several hectares of catchment, small schemes may involve individual plants. Success depends on having right ratio of catchment to cropped area. New developments applying plastics to catchment to increase run-off.	Ancient agricultural areas, Negev Desert, Israel. Pasture improvement by flood water retention, Niger. Micro-catchments for fruit trees, Botswana rice cultivation, Gambia.
Swamp irrigation	**Fresh water swamps** protected from saline seawater by bunds/dykes. Used for growing rice. Also tidal swamps planted after rains leach soil.	Gambia River, Gambia.
	Inland valley swamps – small valleys (1–100 ha) where season/perennial streams can be used/controlled for paddy rice cultivation.	Sierra Leone, Burundi

Classification	Description	Examples
	Bolilands and dambos – depressions in swamp grasslands.	Rokel River, Sierra Leone, Guinea, Mali, Burkina Faso, Côte d'Ivoire, Ghana, Malawi and Zambia.
	Lake swamps – large areas of flat plain flooded as lake level rises.	Lake Victoria, Tanzania
Spate irrigation	**Water spreading** – spreading floodwater in rivers and wadis across cultivated land in a controlled manner.	Lower Omo Valley, Ethiopia, food and fodder crops
River flood plain irrigation (RFPI) - Wet season	**Flooded lands**. Usually rice grown in floodwaters. Many techniques.	
	Controlled irrigation — controlling the rise in floodwater using dykes, canals and sluice gates. Used for both deep water and paddy rice	Niger and Bani Rivers, Mali.
River flood plain irrigation (RFPI) - Dry season	**Recessional irrigation**. Impounding receding floodwaters with earth bunds.	Rice cultivation along most large rivers in West Africa.
	Residual moisture. Similar to recessional, water is stored in soil rather than on the surface.	Dry season cultivation of dambos or vleis in Malawi, Zambia, and Zimbabwe.
	Pumped irrigation. Large areas of flood plain where surface water storage and shallow ground water can be exploited using lifting devices, often for vegetables.	Increasingly common in Nigeria also along most large river flood plains. River Omo, Ethiopia
	Shadufs – traditional technique of lifting small quantities of water using the 'lever principle'. Usually low lift 1–2 m.	Most large river flood plains in West Africa, Niger, Bani Senegal, common along Nile. Tana River, Kenya.
Hill irrigation	Land irrigated some distance from water source, supplied by canal or pipe. Source may be a stream, small dam storage, gravity or pumped.	Traditional cultivation by the Chagga tribe on the slopes of Mount Kilimanjaro, Tanzania, Malawi, Ethiopia
Groundwater irrigation	Involves exploitation of groundwater down to 15m.	Exploited for small gardens, e.g. Burkina Faso, Niger, Togo, Benin, Zimbabwe, Botswana

Source: Kay, 2001

3.3 Why support multiple use irrigation systems?

Single-use approaches to water development and management do not reflect the realities of water use by poor people (IWMI, 2006). People use domestic water supplies for activities such as irrigating backyard gardens, keeping livestock, fishing, processing crops and running small-scale enterprises. In areas without adequate domestic water supply, they use irrigation water to meet household needs, such as drinking and bathing, as well as to support a range of income generating activities in addition to crop production.

When communities design their own water systems, they invariably plan for multiple uses including provisions for domestic and livestock water needs. When single-purpose irrigation schemes are developed by public agencies, they are almost always used for multiple purposes (van Koppen, et al, 2009). However, because these uses are unplanned and only rarely acknowledged, they often lead to unnecessary health risks for water users, water shortages at the tail ends of supply systems, damage to infrastructure, and conflicts between users.

Multiple use of water occurs in most irrigation schemes, whether considering small, medium or large scale irrigation systems. Designing-in multiple-uses of water in irrigation systems can maximise the health benefits and productive potential of available water supplies, leading to increased incomes, improved health and reduced workloads for women and children. Systems that cater to multiple uses are also more likely to be sustainable, because users benefit more from them, have a greater stake in them, and are more willing and better able to pay for the services provided (Merrey et al, 2005).

3.4 Modernising irrigation services

The need to produce more food, with increasing constraints on water and labour resources available, is prompting new interest in investments in irrigated agriculture. But the traditional focus on large scale irrigation, constructed and operated by government agencies, is being supplemented by combinations of individual and community led small-scale irrigation systems, including innovations in water extraction from rivers, canals and groundwater with pumps energised by small engines, solar powered motors, and wind turbines. In all types and sizes of schemes, farmers are adopting innovative field application methods, including precision levelled or graded fields, pressurised sprinklers and drip systems which enable increased areas of irrigation with the available water resources. For these investments to be fully effective the irrigation schemes that deliver water to the farms must provide more reliable irrigation services than has often been the case. The concept of service delivery to farmers is embodied in the definition of irrigation modernisation used by the International Commission on Irrigation and Drainage (ICID) - "*Process of upgrading infrastructure, operations and management of irrigation systems to sustain the water delivery service requirements of farmers and optimise production and water productivity"*. This definition is equally applicable to new-build or rehabilitation of existing schemes, involving matching irrigation infrastructure and the operations and management approaches to the needs of the farming systems they deliver water to.

Although the larger formal irrigation schemes have often performed less well than expected, they are well placed to contribute to overcoming the challenges of the '*perfect storm of rising food, water and energy demands*' expressed by Sir John Beddington (BBC, 2009), at the time the United Kingdom Chief Scientist. Further investments are urgently needed to improve performance of these schemes in order to maintain food security as urban populations increase and economic development enables changing diets. Irrigated agriculture must adapt to the effects of rapid changes including new technologies, mechanisation, water and natural resource use, and changes in food systems. Identifying and implementing investments in the larger schemes, and achieving significant impact from such investments on the majority of farmers in the scheme, will take over 10 years. This indicates that urgent action is required to meet the growing challenges to food security and poverty reduction in many developing economies.

In this iteration of irrigation development the opportunity to provide for multiple uses (Section 3.3) through the irrigation system should not be missed and should be included as part of the modernisation of small, medium and large irrigation systems. Investments by governments and development partners should be extended to include support for modernisation of small-scale and informal irrigation services (Box 3.7).

Box 3.7 Why invest in informal irrigation

Smallholder farmers are increasingly interested in financing and installing irrigation technologies and investing their own resources in their agricultural businesses (Giordano et al, 2012). Small-scale AWM could expand significantly if farmers were able to overcome key constraints, such as high upfront investment costs; poorly developed supply chains; high taxes and transaction costs; difficulty accessing information and knowledge on irrigation, seeds, marketing, equipment and other inputs; and imbalances of power that leave farmers at a disadvantage when selling their produce.

3.5 Informal smallholder irrigation

Water sources depend on the local context and resources available. For example, in Malawi, informal small-scale irrigation is largely based on pumping (treadle and motorised pumps) and river diversions. Application is frequently by manual watering cans (Xie et al., 2014). In Ethiopia, most informal small-scale irrigation is based on river diversions, small reservoirs and diesel-operated motorised pumps (Haileslassie et al., 2016). In semi-arid and arid regions spate irrigation is common where water is spread over the land, usually, from flash floods in wadis. Surface water harvesting and small stream diversion, for example into 'hafirs' in Sudan, is another form of traditional informal small scale irrigation. Multiple uses of water resources include combinations of livestock, tree crops and field crops.

Informal small-scale irrigation systems can offer greater equity in access for smallholders than large-scale systems. However, women are often under-represented in use and ownership of small-scale irrigation equipment and services (van Koppen et al., 2012). Conflicts over water, increasing occurrence of land degradation, and sedimentation of reservoirs are key challenges to informal small scale and community managed irrigation schemes; however, Dillon (2011) concluded that, in Mali, such schemes have a larger effect on agricultural production and agricultural income than formal large-scale irrigation. Hagos et al (2009) found informal small scale irrigation to be more profitable than formal large scale irrigation in Ethiopia.

But, in many informal small-scale irrigation schemes, marketing produce is a major problem. Depending on the proximity to market, farmers focus on crop varieties for staple food crops (e.g. cereals such maize and rice) and nutrient dense crops such as vegetables and fruits. Due to the perishable nature of many higher value crops and a lack of suitable storage facilities, farmers must sell at low prices immediately after harvest.

The rapid expansion of urban population and the related expansion of urban areas into surrounding agricultural lands is driving growth of informal urban agriculture, which shortens the transport chain from field to market. These systems are important sources of income and nutrition for substantial numbers of poor and marginal residents of the growing cities and towns in Africa (Table 3.4).

Table 3.4 Classification of Urban Agriculture in West Africa

Farming systems	Urban areas	Peri-urban areas
Market gardening	Irrigated vegetables (year-round or seasonal), flowers and ornamentals, rain-fed cereals on undeveloped open spaces.	Fruits, dry-season irrigated vegetables alternating with rain-fed cereals; rice.
Subsistence production	Backyard or front yard farming.	Home gardens; farming around homestead.
Livestock husbandry and aquaculture	Predominantly poultry, small and large ruminants, equines.	All kinds of poultry/ livestock, increasingly aquaculture.

