Agricultural Water Management Technologies for Small Scale Farmers in Southern Africa: An Inventory and Assessment of Experiences, Good Practices and Costs

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International Water Management Institute (IWMI)
Southern Africa Sub-Regional Office
141 Cresswell Street, 0184 Weavind Park
South Africa

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Acronyms and Abbreviations

ACT	African Conservation Tillage Network
ADB	Asian Development Bank
AfDB	African Development Bank
AIDS	Acquired Immune Deficiency Syndrome
AWM	Agricultural Water Management
CSE	Centre for Science and Development (India)
DfID	Department for International Development (UK)
DWAF	Department of Water Affairs and Forestry (South Africa)
EU	European Union
FANRPAN	Food, Agriculture and Natural Resources Policy Analysis Network
FAO	United Nations Food and Agriculture Organization
GART	Golden Valley Agricultural Trust (Zambia)
HDI	Human Development Index
HIV	Human Immunity Virus
HP	Horse power
ICRISAT	International Center for Research in the Semi-Arid Tropics
IDE	International Development Enterprises
IPTRID	International Programme for Technology Research in Irrigation and Drainage
IRHA	International Rainwater Harvesting Alliance
IWMI	International Water Management Institute
IWSD	Institute of Water and Sanitation Development
MDG	Millennium Development Goals
NEPAD	New Partnership for Africa's Development
NFI	Net Farm Income
NGO	Non-Governmental Organization
RWH	Rainwater Harvesting
RELMA	Regional Land Management Unit
SADC	Southern African Development Community
SARIA	Southern African Regional Irrigation Association
SAKSS-SA	Strategic Agricultural Knowledge Support System-Southern Africa
SEARNET	Southern and Eastern Africa Rainwater Network
SIWMI	Stockholm International Water Management Institute
SIWUP	Smallholder Irrigation and Water Use Program
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
SWMRG	Soil and Water Management Group, Sokoine University of Agriculture (Tanzania)
UK	United Kingdom
USAID	United States Agency for International Development

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Of course with this assistance, the authors (Douglas Merrey, Regassa Namara, Marna de Lange) remain responsible for any errors or misinterpretations in this report.

Douglas J. Merrey
Principal Scientist for Policies and Institutions
International Water Management Institute
Pretoria, South Africa
April, 2006

Executive Summary

This study was carried out using funds received from the Investment Centre of the Food and Agriculture Organization of the United Nations and the Southern Africa Regional Office of the Office of Foreign Disaster Assistance, United States Agency for International Development. In the former case it is intended to support the preparation of the Southern Africa Development Community (SADC) Agricultural Water Management for Food Security Project to be supported by the African Development Bank; and in the latter case it is intended to provide guidance for improving the effectiveness of current programs on micro-agricultural water management (micro-AWM) technologies implemented largely through NGOs.

The methodology involved several activities: we designed a terms of reference and inventory format for obtaining country-level data through partners in Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe. The partners interviewed key informants, reviewed local literature, and drew on their own experiences. We commissioned an in-depth impact assessment of treadle pumps in Malawi. We commissioned a study to carry out a more global literature review through the internet; and we carried out literature reviews and some field visits. Therefore, except for the Malawi treadle pump study, this is an extensive review, not an in-depth field work based assessment. Our basic findings are as follows.

1. Low average rainfall that is seasonal, highly variable in time and space, and increasingly unreliable is the major impediment to farm households increasing their production of food, cash crops, and livestock products in Southern Africa. The impacts of this unreliable and inadequate water supply are compounded by many other problems, both natural (for example poor soil fertility) and human-created (for example lack of support services and infrastructure and deteriorating health). Improving the reliability of water supply for agriculture is therefore a necessary though not sufficient condition for reducing poverty and malnutrition and generating faster agricultural growth.

2. There is reasonable though not conclusive evidence that some of the micro-AWM technologies reviewed in this study, under the right conditions, do lead to substantial improvements in households' food security and incomes, and that they do so in a cost-effective manner. This is especially true for treadle pumps, but there is enough case study and anecdotal evidence to suggest that the statement also applies to low-cost drip kits, clay pot irrigation, conservation farming practices that integrate nutrient and water management, and a variety of *in-situ* and *ex-situ* water harvesting and storage technologies.

3. There are many actors and many projects involved in studying and (especially) promoting a large number of different micro-AWM technologies and practices in Southern Africa. However, there has been little or no systematic analysis of their effectiveness, impacts and sustainability, or attempts to understand what strategies work and why, and what does not work and why. Undoubtedly the same mistakes

are being repeated needlessly throughout the region. While a multiplicity of effective local and international NGOs is to be encouraged, it would be useful to find out systematically what are the main strengths and weaknesses (comparative advantages) of each, and develop mechanisms for better coordination and sharing of experiences and lessons learned. For example, International Development Enterprises (IDE) and KickStart have specific models for trying to establish viable micro-AWM technology supply chains and in IDE's case, linkages of smallholder farmers to profitable output markets. Perhaps other NGOs who at the moment focus largely on provision of technologies could learn from their experiences and thereby improve their long term developmental impacts.

4. The tremendous diversity of conditions in the SADC region must be acknowledged. Even within districts, there is such diversity in soils, micro-climate, cultures, and access to markets that what works on one farm may not be appropriate next door. This means there is no possibility of generalizing, no cook book approaches or sure-fire universal panaceas that will work everywhere. Unfortunately, it appears that there are cases where micro-AWM technologies not really appropriate to local conditions and needs are promoted (and rejected). Further, there has been a failure to take an integrated approach, in several senses: recognition of the multiplicity of household water needs given the diversity of livelihoods (for example integration of livestock, crops, brick making, etc.); recognition of the potential synergies of integrating micro-AWM technologies, for example combining treadle pumps with efficient application technologies with soil conservation practices; integrating water and nutrient management; and pursuing implementation strategies that integrate attention to support services (inputs), attention to production processes, and to outcomes on the demand side in terms of both household food security and nutrition and access to well-functioning markets.

5. Following from the diversity of the region, it is no surprise that there are no cases of successful massive scaling up and out of specific micro-AWM technologies and practices. Adoption, adaptation, or rejection decisions are a function of many factors including lack of information or access, lack of fit between the technologies on offer and the capacities and needs of households, inefficient promotion strategies, flawed assumptions about households' needs and capacities and the real costs and benefits from their perspectives (for example the assumption of surplus labor availability), ineffective targeting, lack of capacity to manage projects offering a large array of small-scale technologies to thousands of poor households, and lack of credit.

6. An issue that already requires attention in some areas and will become increasingly critical is the potential mismatch between the supply of water resources and demand for water, especially on small watersheds and *dambos* during the dry season. With increasing intensity even of the use of small treadle pumps, communities may need assistance to develop appropriate mechanisms for regulating equitable access to diminishing water supplies.

7. Government policies are often either unfavorable or contradictory vis-à-vis micro-AWM technologies. On the one hand, there is a tendency of governments to favor large-scale infrastructure investments, especially when there are pressures to spend –and be seen to be spending—large budgets on time. In some cases policies are contradictory: for example, in Malawi while some institutions have promoted programs to encourage local manufacture of treadle pumps and provided subsidies or credit for small farmers to purchase them, more recently the government has initiated a program to hand out thousands of such pumps (mostly imported) free of cost. Such a policy may undermine efforts to develop an effective and sustainable market-based supply chain (including local manufacturing) for pumps and spare parts. This reduces the potential synergies from linkages between agricultural growth and the growth of agri-based industries. On the other hand, a case can be made for a *consistent* limited-period policy to kick start such industries by making large numbers of technology available at a subsided rate, then encourage local support services and manufacturing for replacement pumps.

8. The SADC region is highly inequitable in terms of distribution of income, with evidence that the poor are getting poorer (for example declining levels of calorie consumption). This state of affairs is compounded by the impact of the HIV/AIDS pandemic, high rates of malaria and other illnesses, all further compounded by malnutrition, especially among small children. In many rural areas of the region, there is currently a vicious cycle underway which is undermining resilience, creativity, and labor availability, leading to long term deleterious impacts on the potential to achieve the Millennium Development Goals (MDGs) in the region. Indeed, most observers now agree SADC cannot meet the MDGs. There is a quiet crisis underway whose long term consequences will be immense unless concerted efforts are made to reverse these trends.

Our major recommendations are as follows:

Recommended micro-AWM technologies and practices

1. In many regions in southern Africa where there is a water source no more than 6 meters below the surface or 200 m away from where the water is needed, treadle pumps offer a potentially high-return and high-impact intervention. The pumped water can be used for many domestic and productive purposes, not only irrigation. The evidence from Malawi, Tanzania and Zambia demonstrates the potentially very high impact on food security and incomes. We therefore recommend this technology for widespread promotion.

2. The evidence we have shows that many individual farmers have benefited from low-cost drip irrigation kits, even though they have not been implemented on a large scale as yet in Southern Africa. Nevertheless, under the conditions discussed in the relevant section of this report, they hold a great deal of promise, and we therefore recommend their promotion under the specified conditions.

3. Like low-cost drip irrigation kits, although so far clay pot irrigation has not been implemented on any scale, we believe this is also a low-cost technology that can result in a very high level of water and labor productivity under the same conditions as for drip kits. We therefore recommend further adaptive research and if the results are favorable, wider promotion of clay pot irrigation.

4. The term "conservation agriculture" covers a large range of *in*-situ water and land management technologies and practices, some of which require large initial investments to implement. But some of the practices described under this heading are relatively low-cost, with high potential returns. The critical issue is that many interventions have failed to address the necessity of integrating water and nutrient management: adding water by itself can actually lead to more rapid depletion of nutrients, while soil nutrients cannot be efficiently used by plants without water. Because of the complexity and diversity of most African farming systems, there is no monolithic package of conservation agriculture technologies; rather, we recommend that farmers be supported and assisted to try new ideas and combinations of practices that work under their conditions.

5. As with *in-situ* water and land management practices, there is a wide range of low-cost and easy-to-construct *ex-situ* water harvesting and storage practices that under specific conditions are effective and can have large impacts on food security and livelihoods. As is the case for others, adaptation to local conditions with poor people empowered to make their own decisions rather than being passive recipients, is critical to success. We therefore recommend wider dissemination of these practices.

Strategic recommendations

1. Following from the observations above regarding the diversity of conditions and situations and the fact that no single micro-AWM technology or practice can be a panacea, we strongly recommend that supporting the creativity of the user is essential if people are going to improve their food security and escape from poverty. Therefore, participatory approaches that encourage and support creativity and innovation, for example by offering choices and menus that can be adapted and combined as needed, participatory approaches that empower users to make their own decisions, and provision of support services that reduce risk and make available resources that are not otherwise at hand.

2. Effective targeting of the poorest and most food-insecure is a huge challenge, but absolutely essential to achieve the MDGs. It is food-insecure households, not government, NGOs, donors, or wealthy people, who will achieve the MDGs (or not achieve them). Specifically, we recommend focusing on supporting those who are most hungry and risk-averse; living with HIV/AIDS; relying on rainfed agriculture with little prospect of getting access to irrigation plots in the near future; and need access to sufficient staple foods and sources of nutrition especially for young children and pregnant women. In many cases this will be households headed by women or at least in which women play the critical role in producing and providing food.

3. The previous recommendation creates a dilemma: there is currently much emphasis on improving access to markets, and focusing on production for markets as a way of generating profits and promoting agricultural growth. This is indeed important, but in the short to medium term at least, does little to help the poorest and hungriest people. We therefore recommend that far more resources be allocated to targeting and assisting the very poor. Helping them achieve basic food sufficiency (in terms of calories and nutritional balance) will make it possible for many of them to take the next steps into market-oriented commercial production; for others it will make it possible to use income generated from off-farm employment for essential needs like school expenses; and for all it will improve their health and labor productivity, enabling them to participate more effectively in productive and educational pursuits and lead better lives.

4. While supporting the need to invest in major water (and indeed other) infrastructure at a far greater scale than seen so far in Southern Africa, we strongly recommend scaling up investments in micro-AWM technologies and practices as well, because they offer a relatively faster and more cost-effective way to achieve the MDGs than, for example, major irrigation investments. Global experience demonstrates that it takes decades to achieve the full benefits of large irrigation investments; and that it is relative expensive on a per hectare as well as (and more importantly) a per-household basis. Many micro-AWM technologies are far less expensive per household than formal irrigation, their benefits begin immediately upon acquisition, and they are not plagued by all the management problems, transaction costs and negative externalities often characterizing formal irrigation. Of course, for poor people living in areas where there is no adequate source of water, or where there is a high risk of major drought, infrastructural development is necessary to bring water close to the people in need.

5. Micro-AWM technologies are "divisible"; i.e., can be used by individuals or small groups directly. They also lend themselves to provision by the private sector, unlike large water infrastructure projects with large public good and common property characteristics. But most SADC countries by themselves have too small a local market for a competitive micro-AWM industry to develop. Therefore, we recommend that governments examine how to make their policies more conducive to encouraging private sector firms to manufacture, supply, and even experiment and innovate micro-AWM technologies; and that at the SADC level, an effort be made to encourage a regional market in this sector. India provides a model in this regard—there is a healthy competitive and profitable industry catering to a large and diverse market, providing low-cost micro-AWM technologies, and innovating to improve quality and lower costs. This industry contributes to improving the productivity and profitability of agriculture and itself creates jobs and contributes to overall economic growth. Governments can also consider "kick starting" the micro-AWM industry by a limited-term consistent policy of providing large numbers of subsidized units to create a market for support services including repair, spare parts, and future replacement.

6. We recommend that governments re-examine their policies toward micro-AWM and clarify and streamline them to be directly supportive. In some countries there are too many government institutions involved, often with different and even contradictory policies. We therefore also recommend that countries explore mechanisms for coordination, and even consider identifying a "lead institution" at government level. The proposed SADC Agricultural Water Management for Food Security Program can provide an effective mechanism for helping governments clarify their policies, and assisting in the creation of a larger SADC market for micro-AWM technologies.

