Chapter 5

The case for a new irrigation research agenda for sub-Saharan Africa

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Introduction

Over the past 50 years, increases in global food production have been able to outstrip population growth. Asia has been the star performer, with per capita food production doubling over the period. Africa, on the other hand, shows no real progress. Food production per capita today is similar to what it was in 1961 and food imports have steadily risen. Total cereal production has increased more or less in line with population, but this increase is almost entirely due to cropping more land, not increasing yield per unit area. In southern and eastern Africa, per capita yields have even declined substantially over the past few decades (Pretty *et al.* 2011).

The Green Revolution package of improved varieties, agrochemicals and irrigation that has so impacted on the rest of the world has largely bypassed Africa. Even the two simplest ingredients of the package—improved varieties and fertiliser—have yet to have major impact. Irrigation is the hardest part of the package to implement successfully because of the high costs of developing irrigated land and the inability to generate sufficient profit to cover recurrent operation and maintenance expenses. Moreover the investment in irrigation can only be fully reaped once the other elements of the production package are in place. There is little point in adding water to low-fertility soils growing low-yielding varieties.

Irrigation also must support a governance component that is not required for rain-fed farming. Water must be allocated, infrastructure maintained, fees collected and conflicts resolved. Governments worldwide are handing over these responsibilities to farmer groups, and Africa is struggling through this transition

(Shah *et al.* 2002). Typically large numbers of smallholdings make up a scheme, so the transaction costs are large and these cannot be supported by the generally low productivity so common in sub-Saharan Africa. The food crises of the mid 1970s sparked the development of new irrigation schemes around the world, but the rate of new development has steadily declined. Lending to sub-Saharan Africa for irrigation projects from the World Bank dropped significantly due to perceptions of disappointing performance, and the vicious cycle of low cost recovery leading to lack of maintenance resulting in poor water productivity (World Bank n.d.).

The most recent food crisis has revived interest in irrigation in sub-Saharan Africa, especially in the light of Food and Agriculture Organization (FAO) estimates that sub-Saharan Africa has attained just 20 percent of its irrigation potential. It would seem that there is a critical role for irrigation to play in the ongoing food security crisis, yet the costs of irrigation development in sub-Saharan Africa are often reported as higher than anywhere else in the world and the performance of the irrigation schemes worse (Jones 1995). So, can increased investment in irrigated agriculture really form a part of the food security plan for sub-Saharan Africa? What would this investment look like and what should the accompanying research agenda be to get the best food security and environmental outcomes from investment in irrigation?

Increasing supply: Exploiting more surface water

The governments of sub-Saharan Africa face a distressing set of problems. The number of food-insecure people nearly doubled in the 30 years after 1980, to 240 million (IFAD 2010). Many countries fall well short of national food sufficiency, and calorific intake across the region is 20 percent below the world average. The Global Hunger Index (GHI), which combines under-nutrition, low child weight and child mortality rates, reports numerous sub-Saharan African countries in the serious and alarming categories (IFPRI 2011). These statistics not only translate into physical suffering, but also predispose the next generation to learning difficulties and disease.

The yields of rain-fed staple crops are low in sub-Saharan African countries and the national annual production fluctuates widely, reflecting the difficult and highly variable growing environment. The potential role of irrigation to increase and stabilise food supply seems obvious and the comparison with Asia inescapable. For example, South Asia irrigates almost 40 percent of its cultivated land, whereas sub-Saharan Africa irrigates just four percent (Svendsen *et al.* 2009; You *et al.* 2010). This proportion increases to five percent when adding informal irrigation such as flood recession cropping, cultivated wetlands and spate irrigation (diversion of floodwaters over extensive areas of floodplain).

The modest development of irrigation in sub-Saharan Africa does not appear to be rooted in scarcity of resources. The size of the renewable water resource on a per capita basis is slightly above the world average, but the exploitation of this water is much lower. In fact, the average global consumption of water is four to five times greater than consumption by sub-Saharan Africans. The New Partnership for African Development (NEPAD) argues irrigation area needs to expand by six percent per year with an annual injection of $42 billion (quoted in Lankford 2005). This is six times the current rate of increase and governments of Africa and the donor community are now looking at serious new investments in irrigation infrastructure (Svendsen *et al.* 2009).