Source: Dreschel el al, 2006

3.6 Formal (medium and large scale) irrigation schemes

In SSA formal medium and large scale schemes are generally developed through public sector investments[10] to develop water sources, storage and diversion infrastructure, and irrigation conveyance and distribution systems. Large scale irrigation systems (LSIS) are not simply a physically larger version of small-scale schemes, with the large systems requiring a combination of formal and informal management institutions (see SECTION 5). The division of responsibilities is typically: (i) O&M of headworks and conveyance infrastructure by formal, often public sector agencies; and (ii) management of the tertiary sub-system networks delivering water to farm-gates controlled by water users, often referred to as informal institutions. As governments have sought to reduce their recurrent irrigation costs, programmes for irrigation management transfer (IMT) or participatory irrigation management (PIM) have been implemented. Responding to budget limitations and the recognition that government operated irrigation services often fail to meet farmers' service requirements, the potential of public private partnerships (PPP) is being explored where there is possibility of high impact and wide application for farmers (Gillingham and Wright, 2014). Examples of common forms of PPP contracts in irrigation are given in Box 3.8.

The formal management systems often operate independently, with inadequate recognition of the water management requirements of the farmers. In the absence of a responsive management system, farmers can take independent and collective action to access the water they require, leading to unauthorised operation of control structures, including damage to prevent the operators resetting the system for the planned distribution. These unauthorised actions lead to inequitable distribution of water; undermining incentives for water user groups to cooperate with each other or the formal irrigation institution. The number of smallholder farmers to receive water in LSIS means these systems tend to be supply-driven, rather than demand-driven, services.

Mismatches between irrigation water delivery and the irrigation requirements result in poor water productivity and reduced income for the farmer. Some of the mismatch may be built-in to the irrigation system design, e.g. the warabandi irrigation systems of North India and Pakistan were designed to spread the available water resources across as large an irrigation area as possible. As a result the irrigation service provides water for about 25% of the potential crop water requirements; leading farmers to invest in tubewells to extract groundwater to make up the shortfall with potentially serious impacts on the sustainability of irrigated agriculture.[11]

The size of infrastructure involves high capital and O&M costs but, due to experience of poor service, the recovery of operating costs from water users is generally low. This often results in a downward spiral of low cost recovery, delayed maintenance and declining service quality, leading to lower cost recovery. Eventually, services decline to the point where action in the form of rehabilitation or modernisation, often externally financed, is required. Delayed maintenance can, in some agencies, be a deliberate strategy to trigger rehabilitation projects which provide increased resources to what are otherwise under-funded irrigation organisations.

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[10] *Private sector investments in medium and large scale irrigation systems are found in commercial estates and plantation sector which are managed as individual farms. Some of these also provide irrigation and other services to a network of local out-growers, or contract farmers, to increase the production capacity and/or to increase the utilization of the processing facilities of the core estate.*

[11] *Electricity subsidies mean that farmers have no incentives to minimize groundwater pumping, leading to falling water tables that will eventually become unsustainable. The adoption of solar pumping may exacerbate unregulated groundwater extraction.*

Box 3.8 Increasing role of private sector in small-scale irrigated agriculture

Irrigated agriculture projects, especially those involving smallholder farmers, are difficult to fund on a commercial basis from day one because they cannot deliver short-term predictable financial returns. Unlike other sectors, irrigation projects, are self-contained investments which are linked solely to the local off-take, i.e. the viability of the agricultural activities using the water. Infrastructure providers are thus exposed to market and commodity risks. Commitments, through management or finance, will only be forthcoming if private-sector partners can have a degree of certainty that they will be able to recover their investments.

The most commonly used contractual forms of PPP in the irrigation sector:

Operation, Management and Maintenance (OMM) contract - The private-sector is engaged to undertake operation, management and maintenance of infrastructure services for defined recipients. The private-sector provides a service for which it receives a fee (either from the government or from users). Where rehabilitation or construction works are required, they can also be part of the contract. Assets are publicly financed, and this is an appropriate form of contract where there is limited scope to raise private capital.

Farm service agreement - The private-sector can also partner with smallholder farmers and communities for the provision of farm-level services. Services might be on-farm, such as planting, harvesting and water application; or off-farm, such as storing, processing and marketing (e.g. out-grower services). Such farm services, by improving the agricultural performance of water users, are likely to improve the viability of irrigation infrastructure. The level of private finance investment required depends on the services provided. Farm services can be integral or separate from infrastructure OMM.

Hub farm agreement - The private-sector can be engaged to undertake commercial agricultural production through a land concession or lease. This might be on unoccupied land owned by the government or third-parties, or community land held under collective title (or especially consolidated) and leased in return for a fee of share in commercial operations. The hub farm has purely commercial aims, and will require a certain scale in order to offer commercial opportunities (especially for food crops). Private capital is required for on-farm investments, while irrigation fees can reflect any or all infrastructure related costs (e.g. OMM, investment and finance).

Source: World Bank, Public-Private-Partnership In Infrastructure Resource Center

3.7 Summary

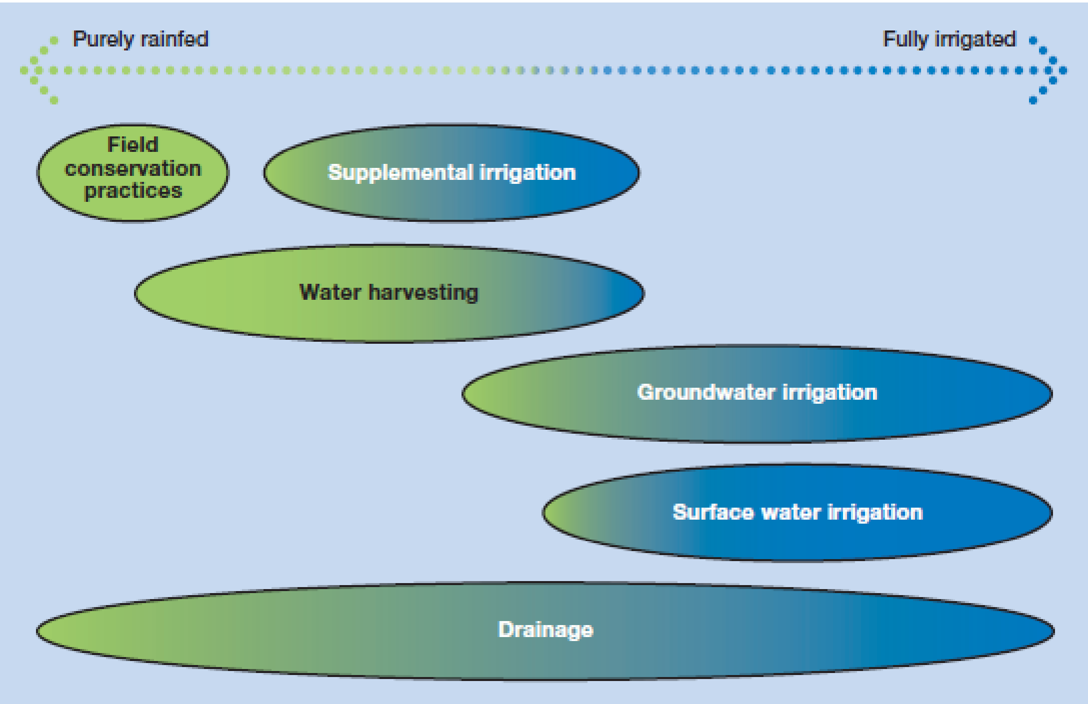
As small-scale water management technologies become more accessible, the potential to expand private irrigation is enormous. This is especially so in SSA, where there is significant scope to extend the area of land that is irrigated or under improved agricultural water management. Investment costs of small-scale irrigation technologies are affordable for individuals and communities, and implementation is relatively straightforward when compared to large-scale irrigation. As a result, the potential for up-scaling the use of irrigation at all scales and reducing poverty is high.

SECTION 4

What on-farm technologies?

The selection of irrigation technologies is divided between: (i) the selection of technologies for water resources extraction and conveyance to the farm-gate, the irrigation infrastructure and management systems (Section 3.1); and (ii) the on-farm choices for field application technologies (this Section). Agricultural water management encompasses a spectrum of interventions and technologies to increase water availability for crop growth (Figure 4.1). These include in-field rainwater harvesting, manual watering with cans and hoses to refill porous pots or irrigate plants directly; simple to complex surface irrigation applications, sophisticated drip, trickle and sprinkler irrigation, manual and automated canal control systems, dedicated irrigation pumps and small reservoirs, through to major multipurpose dams. The multitude of technologies now available means that giving definitive advice on what technology to select in the general case is impossible. However, making the correct selection of technology is critical to the performance and sustainability of an investment in irrigated agriculture to ensure the overall system is fit-for-purpose.[12] Surface irrigation methods are still the most widely used (as shown in Table 3.1) due to simplicity of construction and low operation and maintenance costs.

Figure 4.1 Agricultural water management includes a spectrum of technologies



Source: Comprehensive Assessment of Water Management in Agriculture. 2007

12 *Fit-for-purpose - the most appropriate approach to meet the development objectives and outcomes, taking into account the context and the risk, value, and capacity for use.*

4.1 What on-farm technologies?

The selection of on-farm technologies can be considered as the individual choice of the farmer; however, in practice, this selection has to be closely related to the irrigation service provided by the irrigation system, or the farmer must make additional investments in pumps or on-farm reservoirs to secure the required access to water. Investment costs vary with local conditions (including topography, soils, water resources, etc.), institutional and macroeconomic environment, scheme size, technology, or level of prior investments. In 2003 FAO undertook a desk survey of rehabilitation, modernisation and new-build irrigation costs as summarised in Table 4.1. The substantially higher unit cost of investment in SSA ($4,457/ha with a range from $250/ha to $18,100/ha) compared to the average of the other regions ($1,626/ha) is striking. The range of investment costs reported indicates the difficulty of providing a generalised estimate of unit rates for irrigation investment costs. Each potential irrigation investment requires careful analysis of irrigation options.