7. We recommend that NGOs and governments currently promoting micro-AWM technologies as part of their relief efforts move away from short term relief to long-term development. We have found cases where well-meaning provision of technologies like bucket and drip kits has had no impact, because of the lack of longer term service provision and training. This is not a good use of scarce resources. It is clear that the most successful programs are those that take a longer term integrated perspective toward creating the conditions conducive to sustainability.

8. Finally, we strongly recommend more investment in monitoring, impact assessment, assessing cost-effectiveness, pilot testing of innovations, and sharing the lessons learned widely among governments, investors, donors, private firms and farmers. Creating "learning alliances" among interested partners to collaborate in these endeavors is one effective way to achieve this. Given the potential for shared learning between Asia (especially India) and SSA, we also recommend supporting programs for sharing experiences, comparative studies, and capacity building. Another is to support programs where post graduate students are supported both financially and in terms of methodology to carry out in-depth independent studies whose results can be widely disseminated.

Agricultural Water Management Technologies for Small Scale Farmers in Southern Africa: An Inventory and Assessment of Experiences, Good Practices and Costs

Introduction

Overview: Agricultural Water Management Technologies

There is growing interest in the large range of low-cost agricultural water management technologies in semi-arid developing countries. This is in response to the observation that unreliable water supply is one of the biggest threats to the food security of poor small farmers. The vast majority of the rural poor rely on rainfed land for their survival, making them vulnerable to the highly variable and unpredictable rainfall. Some authorities suggest this variability may be increasing. Even in years having "normal" rainfall, a period of ten to fifteen days with no rain at a critical stage in crop growth can spell disaster for thousands, even millions, of poor farmers. Periodic drought and famine are the result, especially in many sub-Saharan African countries. The Southern African region is especially hard hit by what seem to be increasingly frequent and devastating droughts, floods and famines. In addition to the hunger and starvation that ensues, the results are drastically reduced economic growth rates, serious impacts on the nutritional status of children, compounding of the already serious impacts of malaria, HIV/AIDS and other diseases, and reduced resilience to face the next drought period.

Investment in irrigation is often identified as one of the possible responses to this problem, and has had considerable success in Asia in terms of achieving national as well as local food security, reducing poverty, and stimulating agricultural growth (IWMI/ADB 2005). In sub-Saharan Africa (SSA), irrigation investments never kept pace with those in Asia for many reasons, such that today, of all the major developing regions, SSA has the lowest percentage of cropped area irrigated (FAO 2002). Asia's main era of irrigation investment was during a period when world prices for cereal crops were at an historic high; today world cereal prices have returned to relatively low levels. Conventional irrigation is therefore no longer seen as economically viable unless its costs are kept low, yields are high, and farmers are able to grow at least some high value crops for an assured market. Although some recent reports have called for major irrigation investments in SSA (NEPAD 2003; Commission for Africa 2005), this is unlikely to offer solutions to the food insecurity and poverty of millions of small farmers in the continent, and especially in a water-constrained sub-region such as southern Africa. Large investments in irrigation investment are an important option under specific circumstances and can make a major contribution to long term economic growth; but even if SSA's irrigation potential were developed more fully it would not have the poverty-reducing impacts required in SSA over the next 1-2 decades[1]. Irrigation schemes are also expensive to operate and maintain, both in terms of cash and users' time for labor contributions and

[1] Further, Falkenmark and Rockström (2004:134-135) demonstrate that it is simply impossible to mobilize sufficient "blue," i.e, surface, water for irrigation to meet the food security needs of SSA over the next 20 years; nor is there sufficient financial and human capacity to do so (Seckler et al. 1998). A more recent study by de Fraiture (2005) demonstrates that except for wheat and rice, all other SSA staple food crop demand can be met by 2025 from improved rainfed agriculture.

meetings; therefore if irrigated agriculture is not sufficiently profitable, people will not invest what is required for success—and too many irrigation schemes are in fact performing poorly or are defunct for this reason (Shah et al. 2002).

What are the alternatives? The term "agricultural water management" (AWM) is a broad term covering an increasingly wide range of technologies and practices available for improving water and land management (Box 1). There is now a large set of small-scale low-cost AWM technologies and practices. These include low-cost water lifting technologies (for example treadle pumps), low-cost water application technologies (e.g., drip and sprinkler kits), technologies to capture and store rainwater either in small reservoirs or in the root zone (rainwater harvesting), and conservation tillage and other soil nutrient and water conservation technologies. The term "micro irrigation" is sometimes used to refer to these types of technologies, though the term also specifically refers to modern small-aperture micro sprayers and drippers (de Lange 2006a)[2]. We prefer to use the term "**micro-AWM**" in this report to avoid confusion.

Box 1. A Definition of "Agricultural Water Management"

"Agricultural water management" (AWM) is now a commonly accepted term to cover the range of technologies and practices whose objective is to ensure that adequate water is available in the root zone of crops when needed. It therefore includes capture and storage (in dams, in groundwater) as well as drainage of any water used for agriculture (crops, livestock, fish); lifting and transporting water from where it is captured to where it is used for agricultural production or removing excess water from where agriculture is practiced; and in-field application and management of water, including land management practices that affect water availability to crops. *In-field application and management of water and land is the common denominator*, regardless of the source of the water, and is a critical element of all agriculture. Therefore "AWM" is critical to successful agricultural production.

Some micro-AWM technologies are indigenous and have been used for centuries; others are relatively new with innovations continuing to be made, especially in India and China. Which technologies, or combination of them, are adopted and work also depends to a large extent on the context: the Southern African region is incredibly diverse, not only in terms of cultures, but also climate, soils, rainfall, access to markets, and many other dimensions. Indeed the diversity occurs even at micro level: neighboring farms may differ to such an extent that they cannot grow the same crops.

All Southern African countries and their investment partners share a commitment to achieving the Millennium Development Goals (MDGs), especially those related to reducing hunger, poverty and malnutrition. It is especially important to drastically reduce malnutrition among under-5 children to enable their full physical and mental development—otherwise malnutrition breeds a vicious cycle of continuing poverty and

[2] International Development Enterprises (IDE) uses the term "Affordable Micro-Irrigation Technology" (AMIT) for, specifically, low-cost drip and sprinkler irrigation kits (ITC et al. 2003).

malnutrition into the next generation. But investors and governments cannot by themselves achieve these goals: their role is to create the conditions and provide opportunities so that people can on their own achieve them. Enabling small farmers to stabilize and improve their staple food production (grains, vegetables, dairy products, meat) for own use and for the market, as well as to take advantage of new market opportunities for vegetables and other higher value crops in a way that is cost-effective and that poor small farmers can afford will be critical for success.

Many specialists believe that making relatively low-cost micro-AWM technologies more widely available can make a major contribution (e.g., Falkenmark and Rockström 2004; Polak 2005). There is evidence from Asia, for example, that the introduction of treadle pumps has lifted millions of people out of poverty (Shah et al. 2000). Throughout India, private firms and NGOs are promoting a large variety of highly cost effective agricultural water management technologies whose uptake and impacts are indeed impressive (e.g., Shah and Keller 2002; Namara et al. 2005).

The potential of these agricultural water management technologies has been recognized by increasing numbers of governments, donors, NGOs and private firms in SSA as well. Researchers, for example at Sokoine University of Agriculture in Tanzania, have devoted considerable effort to researching a variety of rainwater harvesting technologies and the conditions under which they work (e.g., Hatibu and Mahoo, eds. 2000). Innovative NGOs such as KickStart in Kenya and Tanzania and International Development Enterprises (IDE) in South Asia and now also in several African countries have been testing treadle pumps and other technologies, and more important, working out business models that will enable private businesses to manufacture, sell and service these technologies and small farmers to purchase them and gain benefits through market-oriented production.

In the drought- and famine-prone countries of Southern Africa as well, many NGOs and some governments and private firms are promoting a wide variety of low-cost agricultural water management technologies. However, there has been very little work systematically evaluating the effectiveness, impacts, costs and benefits of these programs. Are they successfully targeting the poor? What are the gender dimensions—that is, do women have access to the technologies and to the benefits expected to accrue from their use? Are they really as cost effective as some claims suggest? What are the conditions for success of specific technologies and are these conditions in place? What about their sustainability? What advice can be given to governments, investors, NGOs and farmers interested in these technologies? The study reported here is intended to provide responses to these questions, and to specify areas needing further investigation before the questions can be answered definitely.

Terms of Reference for the Study

During 2005, IWMI held discussions with officials from two agencies having similar interests in this topic. But both had limited resources available. The Southern Africa Regional Office of the Office of Foreign Disaster Assistance, United States Agency for International Development (USAID, hereafter) is seeking ways to enhance the longer term developmental effectiveness of its assistance to rural people affected by drought and famine; USAID currently supports a number of NGOs who are promoting various micro irrigation and other small scale agricultural water management technologies. The Investment Centre of the Food and Agriculture Organization (FAO) is designing a project on behalf of the Southern Africa Development Community (SADC) and the African Development Bank entitled "Agricultural Water Management for Food Security." FAO expressed an interest in getting information on the impacts, experiences and for investment purposes, costs of these types of technologies. In view of the limited resources available from each donor, and the fact that both wanted almost the same product, IWMI proposed to both donors to implement this work as one study[3]. This has enabled us to cover a larger number of SADC countries and cast our net wider than would have been possible with the resources from just one donor. USAID's contract included resources for a special impact case study, while FAO's contract put more emphasis on trying to obtain investment cost data. Both donors are therefore getting added value from the value added by the other.

This is therefore a report to both donors and to their clients and partners. It provides a fairly comprehensive report on what we and our partners found out in the study. It is to be accompanied by a series of country reports and inventories, a photo gallery, and a Power Point presentation on the main findings—all to be contained on a CD to enable wide distribution.

Study objectives and outputs

The main goal of the study is to contribute to filling gaps in knowledge on adoption, impacts and sustainability of selected agricultural water management practices and technologies (USAID), and by doing so, to contribute to improving both rainfed and irrigated agricultural water management for increased food security in the countries comprising the Southern African Development Community (FAO). The specific objective is to identify suitable innovative agricultural water management techniques and approaches which will increase the ability of smallholder farmers and herders to sustain production throughout normal production periods even when rains are delayed, irregular or below normal, and extend productive seasons where feasible. FAO also asked that where possible, for each identified technology, we determine the "corresponding unit costs as a basis for agricultural water investment planning in the pilot SADC countries."

The activities to achieve the objectives were as follows:

- Prepare a methodology and design an inventory format as terms of reference for contract research institutions and consultants (termed "partners" here) in selected SADC countries;
- Select and supervise the partners for the following countries: Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe[4];

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[3] This is explicitly acknowledged in the FAO contract to IWMI.

[4] We had hoped to include Angola as well, but could not find either a partner or documentary evidence that would be useful.

- Desk studies, literature reviews and key informant interviews using the internet and other media to obtain materials on experiences in both SADC and other regions and analysis of these materials to derive major lessons and conclusions;
- Where possible field reconnaissance (done in Botswana, Malawi, Namibia; our partners also did this as well as building on their own professional experience);
- One in-depth survey for a prototype impact assessment using qualitative and quantitative techniques (USAID; this study was done on treadle pumps in Malawi);
- Synthesis of findings and preparation and presentation of the report.

The main output specified in the terms of reference is a report consisting of:

1. A rapid inventory and characterization of existing micro- AWM technologies and practices in the SADC region supplemented by selected examples from Eastern Africa and South Asia; this is to include documentation of good practices at field level;
2. A compilation and estimation of units costs of each identified technology (FAO);
3. A report on the results of the poverty impact assessment (USAID);
4. Overall recommendations on those technologies that seem to be especially well suited for adoption by smallholder producers and herders in the region.

This report presents the material promised as the outputs in the terms of reference. In addition, as noted above, we are preparing a CD that in addition to this report, will include the reports and inventories done by our country partners (see Appendix 2 for a list); the impact assessment report on treadle pumps in Malawi; a users' guide to the international literature available on the internet with selected hyperlinks; copies of selected reports and studies; selected photographs; and a Power Point presentation of the main results of the study. IWMI will make this CD widely available in the SADC region.

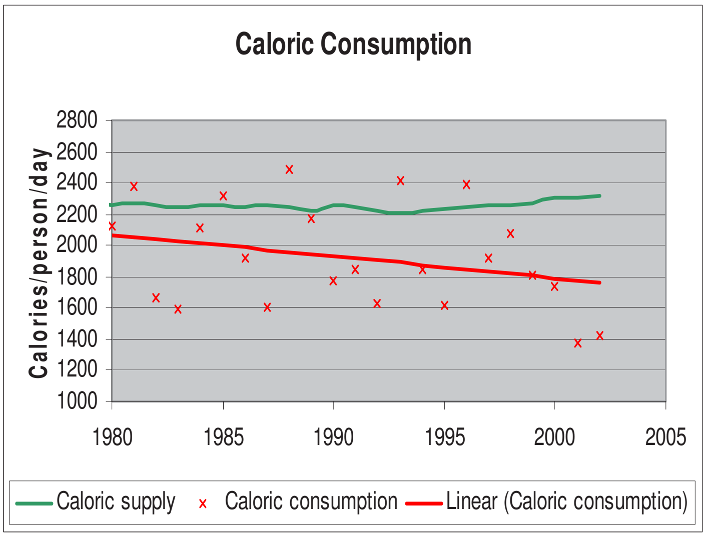
Overview of Food Security, Hunger, and Agricultural Water in SADC[5]

Nearly 60% of the SADC households earn a per capita income of less than $2.00 per day; while this is better than the sub-Saharan African (SSA) average of 80%, it is nevertheless abysmal. Further, income is highly skewed in the SADC region, with an overall GINI coefficient of 50; it is higher in the wealthier countries such as South Africa, Botswana and Namibia, showing that wealth remains in the hands of a small minority. Over 60% of the regional income is held by just 20% of the population; the poorest 20% receive just 3.7% of the regional income. Agriculture contributes a relatively high percentage of total SADC GDP, roughly 25% compared to less than 20% for SSA. While cereal yields have been stable for the past 25 years, *consumption levels* in calories per day per capita have declined from just above 2,100 calories/day in 1980 to less than 1,800 in 2002 (Figure 1). Although the impact of periodic civil unrest and drought-induced famine is highly visible, most poor rural people suffer chronic or seasonal hunger, which is less visible but no less

[5] This material is summarized from the draft website under preparation for the Strategic Agricultural Knowledge Support System for Southern Africa (SAKSS-SA). SAKSS-SA is an initiative managed by IWMI and ICRISAT with FANRPAN, and is currently funded by USAID.

devastating. Overall levels of undernourishment have remained between 35-38% since 1992, slightly worse than the overall SSA percentages. In other words, access to food has decreased. Policies and investments aimed at increasing incomes, including through increased agricultural productivity, are urgently required.