The political will to invest must be matched by a robust understanding of the size of the resource to be developed. The FAO AQUASTAT database estimates the total annual renewable water resource (TARWR) for each county, which is the sum of both surface water and groundwater resources. Surface water is made up of inflows to rivers and lakes and includes river flow entering from countries upstream less their obligation to supply a certain minimum flow to downstream countries. Renewable groundwater is estimated as the annual recharge to aquifers. When viewed as a whole, sub-Saharan Africa utilises just 1.5 percent of its total renewable resource, of which almost 90 percent goes to the agricultural sector. This is in stark contrast with northern Africa, which currently consumes more than 250 percent of its TARWR through overexploitation of groundwater reserves.

The TARWR can be a misleading figure. Places where water is abundant require little irrigation, whereas water resources in dry areas are often overexploited. A country such as South Africa consumes 25 percent of its TARWR and is considered severely water stressed. In fact, 25 percent would seem to be an upper limit of consumption, and even this requires major engineering works and inter-basin transfers. Averages are also highly misleading in hydrology, because in flood years the water cannot be used. Conversely, droughts can stretch over many years and overexploited basins will fail to provide the minimum flows needed to sustain ecological functions. Total dam capacity in sub-Saharan Africa is about 80 percent of the world average, equating to about 15 percent of the average annual river discharge (Svendsen *et al.* 2009); however, much of this water is contained in a small number of large dams, which are primarily used for hydro-power generation, not irrigation.

You *et al.* (2010) conducted an extensive modelling exercise to evaluate the NEPAD vision of increasing the irrigated area from 12 to 20 million ha across sub-Saharan Africa. They compiled a ten km grid GIS (geographic information system) map to show the productivity of different crops and combined this with a hydrological model and an economic model. The hydrological model calculated run-off as the maximum potential supply of water. They separately calculated the potential new irrigable areas from dam-based systems and for small-scale systems. For dam-based systems, the irrigable land was limited by the topography and delivery costs around the dam site itself. For small-scale systems, the limit was the amount of available run-off water, and the constraint that irrigated areas had to be within five hours' travel time of a local market.

Assuming a development cost of $3,000/ha for dam-based systems and $2,000/ha for small-scale systems, they calculate that an extra 22 million ha could be irrigated, giving an internal rate of return on investment of at least six percent.

The calculations incorporate a number of conservative assumptions, such as an overall irrigation efficiency of 0.4, attainable yields of 30–80 percent of the potential and that 30 percent of dam capacity was available for irrigation. These investment prices are low compared with other studies and probably only attainable if the cost of the dam was paid for by another sector, such as hydro-power generation. When You *et al.* (2010) doubled the per hectare investment cost, the area that could be profitably irrigated dropped by nearly 50 percent. Nevertheless this area of irrigable land is above the ambitious NEPAD target, so at first cut the land and water resources do not seem to be the limiting factors.

Paying for irrigation infrastructure

Despite the renewed interest of large donors to invest in irrigation infrastructure, development costs in Africa have historically been higher than elsewhere. Jones (1995) reported that the average cost of irrigation development in sub-Saharan Africa was $18,000/ha compared with $4,800/ha in the rest of the world (1991 prices). This alarming statistic stimulated a major review by the International Water Management Institute (IWMI), first to confirm these figures and second to try to explain them (Inocencio *et al.* 2007). They analysed 314 irrigation projects from Africa and around the world to try to tease out the factors that contribute to the cost and performance of irrigation schemes. Inocencio *et al.* (2007) then compare the case studies in sub-Saharan Africa with the case studies from other developing countries, which were drawn from the Middle East, Asia and Latin America.

The study showed that the average cost of new irrigation projects in sub-Saharan Africa was $14,500/ha compared with $6,500/ha in the other developing regions – more or less confirming the common perception. Not only were the development costs higher, but also the probability of a successful project in sub-Saharan Africa was 56 percent compared with an average of 72 percent in the other regions. The condition for 'success' was set at projects that produced an economic internal rate of return (EIRR) greater than ten percent, which is widely accepted by donors as the threshold for public investment.

High costs combined with high failure rates seem to spell doom for irrigation investment in sub-Saharan Africa; however, if the irrigation projects were divided into those considered a success and those considered a failure, it may be possible to diagnose and overcome the problems. The calculation of EIRR takes into account the total cost of the development, operation and maintenance costs and returns due to water provision over the lifetime of a project (assumed to be 30 years) and the gestation period of the investment.