Table 4.1 Average regional investment costs for irrigation systems (1980-2000), by on-farm methods ($/ha – 2000 prices)

On-farm irrigation technology	East Asia	Latin America and Caribbean	Near East North Africa	South Asia	Sub Saharan Africa	Average cost ($/ha)
Localized			2,594			**2,594**
N/A	2,199	2,316		1,998	3,796	**2,340**
Oasis			4,337			**4,337**
Spate			455			**455**
Sprinkler		2,143	3,560	1,220	4,175	**3,279**
Surface	1,442	833	2,066	1,533	4,525	**2,278**
Average cost ($/ha)	**1,470**	**1,598**	**1,892**	**1,546**	**4,457**	**2,280**

Source: FAO. 2016. AQUASTAT. Food and Agriculture Organization of the United Nations (FAO). *http://www.fao.org/nr/water/aquastat/investment/index.stm Accessed 15 September 2016*

In line with the Sustainable Development Goals agreed in 2015, increasing attention is being directed towards increasing efficiency on all aspects of the water sector.[13] Agriculture as the largest user of water diversions from surface and groundwater, and also the largest consumer of water, will play a central role in improving how water resources are used.

The increasing availability of more advanced irrigation technologies (drip and sprinklers) and availability of small pumps, energised by fossil or renewable energies, is enabling individual farmers to create their own small irrigation schemes within the farm or with neighbours as an independent group scheme.

4.1.1 Pressurised irrigation (sprinkler and drip)

Pressurised technologies have their merits particularly when irrigating high value crops i.e. fruit and vegetables and where the water needs to be pumped in any event e.g. groundwater and or rolling topography not suited to grading or levelling for surface irrigation.[14] New

13 *Target 6.4 - By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.*

14 *The widespread availability of low-cost lay-flat plastic tubing is also enabling farmers to improve water delivery, from pump-sets located at the canal side and from tubewells, for surface irrigation applications to remote fields while minimizing transmission and management losses.*

technologies are opening new opportunities for farmers, but the technology alone is not sufficient to achieve high performance (Box 4.1).

Sprinkler Irrigation is similar to drip irrigation in that it does not use the soil surface to transport the water but uses pressurized pipes. However, sprinkler irrigation, like surface irrigation, does apply relatively large depths of water in each irrigation event and thus utilises the properties of the soil to store this water. There is increased interest to use pressurized irrigation methods to grow rice. Limited studies in Asia have shown that drip and sprinkler systems have potential to improve on-farm irrigation application efficiency up to 80% in several crops, including rice.[15] Sprinkler irrigation in its various guises - e.g. fixed, lateral roll, centre pivots, rain gun - is both capital and operationally expensive, particularly with regard to energy costs. Sprinkler irrigation also requires highly skilled farmers and effective support services to maintain and repair equipment. Sprinkler irrigation is suited to broad-acre crops.

Drip (also called Trickle) Irrigation is typically designed with a capacity to apply the maximum daily crop requirements (with some modest margin for inefficiencies). Therefore, in drip irrigation there is far less emphasis placed on the ability of the soil medium to store water and nor is the soil surface used to transport the water. Drip irrigation also involves both significant capital costs (estimates range from $500/ha to $3,000/ha at 2012 prices) and a requirement for technical know-how at the farm level; and also demands an effective spares and repairs industry. It is generally better suited to high value row and tree crops. A particular concern with drip irrigation in arid areas is the lack of leaching of salts in the soil due to the high application efficiencies achievable. Delivery of water, effectively, direct to the crop root system reduces growth of weeds between the plants, reducing the labour or agro-chemicals required for weeding, and also reducing non-beneficial transpiration.

Box 4.1 Technology alone is not enough?

Proponents of new technologies often mistakenly attribute the capacity to produce efficiency, productivity, modernity and fairness to the hardware itself. That is a big mistake. Hardware only operates within an existing network of institutions, discourses and practices.

A viable enabling environment can make the difference between technology with promise and functioning and effective farming systems. With proper and judicious support, newly introduced technologies can be successful.

For example, consider the TN Drip Project. In the Coimbatore District of Tamil Nadu, India, over 90% of the farmers who had been encouraged to invest in drip irrigation did not know how to use the technology properly. Increases in crop production were disappointing. A capacity building initiative, led by the IWMI-Tata Water Policy Research Program and local partners, trained farmers in all aspects of drip irrigation. This led to reduced water abstraction, more effective irrigation and yield increases of up to 40% for some crops.

This points to a pattern. Drip irrigation systems in emerging economies tend to work best in places where there is a full range of support and training services. These business models are gradually becoming more common. *Jeremy Bird, The Source, February 2016.*

15 *A farmer from Tirupur district has been selected for 'Innovative rice farmer award' for the year 2015 by the Indian Institute of Rice Research, Hyderabad, for large-scale adoption of drip irrigation. A total of 12 farmers cultivated CR1009 under direct sowing under drip in 2013 and during 2014 a total of 23 farmers cultivated COR51 in drip system. On average the farmers achieved 6.0 to 7.5 tonnes per hectare yield under drip irrigation. http://www.niticentral.com/2015/09/02/farmer-gets-award-for-large-scale-adoption-of-drip-irrigation-332019.html Average rice yield in India – 2011/12 2.3 to 3.3 t/ha depending on season. (Accessed October 2015)*

Much of the motivation for investment in 'high-tech' on-farm systems is a concern by government agencies and development agencies to increase irrigation efficiency to increase agricultural production and/or to 'release' water for other uses. It can be argued that increasing the efficiency of individual farms can reduce farm water use and potentially reduce the energy costs of pumping water which goes to waste. This is true and maybe worthwhile. But for the farmer the incentive for increasing efficiency is not water-saving but money saving, which is what farmers are generally most interested in.

4.1.2 Surface Irrigation technologies

This is by far the most common irrigation method used. Across Africa it accounts for 76% of all irrigation (Table 3.1). This figure will be much higher for SSA as it includes all the mechanised irrigation across North Africa and the commercial farming in South Africa.

In surface irrigation the soil surface is used to transport water across the field (as opposed to pressurised irrigation where pipes convey the water to the crop). Clemmens (1986) reported that although plants may use water at a rate in the range of 2-10mm/day, surface irrigation is designed to apply 50-150mm depth of water per event. Therefore, surface irrigation in addition to using the soil surface as a medium to transport water relies on the soil medium to retain water i.e. as a storage reservoir; leading to a surface irrigation event taking place typically once every week or ten days.

There are a number of important factors that should be taken into account when determining which surface irrigation method (basin, furrow or border irrigation) is most suitable for a given location. It is not possible to give specific guidelines leading to a single best solution; each option has its advantages and disadvantages. Factors to be taken into account include:

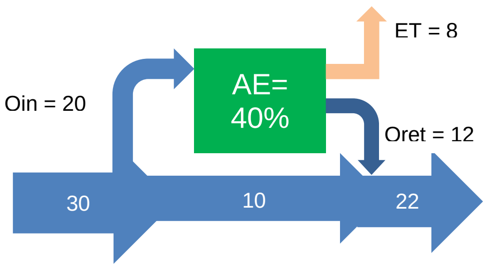
- natural terrain and soil (slope, soil type);
- type of crop(s) to be irrigated;
- required depth of irrigation application, flow rates and time available;
- level of technology available;
- previous experience with irrigation; and
- required and available labour.

There are various forms of surface irrigation (border strips, basins, furrow irrigation), though basins are most common. The methods are simple and relatively low-cost investments for farmers to create and maintain; requiring little external assistance. This is why, despite the potentially higher irrigation application efficiencies (Box 4.2) and crop production that can be achieved with the high-tech alternatives, surface irrigation remains the most common on-farm irrigation methods (Box 3.5). The downside is that it is a difficult technology to use effectively and farmers do not always have the skills or control over water supplies to attain the potential levels of application efficiency.

Box 4.2 Irrigation Efficiency can be a misleading term

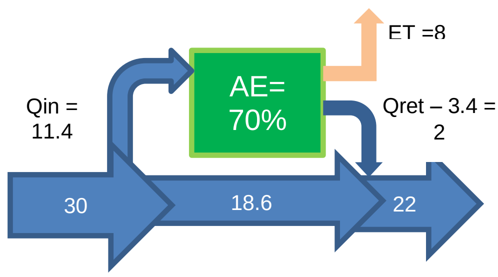
Most people are familiar with the term *efficiency* and understand that it is a dimensionless ratio (a percentage) reflecting the quantity of a resource required to be used to provide a useful amount of the same resource, such as energy. We are also used to the concept of productivity – the quantity of a desired product produced by the consumption of a resource, for examples mile per gallon (mpg) or Kilometres per litre. In these cases a sound management or design objective is to use less resource to obtain the desired output. Because once used, the fuel cannot be used again – fuel consumption and fuel use are the same.