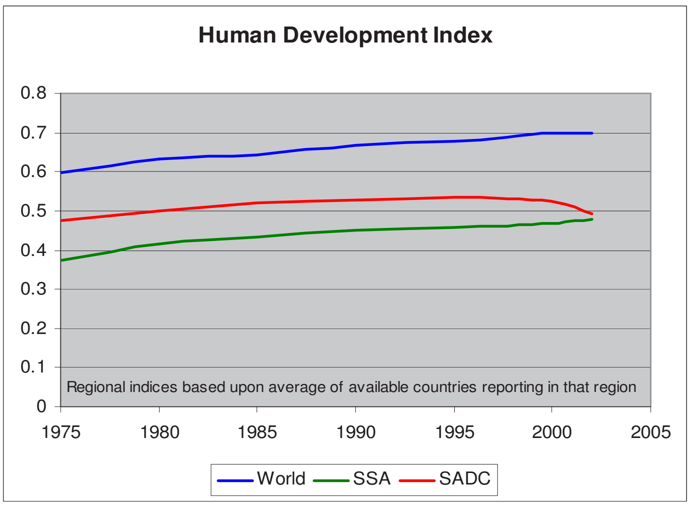
Figure 1. Caloric Supply and Consumption Trends in SADC Region



Source: Draft SAKSS-SA Website.

These dismal statistics are reflected in the UN Human Development Index (HDI) figures. Life is generally improving worldwide and even in SSA according to this Index—except for the SADC region (Figure 2). The recent decline in the HDI is a result of decreases in health and lifespan, largely as a result of the HIV/AIDS pandemic; the SADC region has shown strong improvements in other measures such as higher literacy rates and better

Figure 2. Human Development Index Trends

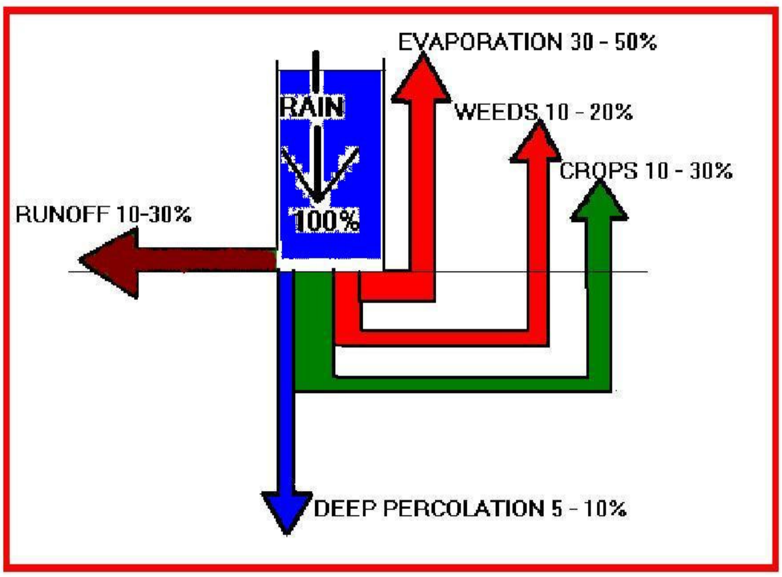


Source: Draft SAKSS-SA Website.

access to water supply than is the case for SSA as a whole. However, these positive trends have been overwhelmed by the impact of HIV/AIDS. The deleterious impact of HIV/AIDS is further exacerbated by malnutrition, in a vicious downward cycle. Projected declines in rural population suggest that already-scarce labor will become increasingly scarce, putting a premium on the need to increase labor productivity to sustain agricultural growth. This labor scarcity is not only from loss of adult workers, but from illness and poor health which reduces productivity, and time spent caring for the sick and attending funerals.

A major reason for the low and erratic rate of growth in agricultural production is the highly uncertain and unpredictable rainfall, combined with low soil fertility (FAO 2003). Even in years of "average" rainfall, a shortfall during critical periods of crop growth often leads to widespread crop failure. Therefore, as an FAO study on water management in the SADC region notes, water storage is absolutely crucial for stabilizing and increasing crop yields (FAO 2003). Water can be stored in many ways: large and small dams, aquifers, on-farm storage tanks, and in the root zone of crops. The latter is crucial, and can be achieved through better management of water at the farm level: currently, as much as 70-85% of the water falling on fields is "lost," i.e., evaporates or runs off without being available for crop evapotranspiration. Figure 3 provides a conceptual diagram illustrating the potential for improving the productivity of rainfall: if unproductive evaporation, runoff and consumption by weeds are reduced, there will be more water available for the crop[6].

Figure 3. Partitioning of rainfall at field level



Source: Hatibu and Rockström (2005: Figure 1).

[6] This is not to discount the critical importance of large-scale water storage as well; per capita storage capacity is very low in Africa causing serious vulnerability to periods of low rainfall; droughts and floods have devastating impacts on economic growth as well as the rural poor.

Conventional irrigation is in principle one way to ensure a reliable water supply to crops. However, there are no reliable figures on the irrigation potential of the SADC region. Further, conventional irrigation is relatively expensive (per capita and per ha), and at current and projected world cereal prices cannot easily be justified for such crops; it takes many years, even decades after construction to reach full productivity; and there are serious questions about how much water is available for irrigation in much of semi-arid southern Africa. FAO has argued that it would make more sense to focus investments on improving food security, nutrition and livelihoods of the most vulnerable people through a combination of improved water management in rainfed agriculture (including what we have called micro-AWM) and improved soil fertility management, for example through conservation agriculture (FAO 2003).

Micro-Agricultural Water Management Technologies in Global Perspective

There is now a very large and rapidly growing global literature on rainwater harvesting (RWH), conservation agriculture including soil water conservation measures (SWC), and the various forms of low-cost small-scale water lifting and application technologies. We have provided a guide to some of this literature in a separate document (de Lange 2006a) as well as in the CD. Further, there are a number of networks devoted to this field, especially to rainwater harvesting. These include the Southern and Eastern Africa Rainwater Network (SEARNET, www.searnet.org) and the International Rainwater Harvesting Alliance (IRHA, www.irha-h2o.org). SEARNET has established a partnership with the premier research and advocacy NGO for rainwater harvesting in India, the Centre for Science and Environment (CSE, www.cseindia.org). CSE has published important work documenting a very large variety of indigenous and modern rainwater harvesting technologies and practices in the sub-continent (Agarwal et al., eds. 2001; Agarwal and Narain, eds. 1997). Recently, a group of international water management research and advocacy groups (including IWMI) also endorsed the critical importance of such "green water" technologies (SIWI et al. 2005). Beukes et al. (eds. 2003) contains a large number of articles on experiences with "water conservation technologies," with special reference to southern Africa.

Similarly, there is a growing movement to promote low-cost treadle pumps and drip irrigation as a practical way to enable farmers to grow more food and lift themselves out of poverty: Paul Polak, founder of International Development Enterprises (IDE, www.ideorg.org), for example, has provided a powerful argument that a package of affordable irrigation and access to markets can make a substantial contribution to achieving the MDGs (Polak 2005)[7]. An evaluation of the impact of IDE's treadle pump program as of the late 1990s in Bangladesh (Shah et al. 2000) provides strong evidence for this optimism – though it must be noted that the hydrological conditions there are not replicated anywhere in Africa. In 2000, IPTRID published a report (Kay and Brabben 2000) evaluating the potential for treadle pumps in Africa, based on an analysis of experience in Zambia, Zimbabwe, Niger and Kenya; it remains one of the few

[7] See IDE's website (www.ideorg.org) for various reports on cases in Asia, Africa and Latin America.

comparative studies of the technical performance of the different treadle pumps then available.

A recent large-scale assessment (286 interventions in 57 poor countries covering 37 million ha and 12.6 million farms) also shows that "resource-conserving agriculture"—including among others rainwater harvesting, conservation agriculture, and integration of livestock and aquaculture into farming systems—has led to an average crop yield increase of 79%, and very high water productivity gains (Pretty et al. 2005). The water productivity gains ranged from 70% to 100% for rainfed cereals, legumes and roots and tubers. This work supports experimental, theoretical and practical work by Rockström (e.g., Rockström et al. 2003; Falkenmark and Rockström 2004), Hatibu and Mahoo (eds. 2000), Ngigi (2003) and others demonstrating a doubling of rainfed crop yields in the semi-arid tropical regions of SSA is possible with currently known technologies for improving water and nutrient management. The World Bank has also recently acknowledged the importance and potential for increasing the productivity of rainfed agriculture through soil moisture conservation, water harvesting, supplemental irrigation, and the use of low-cost technologies such as treadle pumps and drip kits (World Bank Water for Food Team 2005). Mati (2006) provides a good source on experiences with a large number of RWH and SWC technologies in eastern and southern Africa, while Ngigi (2003) describes and illustrates examples from the same region. Forthcoming work by IWMI (Barry et al. forthcoming, 2006; Adeoti et al. forthcoming, 2006) provide similar coverage for West Africa.

Hatibu and Mahoo (eds. 2000) offer well-illustrated and easy-to-use guidelines for designing and implementing effective rainwater harvesting; though aimed at Tanzania it is relevant to many semi-arid areas in eastern and southern Africa. However, Hatibu et al. (2004) report on a study that warns that the returns to labor investments in RWH alone sometimes cannot justify the investment; it is essential to assist farmers to change from subsistence to commercial market-oriented objectives, and to combine RWH with nutrient management to achieve high returns. In West Africa, some RWH technologies are also reported as too expensive for farmers without subsidies (Barry et al. forthcoming, 2006). That said, other experiences, for example the Water for Food Movement in South Africa and Lesotho, demonstrate that relatively low-cost household level RWH can have a major impact on local food security even without an emphasis on commercialization (Marna de Lange, personal communication). In this perspective, it could thus be anti-poor to insist on market-oriented production as a condition in all programs promoting micro-AWM.

Implementing programs promoting these technologies and practices at a large scale, in a manner that targets the benefits to the poorest people, and is sustainable and profitable is not easy. Micro-AWM technologies by themselves are not a panacea for a complex and deeply rooted problem like rural poverty and malnutrition. This is why relief-oriented micro-AWM programs implemented by NGOs often have limited impact (Moyo et al. 2005; IWSD 2006a). To have a long-term sustainable impact, they require an integrated, holistic and carefully targeted approach that encourages and supports creation of market-based input supplies and services and profitable output markets, and that make it possible for the very poor to gain access to and make good use of the technologies. For example, Namara et al. (2005) discovered that in Gujarat and Maharashtra (India), the main beneficiaries of IDE's drip irrigation programs were relatively rich farmers with access to water and markets for high value crops. A broader survey comparing IDE's drip irrigation program in three Indian states to its program in Nepal confirmed the same finding for India, but found that in Nepal, IDE had successfully targeted very poor people, including women (Shah and Keller 2002). Mangisoni's (2006) study of the impact of treadle pumps on poverty in Malawi shows very positive outcomes. On the other hand, studies of KickStart (www.approtec.org) and Enterprise Works (www.enterpriseworks.org), two NGOs promoting treadle pumps in eastern and west Africa respectively, show that while these programs are having important positive effects they are not necessarily reaching the poorest farmers (Van Koppen et al. 2005). A recent study of the impact of drip kits in Zimbabwe shows that without more effective targeting, training and other support as part of a long-range development program, drip kits will have very minimal impacts even on household food security in the short run (Moyo et al. 2005), confirming a similar conclusion by van Leeuwen (2002) from a broader review of African experiences with drip kits.

The major conclusion emerging from this brief review is to recommend support for exchange of experiences and lessons learned, comparative analysis, and partnerships among African countries and between Africa and Asia, especially India.

Analysis of Selected Experiences in SADC: Good Practices

Introduction

In this section, those micro-AWM technologies we consider most promising and/or most commonly used are described and some information given on their current use in the SADC countries we studied. Table 1 provides a detailed listing of technologies by country, based on the country reports and other literature. This is complemented by Table 2, giving the results of an informal survey of specialists done at a recent workshop of the Southern African Regional Irrigation Association (SARIA) in January 2006. The technology descriptions here are mostly from a comprehensive report by Professor Bancy Mati (Mati 2006), while the information on their application in SADC countries is largely from the reports by the partners who worked on this study supplemented by other sources in some cases.

As in the table, the technologies are divided into four categories:

- water lifting (pumping) technologies;
- technologies for water application to plants;
- *in-situ* soil and water conservation (SWC) technologies including conservation agriculture; and
- *ex-situ* rainwater harvesting and water storage technologies.