When projects considered a failure on EIRR grounds were eliminated from the case studies in sub-Saharan Africa, the investment costs per hectare were markedly lower. The cost of successful new construction projects dropped from $14,500/ha to $5,700/ha in sub-Saharan Africa and in the rest of the regions from $6,500 to $4,600. This suggests that irrigation projects in sub-Saharan Africa are not intrinsically more expensive than everywhere else. It appears that the costs are skewed by a group of expensive projects at a development cost of more than $20,000/ha that failed to reach the threshold EIRR. Projects in sub-Saharan Africa were also smaller in size, developed in much drier regions requiring more water per hectare (700 mm versus 1200 mm in the other regions) and in very poor countries with higher costs for doing business. All these factors appear to contribute to higher costs (Inocencio *et al.* 2007).

The cost of all new project studies declined in sub-Saharan Africa from $18,000 in the 1970s to $9,000 in the 1990s (in other regions the change is from just $7,000 to $6,000/ha). At the same time, the EIRR increased in sub-Saharan Africa on new construction projects from six percent in the 1970s to 25 percent in the 1990s, and the success rate in sub-Saharan Africa increased from 42 percent to 86 percent over the same period. What factors have contributed to this success?

First, successful projects had greater effort put into appraisal, implementation and supervision by donors, and this has eliminated some of the more spectacular failures of the early years. Second, the tasks of operation and maintenance shifted from solely the responsibility of government to more fully involving the farmers. Third, successful projects had a greater share of the total costs allocated to the 'software' components. The 'hardware' of irrigation projects represents the engineering infrastructure, whereas the software includes better technical assistance, design and management in the construction phase as well as better agricultural support, institution building, and training agency staff and farmers after construction (Inocencio *et al.* 2007).

Although the greater spending on the software component could almost double the costs of the entire project, the investment was more than rewarded by the improved performance and hence the higher EIRR. Increased farmer contribution to projects was also correlated with success, not because it reduced the costs significantly, but because it improved subsequent project performance. Other factors correlated with success were projects that used both surface water and groundwater, a shift towards horticultural crops and a shift towards development in wetter sites (Inocencio *et al.* 2007).

Managing demand: Using currently available water more efficiently

The supply side of the irrigation equation—that is, providing more water infrastructure—is the easiest option for increasing food supply from irrigation. Politicians favour it because it makes for highly visible new development activities and donors favour it because it is amenable to the usual planning, monitoring and evaluation protocols. Addressing the demand side for water is more difficult. Here the aim is to derive more economic benefit from the same amount of water or the same benefit from a reduced supply by addressing inefficiencies in the existing system.

Consider a typical situation where water is delivered to the farm through open, unlined channels. On reaching the farm, the water may be stored in a small dam before being moved to individual fields in earthen canals. Then water is applied to the crop by flooding the field. Water is lost at each of these three steps through leakage, evaporation and drainage. For example, it would not be unusual to lose 20 percent of the water in conveyance to the farm and a further 30 percent when storing and moving water around the farm. Since it is difficult to uniformly replenish the rooting zone by flood irrigation, a further 40 percent can be lost through drainage below the root zone and water running off the end of the field. The biggest loss is often through direct soil evaporation, where half the water applied to the field can be lost before it is transpired.

Since each of these losses is in series, the overall efficiency is the product of each of the individual steps in getting water from a dam to a transpiring leaf (Hsiao *et al.* 2007). In the above example, just 17 L would be transpired of the 100 L that were released by the dam; however, not all losses are the same. Perry *et al.* (2009) divide up the gross withdrawal from the dam into beneficial consumption by the crop via transpiration and non-beneficial consumption via weeds and soil evaporation. The proportion of water withdrawn from the dam that is not consumed is divided into water that makes its way back to the river or groundwater and thus can be recovered, and water that is not recoverable because it ends up in salty or inaccessible aquifers.

Modernising the irrigation system by piping water, using a pressurised irrigation system, will dramatically cut non-beneficial consumption and non-recoverable return flows. Improving farming practices can have a similar impact. Planting the right varieties on time, scheduling irrigation, supplying nutrients and protecting crops' completion from weeds and attack from pests and disease can double or even quadruple yields. When putting the engineering and agronomic aspects together, remarkable improvements can be attained. Hsiao *et al.* (2007) calculate that if each of the steps in the chain from dam to final harvest fell into the 'poor' category, we might grow only 24 g of food from every 1,000 L of dam water; however, if each step was elevated into the good-practice category, each 1,000 L could produce 1,220 g of food.

The fiftyfold difference between good and bad practices makes one wonder why there would be such a focus on simply doubling the area of irrigated land – the so-called 'supply' solution. The reason is that addressing many of the inefficiencies is expensive and rarely cost effective when the price of water is low. Furthermore, improving yields through better on-farm water and agronomic management requires an enormous effort in training. The local knowledge and capacity to provide such training are in very short supply.