But the rather simple concept of efficiency does not transfer easily to irrigation and can lead to unintended consequences. Consider the following diagram as a base case: 20 units of water are diverted and applied to the field at an application efficiency of 40%. About 8 units are consumed by the crop and 12 units return to the river, giving a downstream flow of 22 units.

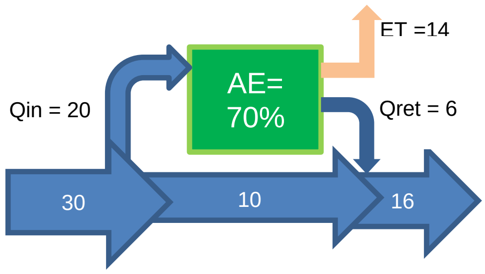


In discussions about irrigation investments, the objectives often include efforts for "water saving" with "high-tech" irrigation methods seen as the solution due to reducing water use and achievement of high application efficiencies. And it is clear that drip irrigation can enable farmers to pump or divert less water to obtain the same crop production – water use is reduced.

Consider the next diagram – representing a case where on-farm application efficiency has been increased to 70%. This would, in principle, enable the farmer to divert only 11.4 units of water, continue to evaporate 8 units, return 3.4 units to the river. The water not diverted, flows downstream for use by other users, but the flow downstream of the scheme remains as in the base case, 22 units. While there may be some value in increasing the flow between the offtake and the return flow from 10 to 20 units, the downstream farmers, who may reasonably have expected increased water availability from the improved irrigation systems upstream, have gained nothing.



Alternatively, the farmer may choose to divert and apply the original volume of water (20 units) to the field, benefiting from the "high-application" efficiency (70%) to spread the water more evenly across the field to avoid areas of under-irrigation and yield reducing crop stress; or the area irrigated may be increased, as illustrated in the next diagram. In both cases more water is transpired (consumed) by the crop (14 units) and less water returns to the river (6 units). The water used is the same, but consumption has increased (14 units) and the water users downstream have lost out as flow has now decreased to 16 units. Not at all what would probably be expected from an investment to increase irrigation efficiency and save water!



As illustrated by these simple water balance diagrams "using less water" is not the same as "saving water".

Notes to Diagrams: AE – field application efficiency; ET – crop consumption; Qin = diverted flow; Qret – return flow

Surface irrigation relies on a horizontal or inclined plane soil surface to transport water. It is here that the most significant and wide spread adoption of improvements to surface irrigation technology has been observed in Asia in the form of laser levelling, particularly for irrigation of paddy rice. Laser levelling has become accessible because the current generation of levellers are coupled to standard tractors and the laser head units are self-levelling i.e. do not require any adjustment. Hence the setting up of laser levellers has become a relatively low-skilled task and thus practical as a service for agricultural contractors in developing economies; as illustrated by the explosive growth of laser levelling in India and Pakistan (Jat et al.2006). The initial cost of levelling is up to $500/ha depending on the topography; and to maintain the benefits repeat levelling is required about every 5 to 6 years. However, the subsequent repeat levelling costs about $150/ha. Small plot sizes, limited availability of tractors and equipment may constrain adoption of these practices for smallholder farming in SSA. However, precision surface irrigation may be possible in contiguous fields where farmers agree to synchronize levelling which may require temporary removal of farm boundaries at about 5 year intervals.

Typical unit costs and advantages and disadvantages of on-farm technologies are summarised in Table 4.2.

Table 4.2 Performance and advantages and disadvantages of on-farm technologies

Irrigation System Application	Efficiency*	Cost** (irrigation labour cost not included)	Advantages	Disadvantages
Wild Flood or Spate	15-40%	$0 - $20 (home made plastic or canvas dam)	• Low input cost • Low maintenance	• Increased labour • Poor uniformity
Furrow	40 - 80%			• High labour
• Gated pipe	40 - 55%	$6 - $9/meter	• Control of delivery time and space	• Low efficiency
• Corrugation	50 - 80%			
Sprinkler		$6,000/ha	• Higher efficiency	• Higher cost
• Mini gun	55 – 75%	----	• Low labour	• Higher operations and maintenance cost
• Portable hand lines	60 – 85%	$4,000/ha	• Suitable for most crops	• Higher labour requirements • Needs continuous supply of water
• Solid set	60 – 85%	$8000/Ha	• Good choice for fields with varied soil and topography	• Requires pressurised water supply • Maintenance can be costly
Surface Drip	70-95%	$2,000-$4,000/Ha	• Higher efficiency • Less time and labour • Reduced runoff • Reduced pumping costs • Typically used for vegetables, windbreaks, trees, vines and shrubs	• High initial cost • Higher management time • Needs continuous supply of water • Filtration required

*Source: Barta, et. al, 2004: Notes: *Application Efficiency refers to the percent of water delivered that ends up in the root zone of the crop. Efficiencies can be much lower due to poor design and management. ** Based on 2012 cost estimates*

4.1.3 On-farm storage

Improving crop water productivity requires application of irrigation water not only in required quantity but also at the right time, corresponding with the timings of crop water requirement. Farmers frequently face the twin problems of inadequacy and untimeliness in availability of water whether serviced by canals, tubewells or in rain-fed areas. Small on-farm storage reservoirs are an effective means to provide farmers with increased flexibility in the timing of irrigation applications in response to assessed field conditions and, in addition, reduce the risks associated with intermittent surface irrigation water supplies or to accumulate limited flow-rate groundwater supplies. Sprinkler and drip irrigation systems will often require on-farm storage systems. Inclusion of on-farm storage in the design of irrigation systems provides additional flexibility in the operation of the irrigation service. These can include Sudanese style ‘hafirs’ which are excavated small reservoirs supplied from surface runoff or small stream diversions.

4.2 Solar energy and irrigation

Renewable energy technologies, (including bio and solar energy) have potential application in irrigation in SSA, with considerable effort being focussed on solar pump irrigation systems (SPIS). Solar technology is not new; some installations such as the Solar Electric Light Fund’s (SELF’s) long running solar drip irrigation project in Benin, operating since 2007, have built on a steady process of capacity building for both the 400+ women growers in their 11 half-hectare gardens and their local NGO partner (FAO & GIZ, 2015). However, use of solar powered irrigation pumps is rising with increasing commitment to reduction of greenhouse gasses, the reduction in cost of solar voltaic panels, and the availability of drip and micro-sprinkler equipment to utilise the relatively low discharge (0.28 l/s - http://sunculture.com/products) of solar pumps typically installed by individual farmers. Using SPIS enables farmers to control application of water and fertilizer to grow high value crops increasing household income (Box.4.3**).**

Box 4.3 Why solar power irrigation systems?

The smallholder farmers that irrigate in the Rift Valley regions of Ethiopia usually produce cabbage, potato, onion and peppers. In recent years they have come to rely heavily on diesel motor pumps, hand and treadle pumps, rope and washer pulley systems and labour-intensive spray can application. All these technologies have high operational costs and/or require significant inputs of labour. But the availability of solar pump equipment is changing farm practices.

“The solar pump makes our life very easy. Before this technology we were using diesel pumps that incurred us high running and maintenance costs and also we were using too much water that leads to scarcity.” Farmer Jambo, Bora district, Meki. Farmer Godana Golande from Bonke district of Gamo Gofa agreed, saying that although he has water around, he is facing serious problems in efficient use and getting water to his plots requires a lot of energy and labour.

The solar pump helps reduce labour for irrigation and has other advantages such as household micro-irrigation development, livestock, domestic use and charging mobile phones.

http://www.iwmi.cgiar.org/2016/05/solar-water-pumps-boost-household-micro-irrigation/

4.3 Some encouraging, but potentially worrying trends

Increasing numbers of smallholder farmers in SSA are investing in irrigation from their own resources (e.g. motor pumps and pressurised application systems) to enable them to draw water from nearby sources, including from main canal systems, without depending on public agencies or water user associations (de Fraiture, et al., 2014). Such approaches are spontaneous and, if unchecked, may pose challenges to equitable access to and sustainable management of public irrigation systems and water resources (e.g. Dessalegn and Merrey, 2014). There are concerns that such approaches may lead to over-abstraction, pollution and conflicts, particularly when linked with drip and other high-tech application technologies.

Unregulated small-scale private irrigation poses several challenges related to social equity and environmental sustainability. First, poor farmers (often women and young people) cannot always afford the upfront investment costs for AWM technologies and the associated agricultural investments needed to generate higher profits. While all farmers face agricultural risks, poorer farmers are often less able to access resources and assume proportionally larger financial risks. Second, investments in irrigation, whether small-, medium- or large-scale, are associated with the relatively more intense use of agrochemicals, which can have a negative impact on water resources and food safety. Finally, competition between upstream and downstream users, and the depletion of groundwater, may be aggravated by the unchecked or un-regulated nature of small-scale private irrigation (Box 4.2).

4.4 Summary

Small-scale, farmer-driven investments in irrigation, accessing local ground and surface water resources, can exist alongside large-scale, public-sector-financed irrigation schemes distributing water from major dams and diversion structures. Investments by farmers in AWM has increased recently thanks primarily to expanding market opportunities and decreased costs, together with the increased availability of AWM technologies. Independent of formal irrigation infrastructure, many farmers now use their own resources to procure irrigation equipment (buckets, pumps, drip systems, pipes and sprinklers) either individually or in small groups.