Table 1: Matrix of the key agricultural water technologies used in SADC countries*

Technology	Botswana	Lesotho	Malawi	Mozam-bique	Namibia	South Africa	Swazi-land	Tanzania	Zambia	Zim-babwe
Lifting (pumping) Treadle pump		X	X				X	X	X	X
Rope and washer pump										X
Elephant pump										X
Hand pump					X					
Small power pumps						X				
Application to crops Bucket and drum drip		X				X		X	X	X
Direct applicator hose (low pressure gravity)							X			
Bucket irrigation						X	X			X
Clay pot (sub-surface irrig)									X	
In-situ SWC/ Conservation Agriculture Flood recession				X					X	
Planting pits/ beds/ *ngoro, chololo,*			X		X			X		
Infiltration ditches/ *fannya juu*/ micro basins/ micro catchments			X	X				X	X	X
Minimum tillage (conservation farming)			X			X		X	X	X
Contour ridges			X			X		X		
Gully erosion control			X			X				
Paddy bunds								X		
Mulch								X		
Dambos/ valley bottoms				X	X			X	X	
Strip farming	X									
Ex-situ RWH/storage *Charco* dam								X		
Small earth dams	X		X			X	X	X		X
Hand dug shallow wells					X					
Boreholes	X				X	X				
Hill & underground spring-gravity			X						X	
Underground tanks			X							X
Above ground tanks			X						X	
Road etc run-off harvesting		X	X							
Roof top harvesting			X							
River diversion/weirs			X			X		X		X

* Notes: This information is based largely on what has been reported by the partners but augmented by other literature; blanks do not imply the country does not have the practice mentioned, only that our partners did not note it as significant and we did not find it in other sources consulted. There is some overlap among these, and in some cases we have grouped technologies that have important technical differences (but are based on the same principle). It is important to note that many of these are used in combination, for example roof top harvesting with underground or above surface tanks; treadle pumps with drip systems, etc.

Table 2. Results of informal survey on low-cost agricultural water management technologies in SADC, at the Southern African Regional Irrigation Association (SARIA) Workshop, 30-31 January 2006

TECHNOLOGY	**5 currently most widely used low-cost AWM technologies**	**5 most promising low-cost AWM technologies for household food security**	**5 most promising low-cost AWM technologies for market production**
Lifting (pumping) Treadle pump	ZA, ZA2, SA4, M	ZA2, SA4, M	ZA, ZA2, SA4, M
Rope and washer pump			
Elephant pump			
Hand pump	SA5, T, L	MD, SA5, L	MD, T, L
Small power pumps	B1, SA3, SA4, L	B1, SA1, T, N, L, M	B1, ZA, ZA2, SA1, SA3, SA5, N, L, M
Application to crops Bucket and drum drip	B2, S, SA1, SA4, L	B2, SA4, L	B2, SA4, L
Direct applicator hose (low pressure gravity)	S, MD, SA1, SA2, SA3, L, M	S, MD, SA1, SA3, T, L, M	MD, SA1, SA2, SA3, T, L, M
Bucket irrigation	B1, S, ZA2, SA2, T, N, L	ZA, ZA2, L	
Clay pot (sub-surface irrig)	B2	B2, SA4	B2, SA4
Other (specify): DRIP		B1	B1, K, N
SPRINKLER	L		L
FLOOD FURROWS	SA5	SA5	SA5
WATERING CAN	SA5		
DRAGLINE		N	N
In-situ SWC/ Conservation Agriculture Flood recession	SA4		
Planting pits/ beds/ *ngoro, chololo*,	B2, SA2, L	B2, SA5, L	B2
Infiltration ditches/ *fannya juu*/ micro basins/ micro catchments	B2, SA4, L	B2, ZA2, SA1, L, M	B2, ZA, SA1, M
Minimum tillage (conservation farming)	B2, ZA2, MD, T	B2, S, MD, SA2, SA3, SA5, N	B2, ZA2, MD, SA2, SA3, T, N
Contour ridges	B1, B2, S, SA1, SA5, L, M	B2, SA3, L, M	B2, S, ZA, SA3, SA5, M
Gully erosion control	MD, SA4, L	MD, L	
Paddy bunds		T	
Mulch	ZA2, MD, L	B1, MD, SA2, SA3, N, L	B1, MD, SA3, SA5, N
Dambos/ valley bottoms	ZA		ZA
Strip farming	B2, S	B2	B2, S
Ex-situ RWH/storage *Charco* dam			
Small earth dams	B2,S,ZA2,SA1,SA4,N,L,M	B1, B2,MD,SA3,SA4	B1, B2, S,MD,K,SA1,SA4,T,L
Hand dug shallow wells	N,L	ZA2,L	
Boreholes	B2,S,ZA,SA4,SA5,N,L,M	B2,S,ZA2,L,M	B2,S,ZA,ZA2,M
Hill & underground spring-gravity	N,L	L	L
Underground tanks	B1,B2,SA2	B2,SA3	B2,SA2
Above ground tanks	MD,SA4	SA2,T	SA5
Road etc run-off harvesting	B2,SA1	B2,K,SA2	B2,K,SA2
Roof top harvesting	T,L	SA2,SA5,N,L	
River diversion/weirs	B2,S,ZA,K,SA1,SA4	B2,K,SA1,SA4	B2,S,ZA,K,SA1,SA4

Note: There were 5 respondents from South Africa (SA); 2 each from Botswana (B) & Zambia (ZA); and 1 each from Lesotho (L), Madagascar (MD), Malawi (M), Namibia (N), Swaziland (S), and Tanzania (T).

From these, we selected a few technologies for further discussion based on a combination of factors, including the number of countries practicing them, their popularity, other literature and studies, and the recommendations of the country partners. For instance, one technology, clay pot irrigation, is not very well known, but was so strongly recommended by the Zambian country partner (Daka 2006) for its accessibility to the very poorest households, that we included it. And indeed, some very interesting literature from across the world echoes this enthusiasm.

The technologies selected for further discussion include the following:

- Treadle pumps and small motorized pumps;
- Drum and bucket drip kits and direct applicator hoses;
- Clay pot irrigation;
- *In situ* conservation agriculture technologies (treated as a group, including pits and ditches, minimum tillage and mulching); and
- *Ex situ* water harvesting and storage structures (small earth dams, boreholes, above- and under-ground storage tanks).

There are no universally applicable micro-AWM technologies. Rather, different technologies are useful in different circumstances. For example, treadle pumps cannot draw water from more than about 6 meters below the pump's position. Similarly, different types of water storage structures are adapted to different rainfall regimes, soils and climates: what works in moist tropical areas will not serve much purpose in arid deserts. Figure 4 provides a map of the agro-ecological zones of southern Africa, courtesy of FAO. In what follows we attempt to specify under what conditions a specific technology will be useful; but obviously technologies have to be adapted to specific local on-the-ground conditions. Before proceeding to discussing specific technologies, we provide some of the results from the extensive inventory of country experiences we carried out. A separate section discusses their costs and benefits.

Perspectives on micro-AWM Technologies based on partners' inventories

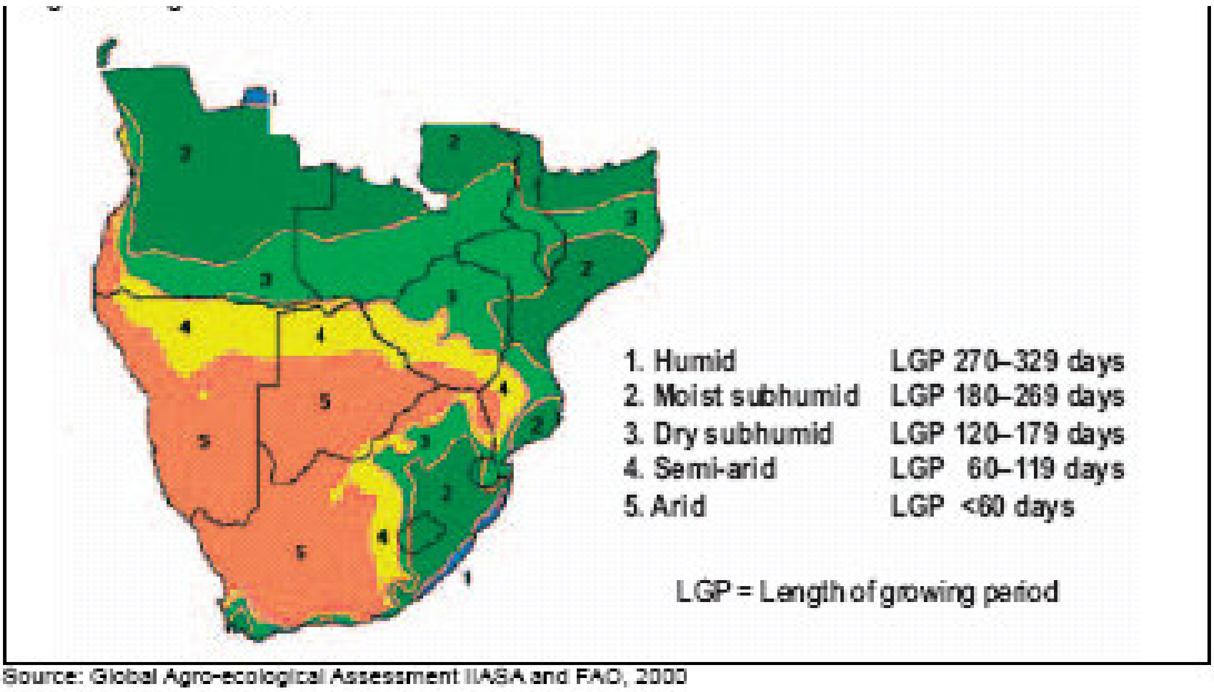
Our partners used the inventory format we had provided to record micro-AWM technologies in 9 SADC countries as shown in Table 1; we added South Africa to the table based on our experience but did not do a formal inventory for that country[8]. None of these inventories are in any way exhaustive or comprehensive; our partners used their professional judgment to choose what to include, and some provided more complete data than did others on each technology and on the range of technologies in use. Therefore, our findings are indicative, not authoritative.

Livelihoods of rural people

The main livelihood strategies of rural people in the SADC region were assessed based on the frequency of responses of the partners to the question: what are the major sources

[8] The CD contains the inventories for each country.

Figure 4. Agro-ecological zones of Southern Africa



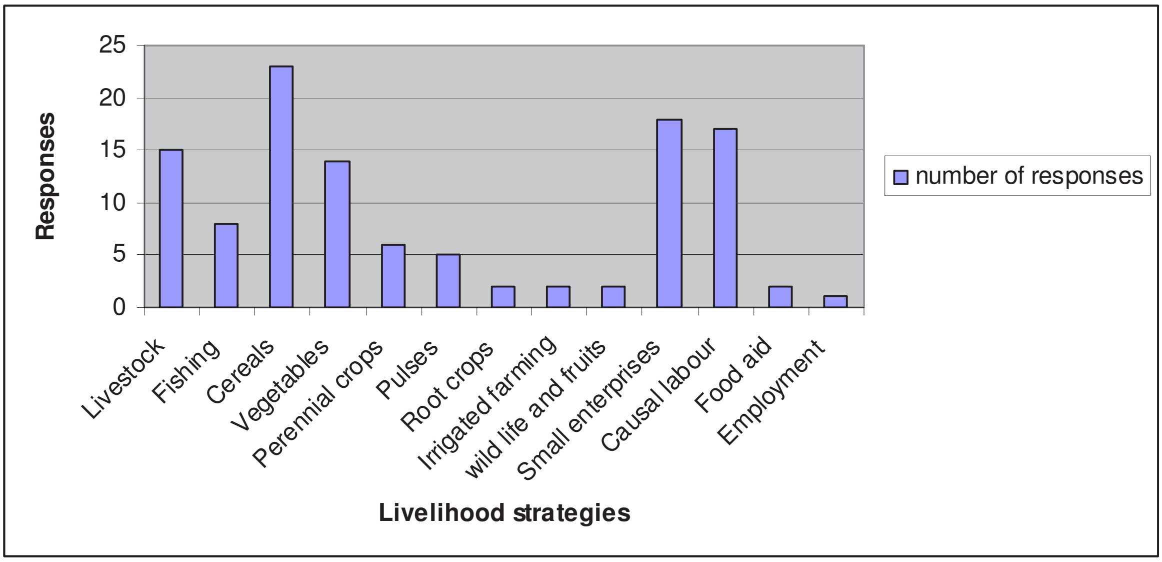
Source: FAO 2003: Map 1. We consider this as indicative only; for example the cold temperatures in parts of Lesotho limit the growing season to a smaller period than is shown here.

of livelihoods in the rural areas of the SADC region? The results are depicted in Figure 5. Figure 5 is instructive on the importance of casual labor and small business activities in the livelihoods of rural people in southern Africa region. The farmers complement their incomes through casual labor and small business activities such as palm oil production, firewood sale, soap making, local beer making, trade, reed mat making, thatching grass sale, etc. Also, some rural households get remittances from one or more of their family members working in urban areas. Another important sector is livestock and fishing. Among the cereal crops, maize constitutes the single most important crop enterprise in the region. Irrigated farming is not a significant livelihood strategy for many people. Irrigated areas constitute only a small proportion of the sub-region's cultivated area, but are important for production of high value cash crops. Most irrigation systems are reported to be poorly managed with only a fraction of the design command under operation. The implications of this for designing appropriate agricultural water management technologies in the region for insuring food security and poverty reduction are very important.

The AWM technologies/practices

There were a total of 61 agricultural water management technologies, practices and systems identified in the region through our inventories. However, this is not an exhaustive figure for the whole range of agricultural water management systems in the region; these are the most important ones. Of these, about 30 are known to be imported and 23 are considered indigenous. The others could not be conveniently categorized as either imported or indigenous. Of the 30 imported technologies, about 9 of them were modified or adapted to fit the hydrological, agro-ecological and socioeconomic realities of the importing countries or communities.

Figure 5. Major livelihood strategies of rural communities in the SADC



Source: Compiled from AWM inventories filled by partners.