It seems that irrigation schemes inevitably go through a life cycle, starting with an exploitation phase and only moving into a conservation phase when water becomes a limiting resource. As the supply becomes scarcer still, a scheme moves into the reallocation phase, where water use shifts to more profitable users (FAO 2012). This could mean changing from irrigating staple crops to irrigating horticultural crops or competition from other sectors for water, such as mining, industry or domestic users. Most sub-Saharan countries are still in the exploitation phase.

Big is beautiful?

One of the main findings of Inocencio *et al.* (2007) was that the success of an irrigation project was strongly dependent on the total cost, which, from the case studies, was strongly correlated with project size. Large projects almost by definition are cheaper on a per hectare basis simply because the infrastructure costs can be divided over a much larger area. Projects in sub-Saharan Africa were on average only one-sixth of the size of those in the other regions, and this flowed through to higher cost and ultimately lower internal rates of return, leading to the suggestion that 'big is beautiful'.

Although there are efficiencies in scale when conducting engineering works, the situation plays out quite differently from a hydrological perspective over the longer term. For example, the Chokwe irrigation area on the Limpopo River in southern Mozambique is one of the largest schemes in southern Africa. It covers an area of 34,000 ha, but 11,000 ha have been abandoned because of waterlogging and salinity. Of the remaining 23,000 ha, only 7,000 ha are actually being used because infrastructure has fallen into disrepair, and was further damaged by the floods in February 2000 and January 2012. Estimates are that Chokwe needs $45 million just to upgrade the existing infrastructure (Chilundo *et al.* 2004).

The Islamic Development Bank is funding the repair work on 7000 ha and the Chinese Government has plans to repair a further 10 000 ha, but no scheme can rely on outsiders to keep bailing it out. It is expected that once 20 000 ha are under cultivation, and farmers pay $108/ha for the water, the scheme could pay its way; however, the farmers will need to lift their current rice yields from 4 to 6 tot/ha to be able to afford such charges (http://allafrica.com/stories/201205290141.html).

But what of the remaining 14,000 ha—mostly affected by salinity and waterlogging? It is one thing to rebuild canals and dig out the surface drains, but dealing with high water tables presents a problem of a different order. The heavy, salt-laden soils along the southern area of the scheme have low hydraulic conductivity and are very difficult to drain. Growing one crop of rice per year using 10 ML/ha across 20,000 ha of Chokwe using Limpopo water at 300 mg/L salt means that 60,000 tonnes of salt are added to the land each year. If all this salt can be flushed back to the river, the system or parts thereof will continue to fail.

This story has been repeated all over the world. For example, the cheapest way to expand irrigated land in the lower Murray of South Australia was to develop along the river. In the Loxton area, irrigation was developed over a naturally saline water table approaching the level of seawater. Within two decades the extra hydraulic loading from irrigation started to push this salty water into the river, increasing the daily discharge from 10 to 100 t of salt per day. Since 1980 the Murray–Darling Basin Commission (MDBC) has spent more than $200 million on salt-interception schemes to counter this (Newman *et al.* 2012). The lesson is clear: over the period that internal economic rates of return are calculated, big schemes make a lot of sense because they are cheaper to construct. Yet schemes that drown in their own salt either because of bad locations or simply because of their own size have far greater costs down the line.

Whereas Chokwe is by far the largest scheme in Mozambique, the country has developed 159 schemes coving 118 000 ha. Although there is significant potential to increase this area, 66 percent of the land with existing irrigation infrastructure lies unused. About five percent of the area comprises relatively small schemes of less than 50 ha and here the unused portion is just less than 50 percent (Chilundo *et al.* 2004). The trend seems to be: the larger the system, the greater are the problems. In contrast, the small wetland and 'dambo' hydrological settings common in Mozambique are intensively used by smallholder farmers, particularly when located near markets. Although tiny in scale and with huge variations in water availability during the year, these systems are well exploited by farmers.

New opportunities for irrigation development

At this point there is conflict between the high-level assessments that favour big schemes on rivers and empirical evidence that smaller schemes can function better. Attention has recently shifted towards the more widespread groundwater resource. There are several advantages here for small-scale irrigators. Farmers who traditionally grow rain-fed crops can produce under irrigation in the dry season, creating new income opportunities. They could also provide supplementary irrigation to rain-fed crops when rains fail during part of the cropping season. The great benefit of groundwater is that it responds much more slowly than surface waters to drought and is therefore a buffer against climate variability. Groundwater also covers large spatial areas, and, if exploitable, provides opportunities for farmers to diversify their livelihood strategies without the social dislocation and landownership problems that plague new surface-water schemes.