However, in many cases, the adoption of irrigated agriculture is not an easy transition for farmers previously dependent of rain-fed cropping systems. Rain-fed farm households are generally resource poor and therefore need strong support services, including provision of capacity development on new agronomic practices (often with increased requirements for agro-inputs), financial management and credit services, water management, and marketing to enable the poor to capitalise on the opportunities provided by improved access to water.

SECTION 5

Institutional arrangements for irrigation

5.1 Irrigation stakeholders

There are a diverse range of stakeholders in the irrigation subsector. They include (i) the government (e.g., policy-makers, regulators, planners, irrigation department staff, project managers, etc.); (ii) owners and cultivators of irrigated land; (iii) suppliers of inputs, services, and funds; (iv) water management associations; (v) other groups who are affected by irrigation water management (e.g., households, power, and industry); and (vi) nongovernment organisations and environmental interest groups. Summaries of the key roles of selected stakeholders in the irrigation subsector are given in Table 5.1 and Table 5.2.

Table 5.1 Simple stakeholder analysis (based on ISSP, 2001)

Key Actors	**Policy**	**Strategic planning**	**River basin planning, allocation and distribution**	**Construction of facilities**	**Maintenance of facilities**	**Monitor water quantity and quality**	**MOM of main system**	**MOM of on-farm system**	**Management at the field level**	**Advisory services**
Politicians	●	●								
Water Resources Department			●	●	●	●				
Irrigation Department				●	●		●			
Agriculture Department										●
Environment Department						●				
WUA management & members					●			●		
Farmers									●	
NGO and community based	●		●			●				
Private sector (seed companies, output value chain)										●

Notes: MOM – management operations and maintenance, NGO – nongovernmental organization, WUA – water user association

The origin and structure of institutions of community-managed irrigation schemes vary within and across countries in SSA. Institutions may be informal or formally organised by Government and NGOs. For example, in Ethiopia, after the construction of an SSI scheme, institutions are established and beneficiaries identified as members of the WUA. The WUA is expected, in principle, to be responsible for the management of the scheme; facilitating water distribution and the ongoing maintenance and operation of the scheme. However, limited financial resources and lack of the required technical skills are major constraints that limit the capacity of most WUAs to fulfil the expected roles (Haileslassie et al., 2016).

Smallholder farmers usually work as individuals or as family groups. However, because of the scale of investment needed to develop and sustain access to water for larger areas they must work in larger groups; i.e. where a scheme requires a small reservoir or a pumping station on a river with a distribution system that a farmer alone could not afford (FAO 2002). The problems of collective action and complex management bureaucracy characterise these larger community and/or agency-managed schemes (de Fraiture and Giordano, 2014). Assistance may be required to help such groups to develop the technical capacities to manage the infrastructure to enable effective service provision and to establish equitable governance arrangements.

Table 5.2 Roles of Key Stakeholders in the Irrigation Subsector

Stakeholder group	Illustrative Roles
Government	• Provide the policy, legal, and regulatory framework for the irrigation subsector
	• Establish effective water rights systems and enforce related policies and legislation
	• Determine water allocations for the head of each system
	• Issue permits for water use and impose limits on water extractor
	• Prepare and implement plans for sustainable basin-level management
	• Approve projects for developing and managing irrigation systems
	• Help build the capacity of irrigation water management associations to operate and maintain irrigation system
	• Resolve conflicts among water users
	• Collect irrigation service charge
Owners and cultivators of irrigated land	• Engage in crop production to meet the needs of the household and of the market
	• Manage the system from tertiary to field level
	• Pay irrigation service charge
Private sector irrigation service providers	• **Commercial farmer as a private irrigation operator:** Smallholder farmers in the command area would be given the option of becoming out-growers to the large commercial farmer
	• **Operation, Management and Maintenance (OMM) contract -** The private-sector is engaged to undertake operation, management and maintenance of infrastructure services for defined recipients.
	• **Infrastructure concession -** The private-sector is engaged to raise commercial finance for infrastructure development and then construct, operate, manage and maintain the infrastructure.
	• **Farm service agreement -** The private-sector can also partner with smallholder farmers and communities for the provision of farm-level services. Services might be on-farm, such as planting, harvesting and water application; or off-farm, such as storing, processing and marketing (e.g. out-grower services).
Suppliers of equipment and services (e.g pipes, pumps, and related	• Provide technical and production support to irrigation systems

Stakeholder group	Illustrative Roles
equipment; construction and repair services; and consulting services)	
Providers of development assistance to the subsector	• Provide financial and technical assistance for developing, rehabilitating, and modernising the irrigation subsector
	• Build capacity of water users for water management
Irrigation water management associations	• Mobilise the active participation of water users
	• Comply with water-related rules
	• Help maintain irrigation systems
	• Pay fees for the use of surface irrigation water
	• Coordinate irrigation and agriculture-related services with relevant groups
Others affected by irrigation management (households, power, industry, and others)	• Participate in issues arising from water management
	• Contribute to basin water management
	• Exercise the right to obtain their share of water supply for their needs
Non-government organisations	• Catalyse the process of developing local organisations for managing irrigation systems and the environment
Environmental groups	• Advocate sustainable environmental management practices
	• Participate in dialogues on the environment and help promote informed choices

Sources: ADB. Various years. *Report and Recommendation of the President*. Various irrigation projects. Manila; Asian Productivity Organization. 2004. *Linking Main System Management for Improved Irrigation Management*. Tokyo. Available at http://www.apo-tokyo.org/publications/wp-content/uploads/sites/5/pjrep-ag-ge-sem-08.pdf (Accessed 20 July 2016)

5.2 Stakeholder coordination and participatory management

Irrigation systems are complex with many participants and many objectives. The ease of establishing a widely-supported set of objectives varies depending on whether the irrigation systems are developed, or controlled and operated by (i) local people in response to their needs, or (ii) a public agency with little involvement of the beneficiaries (Sally, 2002). The execution and performance of the required management functions are also adversely affected if the arrangements are not well-aligned with the bio-physical, institutional and macro-economic environment in which the irrigation system is embedded. The functions can be grouped into the following three categories:

- water management functions, relating to the operation and maintenance of the irrigation and drainage infrastructure;
- agricultural production functions, where the water made available is used for crop production;
- organisational functions, broadly covering the planning, co-ordination and implementation of the tasks and activities (including accounting, resource mobilisation and cash-flow management) that must be correctly performed for the smooth operation of the irrigation system.

Most irrigation systems, whether large or small, that deliver water to multiple smallholder farmers divide responsibility for O&M of the main system from that for the tertiary and lower order channels.

5.2.1 Main system management

In many formal medium and large scale systems, a public sector irrigation agency will be responsible for the development and subsequent O&M of the water source, diversion and control structures, and canals and pipelines. In some instances, a private sector firm may be appointed to operate and maintain the system under a performance based contract or concession agreement, At some control structure, typically the head of a tertiary canal or field canal, the responsibility for O&M of the system and for the delivery of water to farmers is transferred to the group of water users receiving irrigation through the structure.

The original mandate of most irrigation agencies has been to construct and develop irrigation systems. In formal large-scale irrigation schemes supply driven irrigation management is the norm. Unfortunately, because of vested interests, this focus tends to remain with the agency long after economic and environmental constraints suggest that the agency should change its focus. It is now widely recognised that many public sector irrigation agencies require significant reform to reorient themselves from direct management of irrigation systems to regulating the sector and building capacity of water user associations (WUA) to take on additional responsibilities for O&M of the systems. There is a need for a paradigm shift in the way public irrigation systems are managed. Recognition of a need to make irrigation services perform better was part of the underlying drive for increased beneficiary participation that is the foundation of Participatory irrigation management (PIM) efforts. Dissatisfaction with public service delivery in irrigation and recognition that public sector finance resources are inadequate to address the infrastructure and service needs of increasing populations is encouraging governments to seek alternative arrangements to finance and deliver services for their populations. Irrigation agencies will likely require additional investments for capacity development to enable them to focus more on the critical role of managing and operating the main-systems including head-works, and taking an increased role in providing technical and financial guidance to WUA and farmers.

5.2.2 User management of irrigation sub-systems

Participatory irrigation management (PIM) generally refers to efforts to increase participation of farmers in the management of irrigation system below the tertiary outlet; often through the creation of WUAs, and above it through federations of WUAs. The irrigation agency can transfer various system management responsibilities as part of an Irrigation Management Transfer (IMT)[16] programme.

Interest in IMT comes, in part, from the assumed efficiency and productivity gains that could be obtained from farmer participation and decentralized management of irrigation systems. It was also assumed that the transfer of management responsibility to local organisations would improve the accountability of the irrigation service to farmers, improve the cost effectiveness of service provision, motivate farmers to invest more in maintaining irrigation systems and, ultimately, make irrigation systems and irrigated agriculture more sustainable. In addition, shortfalls in government funds to finance the recurring costs of irrigation and the inability to recover costs from farmers has encouraged many countries to adopt IMT reform programs (Giordano et al, 2006).

Although empowerment of water users was enshrined in many irrigation policies and legislation, in many systems the results were often limited by resistant bureaucracies, local elites and limited efforts at capacity building. International experience suggests that a PIM/IMT intervention succeeds only if: (i) it holds out credible promise of a significant net

[16] *Irrigation Management Transfer (IMT) entails the partial or complete transfer of irrigation management rights and responsibilities for an irrigation (sub) system from government to farmer organizations, water user associations (WUAs), other non-governmental agencies (including the private sector) or local government agencies.*

improvement in life-situations for a significant proportion of farmer-members; (ii) the irrigation system has become central to creating such improvement; (iii) the economic and financial cost of sustainable self-management is an acceptably small proportion of improved income; (iv) WUAs have authority over O&M, asset management, financing and dispute resolution[17]; and (v) the proposed organisation design is—and is seen to have—low transaction costs.