Main uses of AWM technologies

The 61 technologies are used for a variety of crop and livestock enterprises in both irrigated and rainfed areas (see Table 3). Some patterns in the use of the agricultural water management technologies with respect to crop choice are evident. The indigenous and introduced *in-situ* soil and water management technologies are used mainly to cultivate staple food crops such as maize, sorghum, cassava, and rice. The introduced technologies such as drip systems, treadle pumps, sprinklers, and capital intensive storage systems are used for growing high value crops such as sugarcane, green maize and vegetables.

Ownership of AWM technologies

The agricultural water management technologies and practices observed in the region are owned and managed differently. Some of the technologies are publicly or communally owned, some are individually owned, and others are both privately and communally owned (Figure 6). Most of the high capital investment structures such as dams, ponds, boreholes, river diversion systems and high pressure sprinkler and drip systems are publicly or communally owned. It is interesting to note that a low cost technology such as a treadle pump is in many instances owned by a group of farmers, who use it on a turn-by-turn basis because they cannot afford the cost individually. For instance, due to cost and limited supply of treadle pumps in Malawi, group ownership of treadle pumps (groups of up to 5 individuals) is sometimes advocated. In the districts of Blantyre and

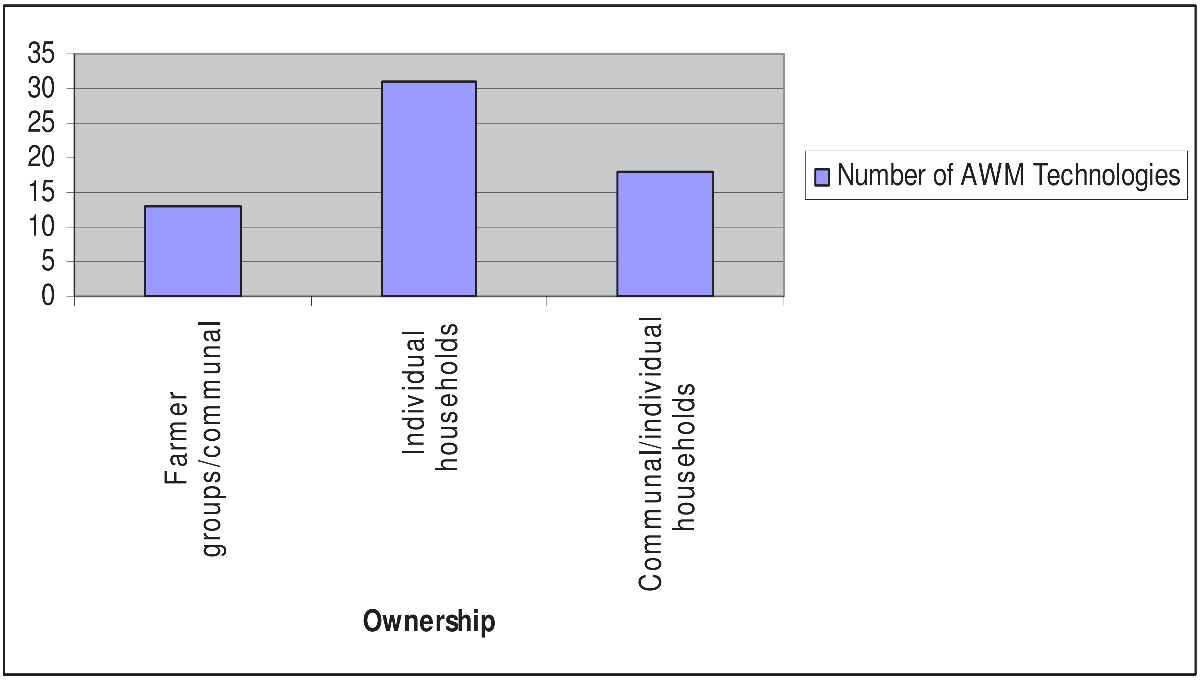
Mchinji, close to 32 percent of the farmers share treadle pumps (Mangisoni 2006). This is an indication of the depth of poverty in the sub-region.

Table 3. AWM technologies and crops produced

Name	**Crops /enterprise**
Small Dams	Vegetables
Pond improvement for livestock	Livestock
Permanent strip farming	Maize and other field crops
Improved wells	Livestock
Vegetative cover	Maize, sorghum, pigeon pea, cassava, sweet potato
Fanya juu terraces	Maize, banana
Stone lines	Maize, beans, vegetables
Terracing	Coffee, beans
Small earth bunds/raised foot paths	Rice
Conservation farming	Maize, beans, pigeon peas
Contour cultivation	All relevant crops
Tied ridging	Cotton, maize, sorghum, sweet potato, beans, cassava
Retention ditches/infiltration pits	Maize, pigeon peas, beans, sweet potato
Planting pits	Banana, fruit trees, maize
Roads, foot path run-off harvesting	Cotton, rice, maize
Stream/ flood diversion	Maize, vegetables, rice
Drip irrigation systems	Maize, cabbage, tomatoes, beans, sugarcane
Sprinkler irrigation system	Maize, okra, leaf vegetables, pineapples, oranges, cabbage, green maize, paprika, green beans
Treadle pumps	Maize, vegetables (tomato, strawberries, onions, rape, cabbage, onions, etc)
River diversion systems	Maize, vegetables
Residual moisture cultivation	Maize, sweet potatoes, cassava, sugar cane, beans
Bag gardening	Vegetables
Roof harvesting with above ground tank	Vegetables, tree seedlings
Shallow wells	Vegetables
Under ground tanks	Vegetables (onions, tomato)
Small earth dams	Maize, vegetables, sweet potatoes, beans
River impounding/weirs	Maize
Under ground water springs	Maize, beans, sweet potatoes
Nombete (planting beds)	Vegetables (tomato, pumpkins, etc)
Omarumba (valley bottom cultivation)	*Mahangu,* maize
Boreholes, watering points	Livestock, human drinking, communal vegetable production
Zilili river flood plain recession	Tomatoes, peas
Micro-basin water harvesting	Maize, groundnut, paparika, sorghum, millet
Inland valley irrigation (*dambos*)	Maize, cabbage, sugarcane, cassava, sorghum, millet

Source: Partners' reports and inventories. Windmills are not listed, perhaps because they are more often used for livestock watering in dry areas.

Figure 6. Mode of ownership of AWM technologies



Source: Partners' inventories and reports.

The mode of ownership of AWM technologies and practices has implications for efficiency and equity. While the publicly/communally owned AWM technologies may pose management challenges, they may be equitable provided the right institutional environment is in place to enforce the rights of the poor to the AWM technology. The privately owned AWM technologies may be efficiently used, but the most needy people may not able to own them individually without at least once-off assistance to acquire them.

Labor requirements of the technologies

Another important aspect of AWM technologies is their impact on the labor pool of the farm households. It is usually taken for granted that small scale farmers in Africa are labor abundant, a view increasingly being challenged at least in the Southern African region because of the epidemic of HIV/AIDS and the increasing importance of wage income for the livelihoods of rural people. The labor intensity of selected AWM technologies as assessed by our partners and their informants is presented in Table 4. Quite significant numbers of the respondents claim that the new technologies require *more* labor than the counterfactual, which may limit their adoption among some farmers. Almost all of the indigenous soil and water management technologies promoted require more labor than the counterfactuals, at least in the initial years of adoption. Among the recently introduced technologies, treadle pumps were judged by many to be labor intensive, though one has to see this relative to the alternative technologies. For example, our Mozambique partner (Mario Marques, personal communication) in an email said that farmers generally perceive that the labor required for treadle pumping does not compensate for the larger volume of water made available compared to buckets[9]. In Malawi and Tanzania, treadle pumps are viewed as labor-saving.

Table 4. Perceptions of the labor requirements of some AWM technologies

AWM technology	**Requires more labor**
Permanent strip farming	No
Vegetative cover	No
Fanya juu terraces	Yes
Stone lines	Yes
Terracing	Yes
Small earth bunds/raised foot paths	NA
Gully control	NA
Conservation Farming	Yes
Contour cultivation	NA
Tied ridging	Yes
Retention ditches/infiltration pits	NA
Planting pits	NA
Roads/footpath run-off harvesting	NA
Drip irrigation	No
Sprinkler system	No
Residual moisture cultivation	NA
Bag gardening	NA
Roof harvesting with above ground tank	No
Shallow wells	No
Under ground tanks	No
Underground water Springs	NA
Low pressure gravity fed sprinkler	NA
Drip irrigation systems	No
Treadle pumps	Yes/No
Nombete (planting beds)	yes
Omarumba (valley bottom cultivation)	NA
Bucket pump	NA
Bush pump "B"	NA
Micro basin water harvesting	Yes
Hill spring water gravity head sprinkler irrigation	No
Ridging	yes
Mulching	yes
Minimum tillage	No
Ngoro pits	yes
Chololo pits	yes
Ladder terracing	yes
Paddy field bunding	Yes

Source: Partners' reports.

9 Adeoti et al. (forthcoming, 2006) report a similar perception of treadle pumps by some farmers in Ghana.

Conservation farming technologies such as permanent strip farming and minimum tillage may or may not need more labor than the alternative farming systems, but they usually need specialized farm equipment. Similarly, the treadle pump technology may or may not require more labor depending on the nature of the technology it replaces. If it replaces watering cans, then treadle pumps may be labor saving. Some of the factors claimed for the lack of wider dissemination of the technology are:

1. Engineers, planners and extension staff have been reluctant to consider human-powered pumps for irrigation (e.g., Zimbabwe). This reluctance seems to be based on moral rather than technical and economic grounds. It is argued that it is "immoral" to propose solutions that force people into hard physical labor—but this attitude of course deprives people of the opportunity to make their own choices.
2. In some countries, the distribution of treadle pumps is further constrained by the fact that water tables are very low – deeper than 6 m – in most areas. For instance, most communal areas in the Zimbabwe are located in the driest parts of the country and where the water tables are deepest.
3. Lastly, for some of the models, the operation and maintenance cost may be substantial. Farmers often claim that cylinders need permanent lubrication and oil. For example, valves at the cylinder bases need adjustments.
4. Pumps need to be moved to and back from the field very often to prevent their theft.

Some of the *in-situ* soil and water management technologies aggressively promoted by researchers are felt to be labor intensive, perhaps explaining their low rate of uptake among smallholders. These technologies are supported by various NGOs. Following the withdrawal of the NGO's services, the pace of adoption usually decreases and some farmers even revert back to their traditional technologies. This is particularly true for those NGOs who support technology uptake through food for work programs.

Concluding observations

A wide range of agricultural water management technologies/practices are therefore available in the southern Africa region. The following conclusions may be drawn so far regarding the identified technologies and practices:

- Micro-AWM technologies and practices are complementary in nature. For instance, while the water lifting technologies, diversion and storage systems are means of accessing water from a source, the application technologies are means of efficiently using the accessed water. This combination has to be appreciated in any future investment planning, particularly given the scarcity of water in many areas of Southern Africa.
- An overemphasis on promoting water lifting technologies without sufficient consideration to the sustainability of the source and the technologies that ensure productive use of the accessed water (application technologies) may not result in the sustained reduction of hunger and poverty.
- The *in-situ* soil and water conservation practices are a means of enhancing the water and land productivity of rainfed and swamp or flood recession farming systems.

- It is important also to note that some of the technologies and practices have been known to the farmers for many years or are indigenous, but the extent of their use or adoption is low. This may reflect their highly location-specific nature.
- The literature on agricultural water management is usually crop-biased while the livestock production sector constitutes a vital livelihood system of the rural people in Botswana, Namibia, Zimbabwe, and elsewhere. A lot of innovative water management systems for livestock production systems that warrant further consideration are available.
- It is also observed that water management infrastructure built for livestock production is often deliberately designed for multiple uses (e.g., boreholes in Botswana).

Low-cost water lifting technologies: Treadle pumps

Kay and Brabben (2000) provide a good introduction to the various types of treadle pumps and experiences up to 2000 in some African countries. The treadle pump is a low-lift, high-capacity, human-powered pump designed to overcome common obstacles of resource-poor farmers to irrigation (Figures 7 and 8 illustrate the basic principles; Figure 9 provides photos of various models). The treadle pump can lift five to seven cubic meters of water per hour from wells and boreholes up to seven meters deep, as well as from surface water sources such as lakes and rivers. There are two types: those that lift water from a lower level to the height of the pump commonly called *suction pumps*, and those that lift water both from a lower level and lift it to a height greater than the height of the pump, known as *pressure pumps*. In all forms, water is pumped by two direct-displacement pistons, which are operated alternately by the stepping motion of the user. The treadle pump has an important advantage over motorized pumps for irrigation of agricultural land of less than one hectare: it is considerably less expensive to purchase and operate, needing no fuel and limited maintenance.