Understanding the size of the groundwater resource and the rate at which groundwater is replenished is the first step in developing a strategy for sustainable utilisation. Surprisingly the first quantitative continent-wide assessment of groundwater resources in Africa was published only recently (MacDonald *et al.* 2012). The average rainfall across the African continent is 660 mm, of which about 130 mm is considered to reach rivers, lakes and groundwater, and thus represents a renewable resource. The groundwater resource is estimated to have an equivalent water depth of 22 m, or 170 times greater than the renewable resource. This groundwater is unequally distributed, with the huge sedimentary aquifers across North Africa holding the equivalent of 75 m depth of water, whereas storage in the widespread Precambrian basement rock aquifers may be less than 0.5 m.

The aquifers across North Africa are recharged at below 5 mm per year and, though a huge resource, are exploited for irrigation much faster than they are replenished; however, many of the aquifers in the rain-fed cropping zone are replenished at 25–100mm per year and are shallow enough to be exploited by relatively small pumps (MacDonald *et al.* 2012). Away from urban areas, groundwater is usually free of human pathogens because of the natural filtering provided by the soil above; however, quality can be an issue—both excessive salt levels and toxic ions such as fluoride and arsenic. Poor-quality water does not appear to be a major issue across the region, although much testing remains to be done.

Assuming groundwater is of suitable quality and close enough to the surface for economical drilling and pumping then the productivity of the aquifer determines the suitability of the resource for irrigation. Large centre-pivot type irrigation systems may need bores that yield around 50 L per second, and such aquifers are rare in Africa. Bores for household water supplies need only have yields of around 0.3 L/s and such aquifers are widespread across sub-Saharan Africa. Ideally irrigation would need a supply of around 5 L/s, but this is not common; however, large areas fall into a zone where bore yields are between 0.5 and 5 L/s, where correctly sited bores could supply sufficient water for community gardens and supplemental irrigation (MacDonald *et al.* 2012).

Low to moderate-productivity bores will prevent the concentration of irrigation in certain areas and thus help mitigate the ever present threats of salinity and waterlogging. Small pumps servicing irrigation areas widely spread across the landscape mean that expensive and often wasteful reticulation systems are no longer required, and farmers have unprecedented control over their water resource. If they own their own pump, they effectively have water on demand, unlike the schemes where water is available on a rotational basis (often once per week), which can lead to conflicts between users in different parts of the scheme. Although the additional pumping costs cut into profit, it can also guard against excessive water consumption. The groundwater resource is, of course, very vulnerable to the tragedy of the commons, as the users are not necessarily formally linked in such a way as to avoid overexploitation.

Large irrigation schemes based on rivers and dams and widely distributed small areas fed from groundwater are two ends of the spectrum. In between lies various forms of water harvesting and capture ranging from in-field run-off–run-on systems to storage tanks and lined dams. Here there is a trade-off between the upfront investment cost and the reliability of supply. In-field rainwater harvesting is not expensive, but nor is there a guaranteed supply of water. Excavated dams measuring 100 m x 70 m x 7 m holding 50,000 cu m cost around $1 million to construct. The cost of storage is therefore $20/cu m and, assuming the dam is completely filled twice during the year, 20 ha of land could be supplied with 500mm of irrigation water. This equates to a development cost of $50,000 per hectare—10 times higher than the cost of developing larger schemes from rivers. Plastic or ferroconcrete tanks have even higher storage costs, with a capital outlay of $50/cu m or more (Makurira 2012).

Small-scale storage systems make sense in the context of multiple-use systems where water is provided for domestic and productive purposes. The basic domestic supply of 20 L per person per day is sufficient for drinking and personal hygiene and has a huge impact on disease reduction and releasing women from the time-consuming chore of fetching water. If this is increased to 50 L per person per day then there is sufficient water for laundry, livestock and some fruit trees around the home. Increasing the water supply to 100 or even 200 L per day can supply a vegetable garden or even a small irrigation enterprise. The progression is called climbing the multiple water use ladder (van Koppen *et al.* 2009).