5.3 Access to and ownership and control of land and water

In the majority of the countries in SSA, land ownership or tenure is governed by national land policies whereby land is public and vested in the government as a trustee. For the majority of smallholder farmers this means that access to land and water is highly insecure limiting the incentives for private investments to improvement of land and water management (Yami 2016). Investments to increase agricultural productivity and reduce poverty are unlikely to be successful without investments supporting resources and inputs (Box 5.1).

Box 5.1 Access and control of land and water are essential for irrigated agriculture

"Inadequate access to or control of water has an important indirect impact by reducing the potential pay-off from other productivity increasing inputs such as fertilizer, improved seed varieties and even education" (de Fraiture, Molden and Wichelns 2010, 497).

"Clearly, providing irrigation water alone will not guarantee increased productivity: not only must water supplies be reliable but they must be provided as part of a comprehensive and sustainable package that empowers farmers to commercialise their yields and production, as well as giving them incentives to do so including improved access to input and output markets" (AfDB; FAO; IFAD; IWMI; World Bank 2007, xxii).

"No investment in costly infrastructure should be planned without having beforehand implemented the conditions for its beneficial use: secure land access for poor farmers; reasonable access to financial services (savings and credit); analysis of market opportunities and risks; where appropriate, enhanced collective organisation of farmers; organised access to quality inputs; and training of farmers in new agricultural practices and irrigation management at individual and collective level. Countries and regions where these basic conditions are in place should be given priority. In other cases, specific activities to strengthen these aspects should be included within projects or developed as parallel programmes" (Morardet, et al. 2005, 43). *Source: Dalaney, 2012*

5.4 Summary

Smallholder irrigation offers significant direct and indirect benefits for low-income farm households in much of SSA. However, the majority of developments are proceeding in an un-regulated and unplanned manner. Because these farmer-led investments are without support from institutions or investors, smallholder farmers face several challenges. These include difficulties in accessing land and credit, insufficient information, poor access to markets, and negative environmental impacts caused by the collective and un-regulated actions of many smallholders. Investing in irrigation is costly, and in the absence of risk-reducing measures small farmers can be exposed to substantial financial risks. However, these challenges are not insurmountable. Therefore, taking action to support the smallholder irrigation sector represents a significant investment opportunity that could help to alleviate poverty and ensure food security.

[17] *In Colombia in the 1970's, the transfer of management responsibility to WUAs in the Saldana and Coello systems, without transfer of related rights and authority, did not work. This led to legal reform to empower WUAs to be able to define the service, set budgets and hire and release staff. (Vermillion & Garces 1996).*

SECTION 6

How to make irrigation work?

Investments in irrigation cannot rely on a "*cookie-cutter*" approach that would replicate a common design and institutional arrangements in different locations. Too often agricultural water management interventions have led to unsustainable or unexpected outcomes. A major reason is that they are often designed and implemented as if operating in a vacuum. Within many rivers, water is already heavily utilised and developments in one location impact existing or planned uses downstream. Where new interventions do not recognise these interactions, a potential for future conflicts exists. Introducing new technology that is poorly matched with the needs, expectations or capacity of the irrigators will often lead to it being damaged before becoming fully operational. Within irrigated areas, governance arrangements for water generally already exist, prior to the intervention. These are often defined by informal institutions, and accepted norms and values. The local rules-of-the-game reflect broader social and power relationships within the communities involved. Ignoring these local rules on decision-making related to wealth and status, norms on gender mobility, or existing social conflicts within the community, can lead policy-makers and water professionals to miss critical issues (WLE, 2016), leading to underperforming investments. The majority of these problems can be anticipated and overcome by better matching investments with the specific local context.

Huppert, 2009, provides a framework to help assess the dangers inherent in failing to appropriately recognise the complexity of the political economy and agricultural domain when designing an intervention programme; defining "systemic"[18] and "non-systemic"[19] interventions. Critically, the Huppert framework provides a guide on which aspects of irrigation development and/or irrigation system operations and maintenance (O&M) are inherently complex, requiring multi-disciplinary approaches and high-levels of careful, often extended, interactions with stakeholders indicated in the upper right quadrant (**Iic**) in Figure 6.1. The framework also identifies the sort of interventions that can be addressed more directly through a typical "project" activity (**Io**) in the lower left quadrant.

Figure 6.1 highlights the need to separate the approaches adopted to address different aspects of the irrigated agriculture domain (Cleveringa et al, 2009), including acknowledging the need for location specific packages of interventions ("What" and "Where") for different communities ("Whom") as critical to determining the appropriate project modalities ("How") when identifying and designing projects to increase food and water security. A set of ten similar questions has been proposed (Jobbins et al, 2015) to guide decisions on investments in irrigation in SSA.

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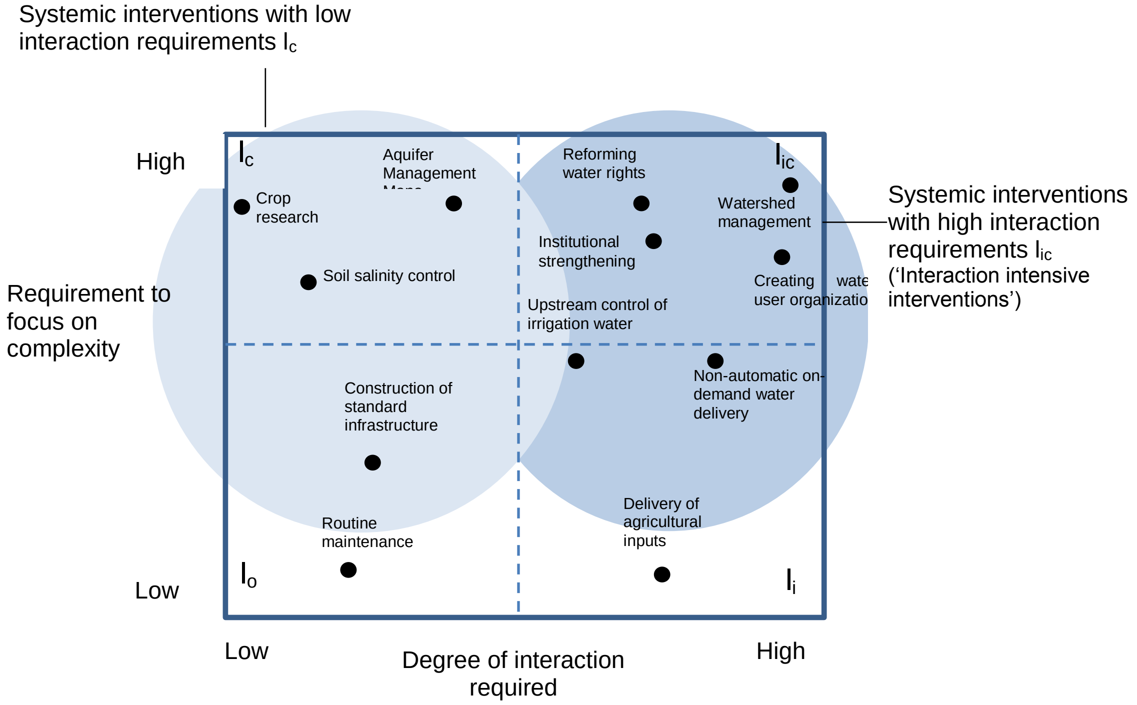
18 Systemic interventions – actions that aim explicitly to change, improve, or reform entire systems or related sub-systems and which must therefore take into account system complexity. Examples include: introduction of new crops to an established farming system, change from single to double cropping, introduction of irrigation to previously rain-fed agriculture, and irrigation management transfer from government agency to user control.

19 Non-systemic interventions – actions that concentrate on specific details of a complex system (or sub-system) and which do not have to address its overall complexity. Examples include: routine maintenance of irrigation infrastructure, hydrological and meteorological data collection, and supply of agricultural inputs.

Figure 6.1 framework to assess complexity of interventions in irrigation (after Huppert, 2009)



6.1 Why a checklist?

The checklists presented here are intended to help deliver successful investments in irrigated agriculture by guiding the user through the critical decision stages by determining: (i) who will benefit from the investment; (ii) what to invest in; (iii) where to invest; (iv) who should make the investment; and (v) how the project should be implemented. Although the stages are presented as a linear progression, in practice the process may start from a consideration of each of the stages, with the possible exception of item (v) – the 'how' question.

The checklists in this Topic Guide are not intended as exhaustive guides on how to assess the issues identified. Rather each serves as a reminder of the scope of issues to be reviewed when considering making an intervention in irrigation infrastructure or agriculture to improve agricultural water management. Each completed checklist may be considered as an aide memoire of whether each issue has been considered, with a short note to record the conclusion of the assessment and any decision taken for further investigation. An important aspect is the recommendation to note why any particular issue is not considered applicable to a specific investment being considered.

The checklists are also shown in Annex I for easy duplication for use in the field.