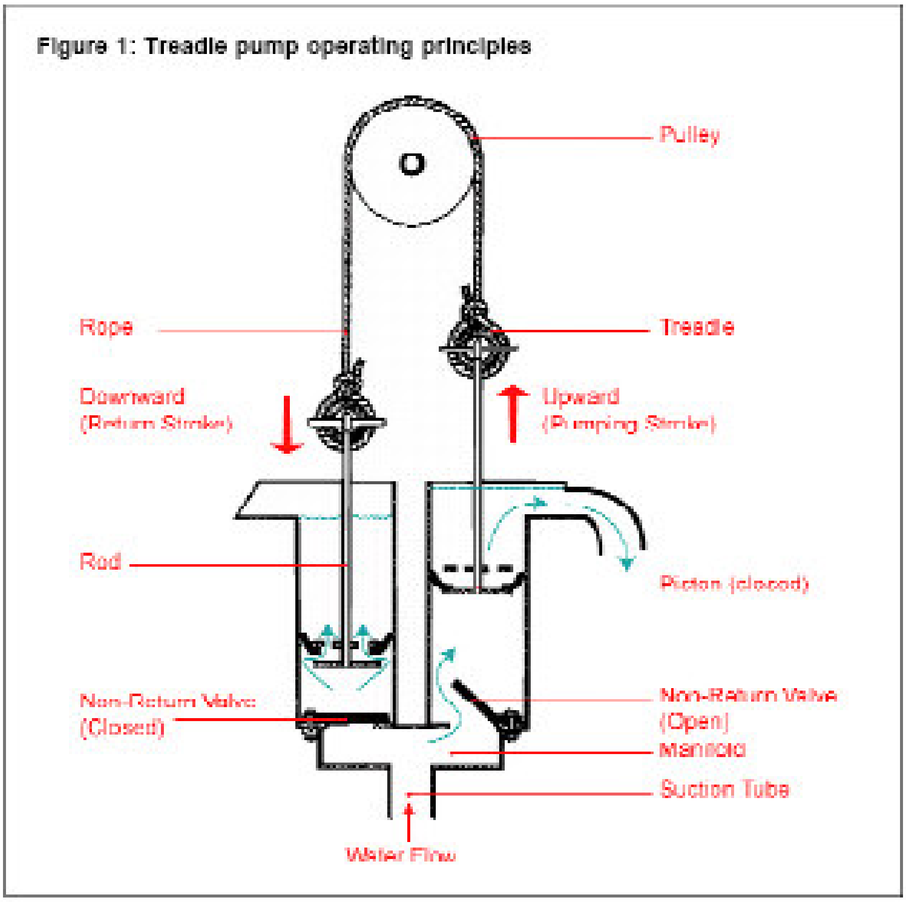
The treadle pump also possesses a number of features which sets it apart from other non-motorized irrigation pumps.

- First, its water lifting capacity of five to seven cubic meters per hour meets the irrigation requirements of most African farmers, the majority of whom cultivate less than one hectare of land.

- Second, because the treadle pump employs the user's body weight and leg muscles in a comfortable walking motion, use of the pump can be sustained for extended periods of time without excessive fatigue. The treadle pump is much less tiring than other manual pumps that utilize the upper body and relatively weak arm muscles.

- Third, the treadle pump can be fabricated entirely from locally-available materials and by using welding equipment and simple hand tools in the metal workshops commonly found in Africa.

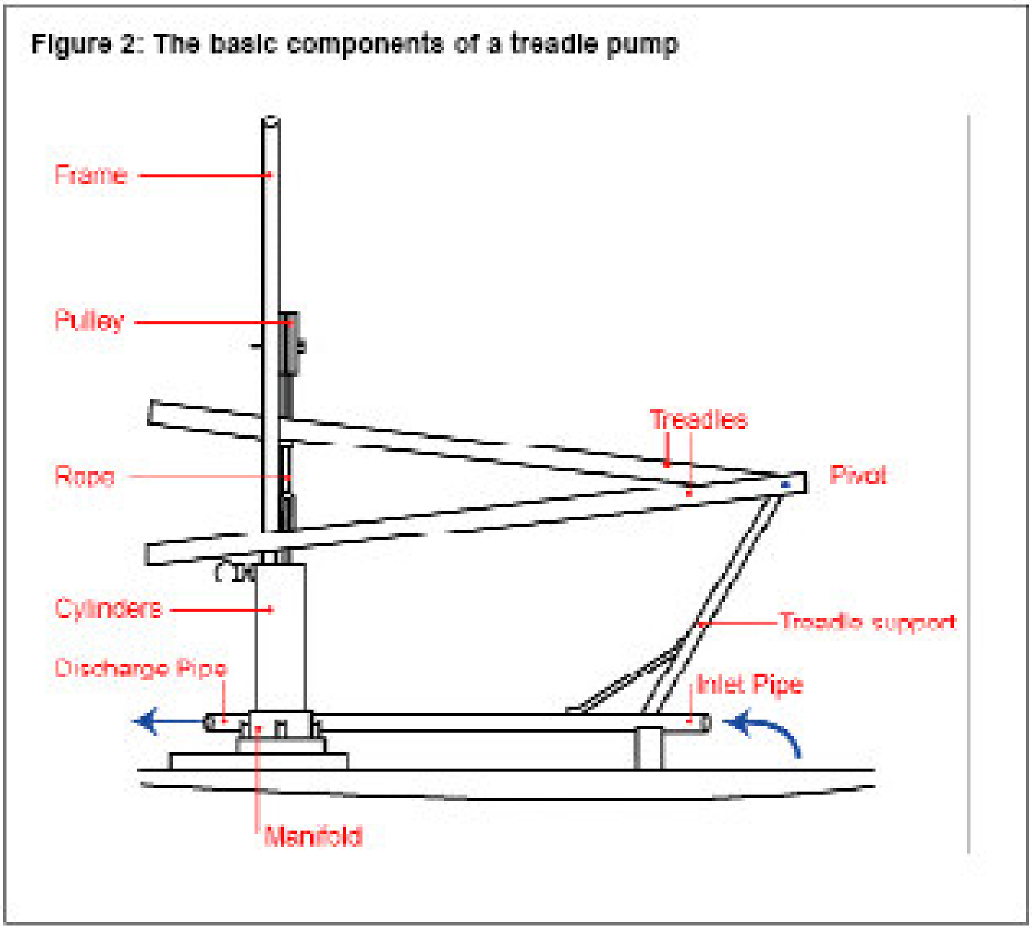
Figure 7. Treadle pump operating principles.



Source: Kay and Brabben (2000: 11; Figure 1).

In our survey, our partners reported on the use of treadle pumps in seven countries: Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia and Zimbabwe (Table 1). We are aware of small treadle pump programs in South Africa as well. Significantly they seem not to be promoted in Botswana and Namibia: although both countries do have areas with water available close to the surface, they are largely desert countries where relatively deep boreholes with power pumps are more common. Our partners report that in Malawi, Tanzania and Zambia treadle pumps are increasingly common and have a very high potential. In Lesotho, Swaziland, Zimbabwe and Mozambique there have been no concerted efforts to promote treadle pumps as part of a program to find sustainable means to raise small farmers' incomes—even though it is clear that the conditions (e.g., areas where water is available close to the surface, market opportunities for sale of higher value crops) are potentially favorable. Observations in Zambia and Malawi suggest that the large areas of inland wetlands, *dambos*, are an especially appropriate context for treadle pumps because water is relatively close to the surface. In Lesotho and Zimbabwe the high cost of treadle pumps— $200 to $370 in Lesotho—is clearly a major impediment (IWSD 2006a, 2006b). In a few countries including Zimbabwe cultural factors are mentioned—the elevated pump makes women uncomfortable to use it, and some engineers and planners consider human-powered pumps that require hard physical labor to be “immoral.” However, in parts of Malawi and in Zambia this was reported as a non-issue[10].

Figure 8. Basic components of a treadle pump



Source: Kay and Brabben (2000: 14; Figure 2).

Zambia experience

Daka (2006) reports a “belief” that about 5,000 treadle pumps have been sold in Zambia to date at prices ranging from US$ 50-100; and he reports examples of very high returns. The Project Completion Report for the Smallholder Irrigation and Water Use Program (SIWUP PCR no date) reports that the promotion of ‘simple irrigation technologies’ including treadle pumps by FAO and IDE went better than other components of the project—but still rates this component “highly unsatisfactory.”

[10] In Kenya, KickStart responded to this issue by redesigning its MoneyMaker pump to be lower.

Figure 9. Illustration of treadle pumps

Source: IWMI Power Point.

However, a recent final program evaluation of the USAID-funded Smallholder Market Creation Project by Mudenda and Hichaambwa (2006) for IDE is more positive. Based largely on qualitative data, the authors suggest that overall the project has had a positive impact, not only in terms of promoting treadle pumps but more important, providing valuable training to farmers; helping them to establish output market linkages and gain access to credit, which in turn has resulted in higher incomes; and helping manufacturers. They report that even though women were not specifically targeted they have benefited substantially. As is reported for Malawi and Tanzania, treadle pumps have many uses: not only for irrigation, but also for other purposes such as domestic use, livestock watering, brick making, and even peri-urban car washes. Nevertheless, they also suggest that there are continuing weaknesses in terms of both the input supply market and farmers' ability to research and respond to output market opportunities. Among others, two other issues are raised that are generally important: the potential for depletion of local water resources especially in the dry season, which can lead to conflicts and crop failure; and recent large-scale imports of treadle pumps by the Zambian government which has undermined local manufacturing capacity.

Tanzania experience

In Tanzania, KickStart has successfully introduced its various "Money Maker" brand treadle pumps (SWMRG 2005; see also Van Koppen et al. 2005). After five years, and building on its experiences in Kenya, it has managed to achieve the following:

1. One manufacturer – Karam Engineering
2. Eight wholesalers

3. Forty nine retailers
4. 650 - Money Maker plus pumps sold
5. 10,216 - Super Money Maker Plus pumps sold
6. 461 - Money Maker hand pumps sold.

Our partner (SWMRG 2005) emphasizes the very high returns to treadle pump investments: for every dollar KickStart receives in outside support it generates over $19.00 in economic growth and higher food security. Net annual incomes in many cases increase ten-fold, from $120 to $1,200 through irrigation of highly profitable fruits and vegetables. Farmers are using their higher incomes to improve the well-being of their families. Regassa Namara in Van Koppen et al. (2005), using as a source an internal KickStart report dated 2003, reports household incomes in a sample of 64 households increased from $621 to $1,800 per treadle pump two years after adoption. Further, although KickStart had not specifically targeted poor farmers—and indeed expected early adopters to be better-off farmers— 80% of adopters had previously been living on less than a dollar a day. The very poor were able to adopt treadle pumps because of the rapid pay-back. KickStart's survey also showed that even though most pumps were initially sold to men (95%), over a period of a year women increasingly took over as pump managers.

On its website (www.kickstart.org/tech/pumps) as of April 2006, KickStart claims to have sold 45,000 pumps in East Africa (including a few in Mali), creating 29,000 new waged jobs and generating $37 million in new profits and wages. More than half these pumps are said to be managed by women entrepreneurs.

Malawi experience

Our Malawi partners have also assessed the results and impacts of treadle pumps very positively (Mloza-Banda 2006; Mangisoni 2006). Mangisoni (2006) reports on a systematic comparison of treadle pump adopters and non-adopters using a sample drawn in two districts of Malawi. The results are summarized in Box 2. They demonstrate a substantial impact in terms of improved incomes and food security, reduced poverty, and a higher level of resilience by adopters, i.e., they are far less likely to fall back into poverty. Overall, an equal number of adopters were male and female, but there was a significant difference between the more urbanized Blantyre District and the more rural and traditional Mchinji District: in the former, 83% of the adopters were women while in Mchinji only 21% were women. All members of the family in both districts participate in pumping, and the resistance among women for cultural reasons is said to be fading.

Treadle pumps: Conclusion

In many regions of SADC, except the arid zone and parts of the semi-arid zone (Figure 4), treadle pumps are a potentially high-return, high-impact micro-AWM intervention. More specifically, they are especially appropriate where there is a water source close to the surface (less than 7 meters) and close to the field to be irrigated (less than 200 meters), and they will be especially profitable when farmers have access to markets where they can sell high-value fruits and vegetables. They can be used for supplementary irrigation of maize during dry spells, though this is not commonly found as far as we are aware[11].

[11] Maize is irrigated off-season, for example in Malawi, to produce high-value "green mealies."

There is evidence that in many circumstances they can benefit very poor people and women, but this often depends on the local culture and social structure. Treadle pumps are also versatile—they can be used for many purposes where water needs to be lifted; they are not limited to irrigation. Table 5 provides a summary of their uses, necessary conditions for success, and advantages and disadvantages.

Box 2. Results of Treadle Pump Impact Assessment in Malawi

The Malawi Government has intensified the use of treadle pumps to increase agricultural production and enrich the livelihoods of resource-poor farmers. The treadle pump as a result is gaining popularity among smallholder farmers throughout the country. This study was conducted in two purposively selected districts of Blantyre in the Southern Region and Mchinji in the Central Region of Malawi. A total of 50 treadle pump and 50 non-treadle pump farmers (who use buckets to irrigate) were interviewed in each district to assess the impact of the treadle pump on food security and poverty. Secondary data sources, e.g., from organizations involved in treadle pump distribution and dissemination as well as major suppliers and manufacturers of treadle pumps, were also used to understand the level of adoption.

The results showed that maize, beans, tomatoes, onion and leaf vegetables are the key crops grown using treadle pumps. Economic analysis using gross margin analysis showed that treadle pump adopters had significantly higher Net Farm Incomes (NFI) as well as NFIs/ha for both irrigated and rainfed production than non-adopters. The treadle pump adopters also reported a number of material gains realized during the period of adoption such as food security, building good houses, payment of school fees and graduation from taking loans from neighbors. The adopters also created employment for fellow villagers and owned livestock, working tools and ox-carts for transportation.

Well-being measurements and analyses of poverty revealed serious poverty levels among non-adopters compared to adopters. The non-adopters also had a greater relative risk of falling into deeper poverty than adopters. Transition matrices depicting movement in and out of poverty showed that from 2004 to 2005, some poor adopters moved out of poverty while some non-adopters dropped from being non-poor to being poor. No adopter moved from non-poor to poor.

These analyses demonstrate that the treadle pump is a key to generation of income, reduction of poverty and maintenance of food security among smallholder farmers in Malawi. To fully realize this potential, some constraints to the dissemination of the treadle pump such as water shortage; relatively high treadle pump price and spare parts; lack of capital for manufacturing of the treadle pumps; and lack of well-organized markets, need to be resolved.
Source: Mangisoni (2006).

The successful programs to promote treadle pumps have paid considerable attention to the manufacture, sales, and after-sales service of treadle pumps, and to training farmers in their use. It is quite likely that the additional attention to helping farmers link effectively to output markets further enhances their positive economic impacts. Providing packages that combine treadle pumps with water-efficient application technologies such as low-cost drip systems can further enhance the returns, especially where either water is scarce, or labor shortage limits the capacity to pump.