There is a huge cost in providing reticulated water to meet the basic domestic demand at the base of the ladder. The marginal cost of supplying more water to households—especially if directed towards growing fruit and vegetables, which provide the nutritional supplements so often lacking in a cereal-based diet—may well be worthwhile. Backeberg and Sanewe (2010) report on the huge potential of homestead farming for food security in rural South Africa where 65 percent of the land available for small-scale farming is made of plots smaller than 0.5 ha around existing dwellings. Providing treated water for agricultural purposes is an unnecessary expense, but there may soon be economical options for treatment at the home itself. Given that water and sewage-treatment plants in Africa often do not work reliably, it may be possible to do the tertiary treatment using a filter or membrane on one tap in the home. Then the reticulation system provides a much larger quantity of primary treated water, and the drinking water undergoes final treatment at a single tap in the home.

A new water research agenda for sub-Saharan Africa

There is political will to develop irrigation in sub-Saharan Africa through the NEPAD strategy and there appear to be sufficient water and land available. Moreover, sub-Saharan Africa has shown great improvements in irrigation performance in recent decades due to the combination of better planning and better management, such that the performance of larger schemes is catching up with the rest of the world. The current value of irrigated agriculture in sub-Saharan Africa is about 25 percent of the total agricultural output. This contribution comes from just 3.5 percent of the cultivated land area (or 4.5 percent if we add the informal sector), meaning that there is a five–sevenfold increase in value of irrigated agriculture over dryland agriculture because of higher yields and more profitable crops (Svendsen *et al.* 2009). This calculation is in stark contrast with the rest of the world where the comparable ratio is around two.

There are also new opportunities fast approaching. The trend in Asia towards small-scale private irrigation is now starting in sub-Saharan Africa where farmers are using their own initiative and financial resources. The movement started with the use of treadle pumps, which can irrigate around 0.2 ha for a cost of $50–100; however, as occurred in Asia, in Africa motorised pumps costing less than $250 that can irrigate one to two ha are proving the most profitable option (Giordano *et al.* 2012). Whereas groundwater supplies 60–80 percent of irrigation water in India and Bangladesh, it probably accounts for less than ten percent in sub-Saharan Africa. Giordano *et al.* (2012) estimate annual net revenues of $20 billion flowing from the development of small reservoirs and a further $22 billion from expanding the use of small motorised pumps, benefiting hundreds of millions of small-scale farmers through secure access to water.

If the above opportunities can be realised, they will have a major impact on food security in sub-Saharan Africa; but there are formidable obstacles. First, crop yields still fall well below potential. Smallholder irrigated agriculture cannot be a subsistence activity, because profits are needed for operation and maintenance costs. Low productivity feeds into the second problem, which is the abandonment of irrigated lands when infrastructure fails. Van Averbeke *et al.* (2011) show a stark example of this among smallholder schemes in South Africa. Of the 67 gravity-fed flood systems, 20 percent had fallen into disuse and 56 percent of pressurised systems were no longer operational. Even in a country with relatively good extension support, it seems that only the simplest of systems can be maintained.

Third, salinity and waterlogging remain ever present threats. Somewhere between 20 and 30 percent of the world's irrigated land is currently seriously affected by salinity and/or waterlogging, and between 1.5 and 2.5 million ha are abandoned by irrigators each year (Khan *et al.* 2008; Kijne 2006). The example of Chokwe in Mozambique is a stark reminder that sub-Saharan Africa will not be immune from the hydrological problems facing irrigation across the rest of the world. Fourth, despite the apparent abundance of water resources, the transition to water scarcity occurs quickly as irrigation develops, and it is already acute in some areas. The institutional and governance arrangements that can frame the development needs of the country within the constraints of the resource are weakly developed, as are the water user associations that oversee the operation and maintenance costs of the irrigation systems themselves.

The grand challenge for irrigation is to improve productivity and profitability whilst operating within the sustainable limits of the catchment to supply water and dispose of salt. Historically irrigation has been dominated by an engineering paradigm of pipes and canals and 'look-up' tables that profess to advise farmers how much water to use. In practice, very few components of the water cycle are measured and few schemes would have much idea about how much food is produced for a given quantity of water, what the potential might be and what steps would be needed to get there. Moreover, there remain huge barriers between the world views and expertise of the multiple stakeholders, from small-scale farmers to agricultural advisors, hydrologists, donor agencies and the host of institutional structures trying to manage water and food security from local to national and even international scales.