6.2 Who will benefit from the proposed investment?

Irrigation can be a pro-poor investment, enabling resource poor households to increase food production to provide direct food security or to engage in marketing of high value produce to increase household income. Enabling the project to achieve intended pro-poor outcomes requires careful design to enable the intended recipients to participate and benefit from new technologies and services introduced.

A critical step, too often overlooked, is the need to assess whether the new technology is appropriate for the intended user. Do the proposed technologies fit with the farm conditions, the family's consumption requirements (e.g. the storability, cooking and taste traits of new crop varieties), available resources (e.g. some new technologies or crops require lots of labour for weeding and harvesting at already busy times of the year, and this may be difficult for non-mechanised farmers to supply), and the participants capacities (Hazell, 2014).

In the project identification stage it is important to consider the proposed interventions from the perspective of the expected participants, Checklist 6.1.

Checklist 6.1 –Consider interventions from a farmer's perspective

Participants' capacity for:	Assessed Y/N	Comments/Additional studies required
(i) **Access to knowledge about new technologies**.		
(ii) **Access to market opportunities** to warrant investment beyond own consumption needs.		
(iii) **Access to and affordability of the necessary purchased inputs** like seeds, fertilisers and pesticides.		
(iv) **Available financial resources**, such as own savings and access to credit or nonfarm sources of income. This is particularly important for lumpy investments where a threshold level of capital is required.		
(v) **The riskiness of new technologies**. Production and market risks can deter adoption of improved seeds and fertiliser use, particularly if they have to be purchased with credit. For longer-term investments in resource improvements there are additional risks such as the loss of rights over land, loss of assets due to theft, civil strife or natural catastrophes, changes in health, and changes in government policies.		
(vi) **The property rights that farmers have over natural resources** can be important in determining whether they are willing to make investments that improve the long-term productivity of those resources (e.g. planting trees and contouring land). Secure property rights can also be important for obtaining credit in order to make long-term investments.		
(vii) **Ability to organise effective collective action** for some types of productivity enhancing investments that have to be undertaken jointly by neighbouring farmers or whole communities		
(viii) **Appropriateness** of proposed interventions for intended participants.		
(ix) **Have the planned participants been consulted and involved in the identification of the proposed interventions?**		
(x) **Other issues considered**		

As part of the assessment from the participants' perspective – the proponent must consider the **Complexity** of the proposed interventions. Does the project include **systemic** or **non-systemic interventions** (see Footnotes 18 and 19)? How will the project deal with complexity during implementation?

6.3 What should the investment include?

The focus of this Topic Guide is Irrigation Infrastructure; however, experience informs us that addressing irrigation as a pure infrastructure and technology intervention generally leads to disappointing results and unsustainable interventions. Therefore, during the project identification stage, it is important to consider what supporting actions are required to achieve the intended project objectives, Checklist 6.2.

Checklist 6.2 – What should to be included in the investment?

Component elements:	Assessed Y/N	Comments/Additional studies required
(i) **Irrigation infrastructure**		
a. Water resource diversion infrastructure (headworks).		
b. Conveyance system infrastructure (main, secondary canals and control structures)		
c. Tertiary distribution infrastructure (Tertiary canals and structures)		
d. On-farm distribution infrastructure (Farm ditches, pipes)		
e. Water and Energy– renewable energy systems		
f. Is the proposed infrastructure climate change proof?		
(ii) **Water resources and climate change impacts**		
a. Are water resources adequate for the planned irrigation service?		
b. Will the planned irrigation intervention impact other uses/users in the basin? Is there a viable mitigation strategy?		
c. Have potential impacts of climate change impacts been considered?		
(iii) Drainage system infrastructure		
(iv) **Development or reform of Governance and Management organisations**		
a. Reform of management organisations (government, private sector)?		
b. Strengthening and capacity building with informal (community and user) organisations?		
(v) Agricultural support services.		
a. Irrigation equipment supply and maintenance		
b. Climate smart agriculture		
c. Agro-inputs supply and extension services		
d. Value-chain and market development		
e. Mechanisation		
f. Rural financial services		
(vi) Other interventions considered		

As part of the assessment of potential components of the investment project – the proponent must consider the **Complexity** of the proposed interventions. Does the project include **systemic** or **non-systemic interventions** (see Footnotes 18 and 19)? How will the project deal with complexity during implementation?

6.4 Who should be making the investment?

In addition to potential investment of official development assistance (ODA) resources, alternative co-finance structures may be considered. Particular consideration may be given to mobilisation of private sector resources through some form of public private partnership arrangement; but experience of PPP in development of irrigation infrastructure is limited (Box 3.8). However, private sector entities are investing in irrigation in SSA in commercial estates and, in some locations, related out-grower programmes. Furthermore, private sector individuals and groups of farmers are investing in the creation and operation of small informal irrigation systems (Box 3.7). Therefore, when designing the financing model for irrigation the potential to mobilise private sector resources to co-finance ODA investments should be considered, Checklist 6.3.

Checklist 6.3 – Who should be making the investment?

Financing options to consider:	Assessed Y/N	Comments/Additional studies required
(i) Potential for co-finance		
a. PPP for infrastructure development/rehabilitation		
b. PPP for irrigation system O&M		
(ii) Joint investment/support for informal irrigation		
a. Is there potential to support or finance informal small irrigation system developments or upgrading		
(iii) Other financing sources/models considered?		

Notes: O&M – operations and maintenance, PPP – public private partnership

6.5 Where would irrigation be a wise investment?

The estimated investment required for expansion of formal large- and small-scale irrigation systems, plus rehabilitation of existing systems, in SSA would require a one-time investment of over US$40 billion in 2008 prices (Liang Zhi You, 2008). Liang Zhi You proposed that investment in creation and upgrading of irrigation services in SSA should be prioritized according to key criteria which the study indicated resulted in higher returns on investments, Checklist 6.4.

Checklist 6.4 – Where to invest in irrigation in SSA?

Issues to consider:	Assessed Y/N	Comments/Additional studies required
(i) Is it possible to find existing systems (large or small scale) to upgrade or modernise?		
(ii) Is a potential small scale scheme within access to a stable market?		
(iii) Can the irrigation system be linked with an existing or planned reservoir, where the dam is economically viable on hydropower alone?		
(iv) Is the proposed investment consistent with the national agriculture and irrigation strategies?		
(v) Is the proposed irrigation investment the most appropriate economic use of the water resource?		
(vi) Other justifications considered for investing in proposed location?		

6.6 How should the investment project be implemented?

Huppert (2009) provides a detailed discussion of the need to match the project implementation design with the degree of complexity of the proposed intervention. Historically irrigation infrastructure development and rehabilitation has been approached as an engineering problem with limited requirement for significant interaction with the expected project beneficiaries, i.e. a non-systemic intervention (Figure 6.1).

In general irrigation development, rehabilitation or modernisation of existing irrigation systems involves a wider range of interventions than "*just fixing the infrastructure*". Checklist 6.1 and Checklist 6.2 summarise a range of interventions which may be included as activities in an irrigation investment project.

Where institutional strengthening and/or substantial transformation of agricultural practices are planned the complexity of these processes will, in general, not be compatible with the linear project implementation approaches normally applied to infrastructure investments. In these cases, long term support may be considered to enable the transformation to be facilitated and firmly established.

In designing project implementation plans, adequate attention must be given to understanding the complexity of each set of interventions (Figure 6.1) and considering how the specific context of the location of the investment will influence the implementation plan.

6.7 Summary

The identification and design of potential investments in sustainable irrigation infrastructure must consider the wider context of the agricultural systems which the infrastructure is proposed to service. The checklists presented in this section provide guidance on the issues that should be considered when identifying a potential intervention in irrigated agriculture to maximise the likelihood that the resulting infrastructure meets the users' expectations and is sustainable.

SECTION 7

Top five reads

1. **Water for Food, Water for Life. ed. David Molden, Earthscan, London and International Water Management Colombo: Institute, 2007**

   Water for Food, Water for Life is sub titled as "The Comprehensive Assessment of Water Management in Agriculture". The book brings together the outcome of collaborative research involving over 700 researchers and practitioners, to describe key water-food-environment trends that affect our lives today and uses scenarios to explore the consequences of a range of potential investments. It aims to inform investors and policymakers about water and food choices in light of such crucial influences as poverty, ecosystems, governance, and productivity. It covers rain-fed agriculture, irrigation, groundwater, marginal-quality water, fisheries, livestock, rice, land, and river basins.

   Individual chapters can be downloaded from the IWMI web site at http://www.iwmi.cgiar.org/assessment/Publications/books.htm.

   Chapter 9– Reinventing Irrigation (41 pages) describes the evolution and performance of irrigation, presents policy recommendations, and examines likely investment strategies and requirements.

   http://www.iwmi.cgiar.org/assessment/Water%20for%20Food%20Water%20for%20Life/Chapters/Chapter%209%20Irrigation.pdf (Accessed 15 July 2016)

2. **Walter Huppert. 2009. Coping with complexity - Innovative approaches to an emerging issue in agricultural water management. INNOWAT - IFAD, Rome**

   Huppert introduces the proposal that complexity is one of the main stumbling blocks for agricultural water management (AWM) practitioners as they struggle to achieve social, economic and ecological sustainability. He posits that Complexity will become a more important issue in the future, in the rapidly changing context of AWM. The paper discusses essential aspects of meeting the challenge – of *coping with complexity*.