Table 5. Summary of main features of treadle pumps

Uses	Lift water (5-7 m^3) Multiple purposes where water pump is needed Agriculture: supplementary irrigation, irrigate high value crops
Necessary conditions	Water source <7 m deep Water source close to where water will be used (<200 m) Availability of spare parts Output markets highly desirable to get full economic benefit
Advantages	Versatility—can be used for many purposes requiring a pump Low cost to purchase: affordable by many people Low cost to operate—no purchased fuel etc. Easy to maintain and maintenance requirements limited Less tiring to use than other manual technologies Less expensive to purchase and operate than motorized pumps Local manufacture is possible Portable—can be moved, kept at home Easy to share given portability Labor-saving over other manual ways to lift and carry water Increase labor productivity compared to other manual technologies (carrying buckets, etc.) High economic returns if output markets available Can be targeted to poor, women, etc. Can be linked to efficient water application technologies
Disadvantages	Cultural issues, e.g., discomfort of women, reported in some places Expensive in some countries Spare parts not easily available in some countries Potential to deplete small limited water resources Insufficient policy and institutional support

Finally, we suggest there are three "threats" to the longer term impacts and sustainability of treadle pumps:

1. Continuing weakness of the input market side: availability of reasonably priced pumps, availability of spare parts, and availability of finance for manufacturers to scale up;

2. The likelihood that as treadle pumps become more common, they will lead to depletion of limited localized water sources, especially during the dry season when they are most critical: small streams and shallow aquifers in *dambos* for example will be threatened. This means that promoters need to work with local watershed communities to develop an understanding of the potential and limitations of the resources, and establish rules for sharing and limiting over-pumping; and

3. Political decisions to import large numbers of pumps, often accompanied by distribution of “free” pumps, may undermine all efforts to build a local agri-business capacity.

However, on the last point there is a choice to be made. Most observers have argued in favor of the IDE and KickStart approach of building local input market capacity including local manufacturing. However, a plausible argument can be made that this approach is too slow; and a program of massive subsidized or free distribution could lead to very large immediate benefits (especially if it is well-targeted to the poor, and not politically targeted). It would also then create an immediate demand for services in terms of spare parts, repair, and training in their use; and if they are as important to people’s livelihoods as many observers believe, a longer term demand for manufacture and supply of replacement pumps. An evaluation of the outcomes of the distribution of ‘free’ pumps in Malawi and Zambia may provide interesting results.

Water-lifting technologies: Motorized pumps

None of our partners reported explicitly on this technology. However, we list it here because of the revolution low-cost motorized pumps have driven in many Asian countries (for example, see Kikuchi et al. 2003)[12]. Further, in our informal survey of agricultural water management specialists at the SARIA workshop in January 2006, representatives from three countries reported small power pumps are widely used (Botswana, South Africa, Lesotho); representatives from four countries rated small motorized pumps as promising for household food security, and representatives from six countries perceived them as promising for market production (Botswana, Lesotho, Malawi, Namibia, South Africa, Zambia) (Table 2). Low-cost motorized pumps have had a big impact in Asia, but in Africa there is far less experience except in West Africa, especially Nigeria (*fadama* projects; see Abubakar 2002; Van Koppen et al. 2005). Table 6 summarizes their uses, advantages and disadvantages. Impediments to their rapid uptake in SADC countries include:

- In most countries, they are either not available or are too expensive;
- Lack of scale means that the input supply market (spare parts, maintenance expertise) is weak;
- Relatively high fuel prices, and rural electrification is not wide spread; and
- Limited markets for high value produce.

For all these reasons, in most SADC countries it is likely there are currently limited opportunities for poor farmers to make profitable use of motorized pumps. This will change as demand for high-value crops increases over time. We suggest that further research is needed to understand the opportunities and constraints before venturing into this type of technology in the near future.

[12] The costs of pumps in Sri Lanka, in 2000 U.S. dollars, range from $180 for an electric 1.5 HP pump, to about $400 for a diesel 3.5 HP pump. Snell (2004) reports substantially higher prices in West Africa for Japanese-made pumps, but similar costs for Indian and Chinese pumps.

Low-cost water application technologies: Bucket and drum drip kits[13]

Drip irrigation enables the farmer to make use of limited amounts of water and fertilizer which can be applied together with the irrigation water to grow high value crops. Drip irrigation allows precise application of small amounts of water directly to the root zone.

Table 6. Summary of main features of motorized pumps

Uses	Lift water Multiple purposes where water pump is needed Irrigation
Necessary conditions	Water source within reach of pump capacity (which varies) Reliable supply of fuel or electric power Reliable supply of spare parts Availability of skilled repair services Output markets for high-value produce essential to get full value
Advantages	Versatility—can be used for many purposes requiring a pump Higher capacity than treadle pumps or other manual pumps—can irrigate larger areas for example Many models are portable—can be moved, kept at home Easy to share given portability Labor saving; increases productivity of labor and land Can be targeted to poor, women, etc. in principle Can be linked to efficient water application technologies
Disadvantages	In most countries they are either not available or too expensive Spare parts not easily and reliably available Repair expertise not easily available High cost of fuel Limited markets for the scale of high value crops needed to obtain good returns High costs make it difficult for poor farmers to adopt in most SADC countries Weak policy and institutional support

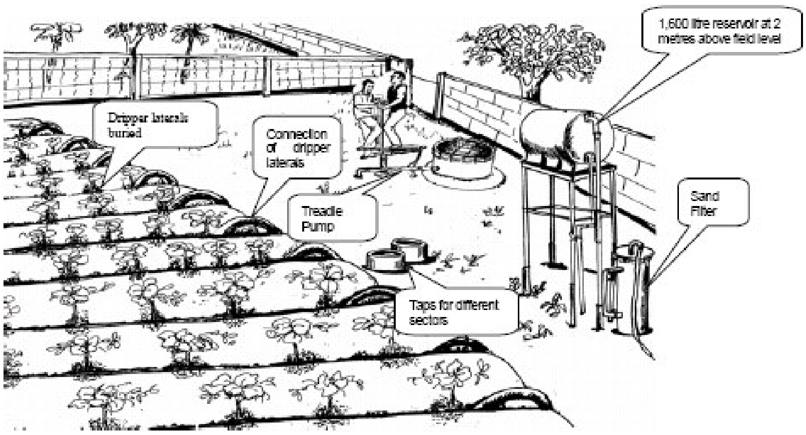
In terms of Figure 3 on water partitioning, it reduces losses from evaporation, weeds, runoff and percolation. Drip irrigation is popularly viewed as one of the most water efficient types of irrigation, but Laker (2006) warns that in large areas in SADC the soils are not suitable for drip irrigation, notably course sands and severely crusting soils. Conventional drip irrigation systems typically cost US$ 5,000–10,000 per hectare or more installed, in East and Southern Africa. There are cases of successful adoption in South Africa, Lesotho, Swaziland, and elsewhere by commercial farmers (see, e.g., IWSD 2006b; 2006c).

Recent advances have introduced some adaptations that make them accessible to small-scale farmers. Simple drip irrigation systems are now available which would cost a

[13] Adapted from de Lange (2006a).

farmer US$ 15 to cover 15 m^2, or US$ 200–400 for a bigger system covering 500 m^2 (Sijali, 2001; Sijali and Okumu 2002, 2003). It is these low-cost bucket and drum drip kits, aimed at poor farmers, which are the subject of this discussion. The reader is referred to Sijali's excellent handbook (2001), with diagrams of layouts and functions of virtually every type of bucket and drum drip kits available in Eastern and Southern Africa. Figure 10 illustrates a drum and drip kit linked to a treadle pump. Ngigi et al. (2005) report high returns in an arid part of Kenya by combining RWH into farm ponds with bucket or drum drip irrigation kits.

Figure 10. Layout of small-scale drum and drip irrigation system



Source: van Leeuwen (2002: figure 1).

Tanzania

In Tanzania drip irrigation has been promoted since 2003. The importation, promotion, selling, and distribution are done by a private company, Balton Tanzania Ltd with its office in Arusha. The promotion is done through different mechanisms, including agricultural shows, TV, radio, and newspapers. The system and components are imported from Israel and Germany. Balton (T) Ltd assists farmers purchasing the system with installation. Since the promotion of the technology started in 2003, more than fifteen farmers have installed the system, in Arusha, Kilimanjaro, Manyara, Coastal and Ruvuma regions on the mainland. The farmers have installed different family drip systems covering from 500 m^2 to 2000 m^2 (SWMRG 2005).

The families that have installed the drip system can be regarded as relatively rich families because the systems are expensive for a poor farmer. For example a system covering 500 m^2 costs Tshs 292,000.00 (US$ 265). However it needs minimal labor and maintenance, mainly replacement of filters. Despite its cost, it seems to be gaining popularity because of its low water use and minimal labor requirements: farmers buying the system are located near town and city centers where labor is expensive, and ground water abstraction is becoming popular. The cost-benefit analysis for the drip irrigation system shows that a farmer can earn about the same amount of income with just a treadle pump, as she can by combining a treadle pump and drip system from an acre (0.4 ha) of onions. However, given the small amount of water used, its convenience of operation, and the minimal labor required, the drip system remains attractive.

Lesotho

The drip kits in Lesotho are supplied for 10 m x 10 m or 20 m x 20 m plots. The kits are low-cost and easy to assemble and operate. Water is supplied from a tank connected to a roof catchment and placed with its bottom at least a meter above ground to provide sufficient elevation head to drive the drip system. The homeowner's roof is used to capture rainfall and direct it to the irrigation tank through gutters (IWSD 2006c).

Zambia

In Zambia, the drip kit is viewed as a simple system operating on the same principle as the clay pot drip system, discussed below. The bucket, a low volume (5 liters – 10 liters) reservoir as compared to the drum (200 liters), is installed at an elevation of 2 m – 3 m above ground to provide a low pressure head -- enough to operate micro-tube drippers installed on the laterals that are connected to the main line from the reservoir. Water is pumped from the source to the reservoir by using a treadle pump. The micro-tubes emit water drop by drop on the soil surrounding the irrigated crops and thus wet the root zone. Water is taken up by the plant and relatively little evaporates due to heat and wind. Fertilizer is supplied along with the irrigation water from the reservoir (Daka 2006).

This system optimizes yields per unit volume of water and land. Yield increases of up to threefold have been registered in pilot trials by IDE and the Ministry of Agriculture and co-operatives. However, in Zambia to date, only about 10 ha of land are irrigated by this system countrywide; the SIWUP Project Completion Report (SIWUP no date) also states this technology has not been adapted at any scale. The major drawback to accelerated uptake is lack of manufacturing capacity in the country leading to sporadic supply of drip kits by IDE. World Vision once supplied some bucket kits as a one-off program to its recipients. The system greatly reduces the labor of irrigating and weeding the crops. This is seen as important to the disadvantaged vulnerable populations that are aged, disabled and weak from HIV/AIDS pandemic.

Zimbabwe

Low cost drip kits have been provided through various initiatives in Zimbabwe. The kits range in size from small gardens of 10 m x 10 m and 30 m x 30 m to small plots of up to 4,000 m^2. They are also viewed as low-cost and easy to assemble and manage. They do not need high quality water, provided the water is filtered. The water source for the drip kits has been groundwater, particularly family wells and boreholes. The drip system requires water of low turbidity to avoid blockages and needs a small head for flow. For these reasons, coupled with the costs incurred in treating surface water and the energy to raise the head, surface water has been excluded in the promotion of the drip kits.

A 20 liter bucket with 30 meters of hose or drip tape connected to the bottom is placed at least 1 meter above the ground so that gravity provides sufficient water pressure to ensure even watering of the entire crop. Water is poured into the bucket twice daily and passes through a filter, fills the drip tape and is evenly distributed to 100 watering points. The multi-chambered plastic drip tape is engineered to dispense water through openings spaced at 30cm (12 inches). Two bucket kits costing around $ 20 will produce enough vegetables for a family of seven and can last over five years. The system is most suited to kitchen gardens. As well as the bucket, a grower needs several strong poles to make a support structure, and tools, manure, water and vegetable seedlings. The poles are used to make a support structure (IWSD 2006d).

IWSD (2006d) notes most drip kits are imported from Israel, but an Indian and locally manufactured model are also available. A technical evaluation rated the Israeli model highest, but also recommended the locally manufactured one—however the local company is not able to meet the demand. Generally they have been imported by NGOs and distributed in the drier regions of the country; IWSD (2006d) however notes the role of the rural and urban poor clients has been "passive."

A technical comparison of the performance of low-cost drip irrigation compared to conventional surface irrigation of English giant rape (*Brassica napus*) showed that while drip irrigation did achieve water saving of over 50%, there were no yield difference, and no labor advantage as farmers were manually filling the drip drums (a problem that can be addressed by combining drum and drip kits with treadle pumps). Further, since the water pricing policy was in terms of area irrigated not water consumption, the water savings brought no direct benefit to the farmers (Maisiri et al. 2005). Moyo et al. (2005) assess drip kit programs implemented by several NGOs and also concluded they are under-performing because a number of pre-conditions were not met. These included: reliable access to a water source; and poor monitoring and support because the programs are implemented as relief not development programs. The authors make a number of recommendations, reproduced in Box 3. ITC et al. (2003) evaluated bucket and drum drip irrigation kits in a study that included eastern and western India as well as Zimbabwe, and concluded that in the present macro-economic conditions in Zimbabwe, farmers' benefits tend to be minimal while costs are beyond their means.