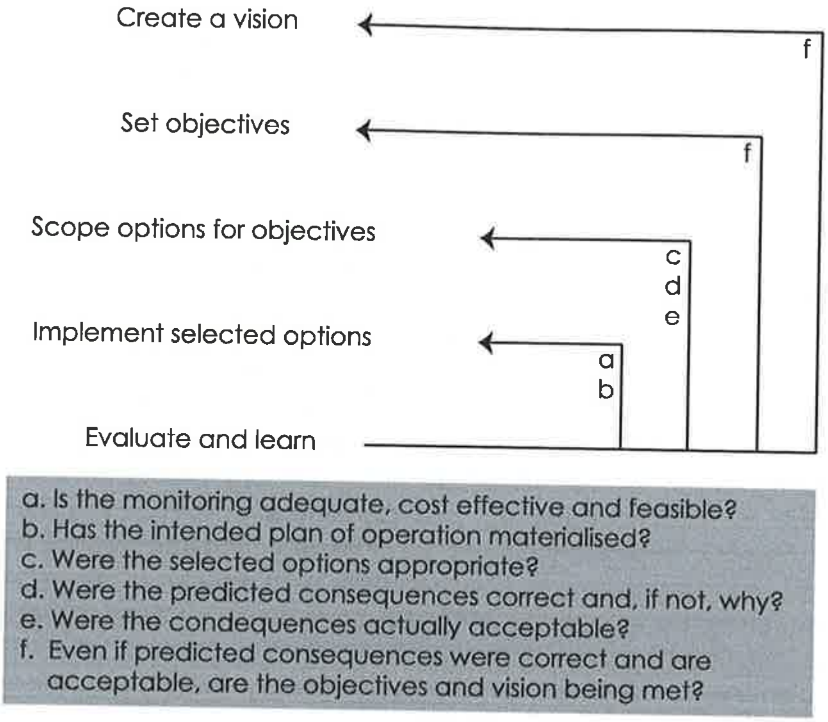
The dilemma described above lands the irrigation problem in the centre of social–ecological complexity. The social complexity arises from multiple stakeholders who hold different world views, may have different value systems and whose interests cover very different time or spatial scales. The ecological complexity arises from the uncertainties of climate and water availability and the fate of excess water and solutes in the landscape. Under these circumstances there is no optimal solution, but instead a need for ongoing learning and adaptation (Pahl-Wostl & Hare 2004). This realisation led to the development of the field of adaptive management, which is built on the premise that we have to use real-life management of the system as a whole and turn it into an experiment by asking the right questions, implementing decisions, collecting the right data and learning from the experience (Holling 1978; Lee 1993). Meffe *et al.* (2002) define adaptive management as 'the process of treating natural resource management as an experiment such that the practicality of trial and error is added to the rigour and explicitness of the scientific experiment, producing learning that is both relevant and valid'.

South African scientists have developed a form of strategic adaptive management for protecting both rivers and natural resources (Biggs & Rogers 2003). The reference to 'strategic' means it is forward looking in that it asks the stakeholders to settle on some longer-term vision that captures the values of the majority and encapsulates some common purpose. This is a vital first step, because finding a common purpose is about seeking consensus rather than focusing on the inevitable differences of opinion among the various water stakeholders. The consensus seeking approach is about moving beyond the problem and 'developing a set of shared values that guide future decision making' (Rogers 2006). It differs from the more familiar compromise situation, when we are forced to trade off conflicting demands on the system against those who hold a contrary position, thus creating winners and losers.

Once the vision is agreed, the planning phase sets the objectives needed to attain the vision and finally a scoping of the options available to meet those objectives. Within this planning process, it is important to set measurable targets so everyone can keep track of how things are progressing. These targets may revolve around, *inter alia*, river flow, groundwater depth and quality, water use efficiency and crop productivity. During the implementation phase, the preferred options selected during the planning phase are enacted and the monitoring data collected. The most important part of this process shown in Figure 5.1 is the feedback loops, because this is where we can learn in a structured way. By monitoring the consequences of our actions we answer the following questions: a) Did the intended plan materialize? b) Was the monitoring feasible and cost effective? (c) Were the selected options appropriate? (d) Were the predicted consequences correct? (e) Were the consequences acceptable? (f) Are the objectives and vision being met? (Roux & Foxcroft 2011).

According to Stankey *et al.* (2005), the principles of adaptive management are widely acclaimed but are difficult to achieve in practice. One of the reasons is that monitoring is expensive. A bigger problem is that scientists often want to measure too many things, so the learning process becomes overloaded with information. The key is to identify and monitor 'slow' or underlying variables that integrate system behaviour. All stakeholders should share a common conceptualisation of the problem and have some expectation of how their management options will affect the processes they are measuring, allowing the group to learn in a structured way (Stirzaker *et al.* 2010).

Figure 5.1 The strategic adaptive management learning cycle



Source: Adapted from Roux, DJ & Foxcroft, LC 2011, 'The development and application of strategic adaptive management within South African national parks', Koedoe, 53(2), Art. No. 1049, doi:10.4102/koedoe.v53i2.1049.