   An important distinction is made between systemic and non-systemic interventions in AWM. Systemic interventions are tasks and services – such as the reform of water user associations or the drainage of wetlands – that need to take account of the complexity of the 'target system'. Non-systemic interventions, such as simple construction tasks, were the need to take account of complexity is limited. This distinction results in the differentiation of groups of interventions in AWM that call for different management approaches.

   The essential differences in management approaches required by the various types of interventions are specified and discussed. These reflections result in the grave observation that conventional project management approaches are not suitable for coping with complexity-oriented interventions. The paper presents different management models compatible with the different types of interventions https://www.ifad.org/documents/10180/0c6bad31-6054-452c-a01e-b13f3d305754

3. **Theo Rauch. 2009. The new rurality - Its implications for a new, pro-poor agricultural water strategy. INNOWAT - IFAD, Rome**

Food production is fundamental to reducing hunger and poverty, and water is fundamental to food production. Yet the demand for food is growing, while available water resources are likely to decline and become increasingly unpredictable. By 2050 food demand in sub-Saharan Africa (SSA) is expected to double. In semi-arid areas, where most poor rural people live, agriculture already consumes as much as 90 per cent of available water resources.

Rauch presents the need for a new, pro-poor agricultural water management strategy to cope with these changes. Pro-poor targeting means acknowledging limited assets such as land, labour and specialised farming skills, and the lack of access to services. This leaves scope to improve rain-fed farming and irrigated, dry season small horticulture even in remote areas. Rauch identifies promising strategic options for making more effective use of scarce water resources, which can provide poor households and small farmers with the ability to cope better with unreliable and variable water supplies and to exploit new market opportunities. Overall, the paper stresses that pro-poor water management must be based on the empowerment of organised users, enabling them to effectively articulate their needs in the struggle for scarce water resources.

https://www.ifad.org/documents/10180/a7a81027-3495-40d8-84b4-3f9b08338bcc

4. **Rudolph Cleveringa, Melvyn Kay and Alasdair Cohen 2009 Synthesis of strategic approaches - Enhancing pro-poor investments in water and rural livelihoods. INNOWAT - IFAD, Rome**

The authors present this paper as a summary of the main findings and recommendations from the papers by Huppert (paper 2) and Rauch (Paper 3). Cleveringa and co-authors show that reduction of hunger and poverty depends on improved access to water for poor rural people. Progress in community water supplies and agricultural water management (AWM), particularly irrigation, is one of the success stories of the twentieth century. However, they draw attention to the disappointing fact that AWM, by far the largest consumer of water in developing countries, has had little impact on world hunger and poverty. The experience of agency- and government-led interventions has not been good. Previous investments have tended to impose 'blueprint' methods that ignored important local issues. There is a critical need to bridge the gap between planning and successful implementation. Traditional design approaches have tended to focus on *what* needs to be done, rather than on *how* to do it, and unfortunately ignore the complex interactions among individuals, the state and service providers.

If poor rural people are not to be the losers again in the struggle for declining water resources, a new, pro-poor water management strategy is needed.

The authors draw particular attention to the need for more focus on *how* to do it, while still addressing *what* to do, *where* and with *whom*. If interventions are to succeed, the new strategy must recognise the changing nature of rural livelihoods and its impact on poverty – a 'new rurality' – and the complexity of socio-economic systems, particularly where governance and local and national institutions are weak.

https://www.ifad.org/documents/10180/a7a81027-3495-40d8-84b4-3f9b08338bcc

5. **Meredith Giordano, Charlotte de Fraiture, 2014 Small private irrigation: Enhancing benefits and managing trade-offs. Agricultural Water Management 131 (2014) 175– 182**

This paper is based on the findings from the AgWater Solutions Project, carried out between 2009 and 2012. The studies — implemented in the African countries of Burkina Faso, Ethiopia, Ghana, Tanzania, Zambia, and in the Indian states of Madhya Pradesh and West Bengal—examined interventions in small-scale irrigation for sustainable and equitable improvements in rural livelihoods. More than 30 field- and community-scale case studies of existing small-scale irrigation technologies, policies and programs, involving more than 20,000 interviews, were carried out across the project countries.

Millions of smallholder farmers in sub-Saharan Africa and South Asia benefit from readily available and affordable irrigation technologies. The rapid uptake of small private irrigation in South Asia had a proven positive effect on poverty alleviation. In sub-Saharan Africa similar trends are emerging and several studies point to considerable upscaling potential. Achieving this potential would substantially boost smallholder incomes and food security. However, the spread of small private irrigation poses several challenges related to equity, efficiency, and sustainability.

Women and resource poor farmers face challenges accessing affordable technologies; market inefficiencies and policy frameworks negatively affect farmer decision-making and technology access; and the unregulated spread of private irrigation may lead to over-abstraction, pollution, and conflicts.

The paper argues that carefully designed intervention strategies and policy engagement are needed for two reasons. First, there is a need to address potential adverse effects of the ongoing, unregulated spread of small private irrigation while safeguarding its proven benefits on food security and poverty alleviation. Second, relatively straightforward measures can extend the benefits to a broader group of smallholders, including women and the poor, while at the same time ensuring sustainable use of the resource. Based on empirical evidence from case studies in six countries, the paper identifies four elements of such an approach: (1) enhancing technology access; (2) catalysing smallholder value chains; (3) fostering supportive policies; and (4) strengthening institutional capacity to manage potential trade-offs at the watershed scale.

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Annex 1 Irrigation Investment Checklists

Checklist Annex 2.1 Consider interventions from a farmer's perspective

	Participants' capacity for:	Assessed Y/N	Comments/Additional studies required
(i)	**Access to knowledge about new technologies**.		
(ii)	**Access to market opportunities** to warrant investment beyond own consumption needs.		
(iii)	**Access to and affordability of the necessary purchased inputs** like seeds, fertilisers and pesticides.		
(iv)	**Available financial resources**, such as own savings and access to credit or nonfarm sources of income. This is particularly important for lumpy investments where a threshold level of capital is required.		
(v)	**The riskiness of new technologies**. Production and market risks can deter adoption of improved seeds and fertiliser use, particularly if they have to be purchased with credit. For longer-term investments in resource improvements there are additional risks such as the loss of rights over land, loss of assets due to theft, civil strife or natural catastrophes, changes in health, and changes in government policies.		
(vi)	**The property rights that farmers have over natural resources** can be important in determining whether they are willing to make investments that improve the long-term productivity of those resources (e.g. planting trees and contouring land). Secure property rights can also be important for obtaining credit in order to make long-term investments.		
(vii)	**Ability to organise effective collective action** for some types of productivity enhancing investments that have to be undertaken jointly by neighbouring farmers or whole communities		
(viii)	**Appropriateness** of proposed interventions for intended participants.		
(ix)	**Have the planned participants been consulted and involved in the identification of the proposed interventions?**		
(x)	**Other issues considered**		

Checklist Annex 7.2 What should to be included in the investment?

Component elements:		Assessed Y/N	Comments/Additional studies required
(i)	**Irrigation infrastructure**		
	a. Water resource diversion infrastructure (headworks).		
	b. Conveyance system infrastructure (main, secondary canals and control structures)		
	c. Tertiary distribution infrastructure (Tertiary canals and structures)		
	d. On-farm distribution infrastructure (Farm ditches, pipes)		
	e. Water and Energy– renewable energy systems		
	f. Is the proposed infrastructure climate change proof?		
(ii)	**Water resources and climate change impacts**		
	a. Are water resources adequate for the planned irrigation service?		
	b. Will the planned irrigation intervention impact other uses/users in the basin? Is there a viable mitigation strategy?		
	c. Have potential impacts of climate change impacts been considered?		
(iii)	**Drainage system infrastructure**		
(iv)	**Development or reform of Governance and Management organizations**		
	a. Reform of management organisations (government, private sector)?		
	b. Strengthening and capacity building with informal (community and user) organizations?		
(v)	**Agricultural support services**.		
	a. Irrigation equipment supply and maintenance		
	b. Climate smart agriculture		
	c. Agro-inputs supply and extension services		
	d. Value-chain and market development		
	e. Mechanization		
	f. Rural financial services		
(vi)	**Other interventions considered**		

Checklist Annex 7.3 Who should be making the investment?

Financing options to consider:			Assessed Y/N	Comments/Additional studies required
(i)	**Potential for co-finance**			
	a.	PPP for infrastructure development/rehabilitation		
	b.	PPP for irrigation system O&M		
(ii)	**Joint investment/support for informal irrigation**			
	a.	Is there potential to support or finance informal small irrigation system developments or upgrading		
(iii)	**Other financing sources/models considered?**			

Notes: O&M – operations and maintenance, PPP – public private partnership

Checklist Annex 7.4 Where to invest in irrigation in SSA?

Issues to consider:		Assessed Y/N	Comments/Additional studies required
(i)	**Is it possible to find existing systems (large or small scale) to upgrade or modernise?**		
(ii)	**Is a potential small scale scheme within access to a stable market?**		
(iii)	**Can the irrigation system be linked with an existing or planned reservoir, where the dam is economically viable on hydropower alone?**		
(iv)	**Is the proposed investment consistent with the national agriculture and irrigation strategies?**		
(v)	**Is the proposed irrigation investment the most appropriate economic use of the water resource?**		
(vi)	**Other justifications considered for investing in proposed location?**		