Many elements are now in place to make adaptive management a methodology of choice for improving water productivity in sub-Saharan Africa. First, the concept of social–ecological complexity is widely recognised and many people are willing to work across traditional disciplinary boundaries. Second, processes that link institutional and technical innovations are needed to succeed in areas where the straight technical or silver-bullet solutions have failed. Third, monitoring equipment is becoming simpler and more cost effective and, when combined with smart phones, will revolutionise data collection, display and sharing. The most recent FAO report concerning 'coping with water scarcity' urges us to move in this direction:

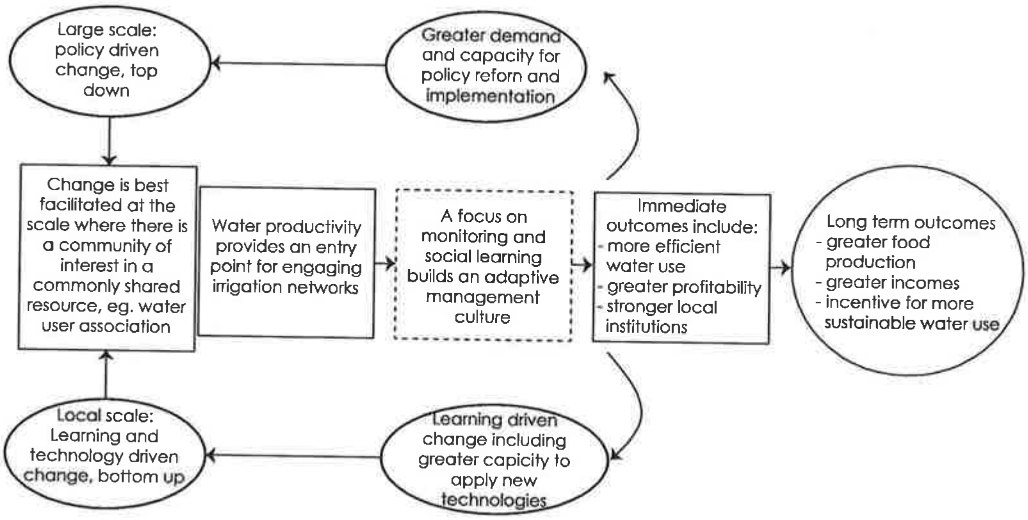
> *Planning and management systems need to be flexible, adaptive and based on continuous social and institutional learning. Adaptive management recognizes the high level of uncertainty associated with future situations, and places emphasis on flexible planning that allows regular upgrading of plans and activities. Such a level of responsiveness is only possible if information and knowledge are updated, and if monitoring and information management systems continually provide decision-makers with reliable information (FAO 2012).*

African governments are embarking on a massive expansion in irrigation without fully addressing the reasons why many previous schemes have been unsuccessful.

It is essential that the mistakes of the last irrigation expansion of the 1960s to 1980s are not repeated, where low profitability did not allow the ongoing investment into infrastructure and the associated institutions that govern equitable and sustainable use. Both a bottom-up technology push and a top-down organizational reform are necessary for lifting irrigation production.

Figure 5.2 gives a framework for how we might implement a new research agenda. We propose the scale of intervention as a water user association. This scale captures the interests of the community in terms of the shared resource and infrastructure, and also represents the financial interests of farmers who are making a living from irrigation. Enhancing these local institutions reinforces social capital and can be a force for equity. We propose that the adaptive management approach is the methodology of choice when trying to bridge institutional and technical innovation (see Figure 5.2, dashed shape). The issues raised by the water user association frame the problem in terms of their long-term goals (see Figure 5.2, far right circle), the policy and institutional environment (top down) and the current technology and aspirations of the farmers (bottom up). Problem framing helps the scientists to determine which aspects of the system need to be monitored in order to structure learning across the network. The information from the monitoring and subsequent learning fosters the intermediate outcome of building capacity in the local institutions and the skill of the farmers.

Figure 5.2 A framework for linking institutional and technological knowledge to improve water productivity



There are two key feedback loops which sustain learning. The first loop is directed upwards as the water user association better understands their requirements and obligations and articulates for better investment of funds or reform of policy. The second loop is directed downwards as farmers see how their practices impact individually on productivity and collectively on sustainability. This creates the awareness and appetite to employ better skills and technology. The process works towards the longer term outcome which includes more productive resources use, profitable and sustainable irrigation schemes and greater food security.

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