Bucket and drum drip kits: Conclusions

While there are numerous individual farmers in Africa who have benefited from low-cost bucket and drum drip kits, we have found no evidence of successful implementation on a larger scale. This is in contrast to South Asia, where there has been considerable success, both in terms of market-driven systems aimed at relatively better-off farmers, and in terms of targeting poor farmers. ITC et al. (2003) concluded these kits do not have much impact on the livelihoods of poorer farmers, but our conclusion is the technology is potentially beneficial and profitable to poor small farmers but only under certain conditions, most of which are specified in Box 3 (see also Table 7). These include:

1. Dry area or growing season when there is a high premium on maximizing productivity of water; they are not likely to be attractive in relatively wet areas.
2. A reliable water source close to the garden to be irrigated.
3. Soils are suitable for drip irrigation or are sufficiently ameliorated to ensure their suitability.
4. Effective program for promotion (social marketing), training, technical support, provision of spare parts, and targeting to people who can really benefit.

Box 3. Protocol for drip irrigation kit distribution programs

For the program to be sustainable, it is important that the NGOs take on board relevant government organs from the inception of the program to the end so that by the time the NGOs conclude their work the program can be handed over to such government institutions.

1.Distance of water source

Objective: Ensure that the drip kit garden is close to the water source

Drip kit garden should be within 50m of the water source or

Provide wheelbarrow or simple water cart [or a treadle pump!] to assist with transport of water for distances up to 250 m

2.Reliability of water source

Objective: Ensure that the beneficiaries have a reliable water source

Before a kit is given, the NGOs in collaboration with relevant Government Departments should make an effort to determine the reliability of the potential water sources.

The potential water sources should be able to supply water for the kit all year round[14].

3.Follow up visits

Objective: Ensure that the beneficiaries get prompt technical advisory service on the use of kit.

During the year of inception the NGO should make high frequency follow-up visits to beneficiaries, i.e., at least once every two weeks for the first crop, and then monthly.

During the second year follow-up visits should be made once every cropping season and then once every year thereafter.

4.Training

Objective: Adequate training of beneficiaries

The NGO in collaboration with Government Extension Services should undertake the training.

Training should be done in the following areas: Installation, repair and maintenance of drip kit

NB. Training on maintenance of the kit should take cognisance of quality of water available for the drip kit in different areas.

Cropping techniques including the cropping calendar and irrigation scheduling.

Pest control using cheaper traditional methods [or integrated pest management].

As a way of motivating the beneficiaries, field days and exchange visits by beneficiaries especially during the inception year.

5. Targeting

Objective: Beneficiaries are people who are able to work in their respective gardens

NGO should ensure that the beneficiaries are able bodied persons[15] who can work in their gardens

Provide water containers relevant to size and age of beneficiary – it is hard to lift a 20 litre bucket [again, a treadle pump can address this problem].

6.Spares

Objective: Beneficiaries are able to carry out repair work in time on their kit without compromising their crop production

NGO should identify a local trader willing to stock the necessary spares, so that the beneficiaries can purchase them when needed.

Source: Box 1 in Moyo et al. 2005 [with some editing]

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[14] A 30 m^3 cistern can do this for a 100 m^2 garden in a 450 mm rainfall area (Marna de Lange, personal communication).

5. They must save labor, especially small kits for poor families whose labor supply is a constraint.
6. Robust but simple technology, which is affordable and easy to maintain and operate.
7. Access to output markets for higher value fruits and vegetables.

Table 7. Summary of main features of bucket and drum drip irrigation kits

Uses	Precise application of irrigation water to plant root zones
Necessary conditions	Dry area or growing season, and relatively small amount of water available; perception of water scarcity Reliable source of clean water in close proximity Soils suitable for drip irrigation (for example not too coarsely sandy) Access to good output markets increases the returns [but can be used for own-use vegetables] Effective program for promotion and support: good technical and agronomic advice, training, spare parts Donor/NGO support over time to establish sustainable program (5 years or so)
Advantages	Raises productivity of water, land and labor; reduces loss of water In principle very low cost, robust and simple Some versions – fertilizer can be combined with irrigation water Can be targeted to poor, women, disabled people Available in different sizes, from 10 m^2 up, so can be adapted to land and water Higher yields, better quality crop, shorter maturity which should translate to higher profits
Disadvantages	Currently no effective examples of programs targeted to poor farmers in SADC Insufficient local manufacturing capacity Poor support—tend to be distributed for emergency relief which shows poor sustainability Dirty water can cause clogging Inadequate institutional support

Direct application hoses

Among our partners, only the partner working on Lesotho recommends this technology (IWSD 2006b). The system described is found in only one scheme, and is a specific one in which water flows under pressure only when the hose is attached to a riser in the field. However, in our informal SARIA survey (Table 2), this technology is recommended by representatives from five countries as currently widely used, and suitable for both improving food security and market production. We suspect these specialists were really referring to flexible hoses. Hoses can be attached to a treadle or motorized pump, or indeed a gravity system with sufficient pressure, and used to direct water onto plants. It

[15] "Able bodied" should not be taken as overly restrictive; since in principle these are labor-saving devices, it means people with handicaps should be able to use them.

is a relatively low cost method and easy-to-use method for applying water, generally in conjunction with a pump.

Clay pot (sub-surface irrigation, also called 'pitcher' irrigation)

> "The buried clay pot or pitcher method is one of the most efficient traditional systems of irrigation known and is well suited for small farmers in many areas of the world" (Qassam 2003).

This is a low-cost indigenous sub-surface drip system achieved by use of unglazed fired clay pots that remain micro-porous and are molded by hand by rural women. There also exist molding machines that can mass produce clay pots with specifications of porosity and firing temperature to eliminate possibility of shrinking and swelling of clay which may lead to cracking. The clay pots are buried in the ground with their necks appearing above ground in a row at specific plant intervals. Plants are placed adjacent to the pot on either side and the pots filled with water and covered with a clay lid to avoid direct evaporation of water and rodents drinking the water.

In our study, only Daka (2006) discusses clay pots for Zambia. He suggests this is a very suitable crop for poor rural women as they make the pots for sale (income generation), and because it is less labor intensive than most alternatives, it has high labor returns and suits people disadvantaged by physical handicaps or HIV/AIDS. Water as well as fertilizer productivity is also very high. Clay pots have a lot of potential for backyard vegetable and flower production even in urban areas. The cost is about $1.00 per pot. In a wet period, they can also be used for drainage by emptying the pots as water infiltrates back in from saturated soil. Daka says a business person is planning to mass produce them.

According to RELMA[16] (Sijali 2001), this is a method of irrigation in which water is stored in clay pots buried in the ground, from where it is slowly released to the plants. This method is particularly good for fruit trees, but also used for vegetable crops in homestead gardens. Such use of soil-embedded porous jars is one of the oldest continuous irrigation methods that probably originated in the Far East and North Africa. The method consists of:

- Clay pots that are placed in shallow pits dug for this purpose;
- Soil is then packed around the neck of the pots so that the necks protrude a few centimeters above the ground surface;
- Water is poured into the pots, either by hand or by means of a flexible hose connected to a water source.

Using the principle of moisture potential, water oozes out of the pot from its high water potential to wet the surrounding soil outside the pot where the soil water potential is low (Figure 11). The water is instantaneously taken up by the crop from its root zone around the clay pot. It has been well established that irrigation intervals between 7 -14 days and water saving between 50% and 70% are achievable, resulting in yield increases between

[16] Regional Land Management Unit, now part of the World Agroforestry Center in Kenya; www.relma.org. The RELMA website has good water and land management guidelines and handbooks.

30% and 45% over conventional flood furrow and basin irrigation systems. This indicates a high potential for labor saving while irrigating. Crops that prosper under this system include tomatoes, rape leaf vegetable, cauliflower, maize and beans which yielded 42, 33, 22, 13 and 5 tons/ha respectively under clay pot system as compared to 40, 27, 16, 9.3 and 4.7 tons/ha under conventional irrigation systems. This was achieved at far higher water productivity than conventional irrigation.

The clay pots have been made at village level and used for storage of seeds, as flower pots and as water storage containers for households. Water stored in clay pots becomes cooler than room temperature, thus simulating a refrigeration system, because some water that oozes out is evaporated from the clay pot surface by heat. The pots are made of locally available clay with optimum properties of strength (to resist crushing), permeability (to exude water into the soil at an approximately steady rate), and size (to hold enough water for at least one day's supply). The potential of clay-pot irrigation has not been fully exploited by farmers in the eastern and southern Africa region, even though the technology is suitable for small-scale farmers. There have not been many reports of previous experience in the region (Sijali 2001).

The value of the clay pot or pitcher irrigation is confirmed by several authors from across the globe. Bainbridge (2002) explains the advantages as follows:

> There are numerous advantages to using buried clay pot irrigation. First, pots are not as sensitive to clogging as drip emitters, although they may clog over time (after 3-4 seasons) and require renewal by reheating the pots. Second, the system does not require a pressurized water system, which is difficult to establish and maintain at remote sites. Third, animals are less likely to damage or clog buried pots than aboveground drip systems. Fourth, by selecting lids that collect rainfall, any precipitation that does fall can be conserved and used. Finally, buried pots are more robust than drip systems because they do not rely on continuous supplies of power or water to operate.

Stein (1990) developed design criteria for clay pot or pitcher irrigation. Table 8 gives a cost comparison of various alternative irrigation methods for very dry and remote conditions (from Bainbridge, 2002), while Table 9 summarizes the necessary conditions, advantages and disadvantages of clay pot irrigation.

We conclude that clay pot irrigation is a cost effective and easy-to-implement alternative to bucket and drip irrigation kits. The pots can be manufactured locally and therefore create employment for poor people (often women), and can be used by poor women and men to irrigation vegetables and fruit trees cost effectively. They are appropriate wherever water is scarce, or where obtaining water is expensive, putting a premium on water conservation.

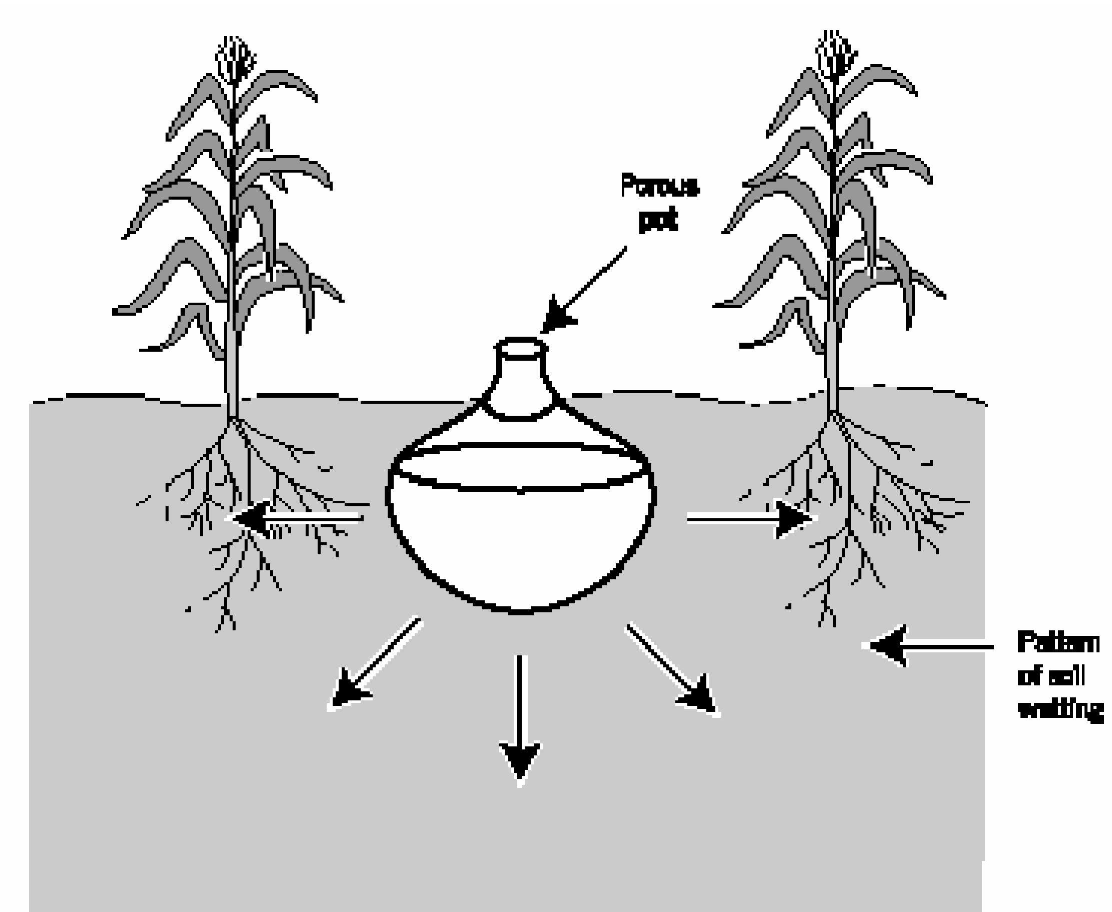
Table 8. Estimated costs for a remote site, one growing season (800 plants)

Irrigation Method	Materials and Labor	Water Demand	Survival
Porous hose	$3	low	high
Deep pipe	$3.25	low	high
Clay pot, lid	$4.50	moderate	high
Porous capsule*	$6	low	high
Perforated drain pipe	$3	moderate	moderate
Microcatchment	$15	moderate	moderate
Drip**	$2.50	moderate	moderate
Wick	$3	very low	moderate
Basin	$3	high	very low

*requires water tank, gravity pressure
**requires water tank, filters, pressure (tower or pump), risky without regular maintenance

Source: Bainbridge 2002.

Figure 11. The pattern of soil wetting around a porous clay pot



Source: Sijali 2001.

In-situ soil and water conservation technologies

Water and soil nutrient management are critical to successful agriculture. Soil nutrients are being mined in much of SSA, leading to declining yields; but with the high cost and sometimes non-availability of fertilizers, SSA has the lowest per ha use of fertilizer in the world (see de Lange 2006a). Yet there are a large number of both indigenous and introduced technologies and practices that can help maintain and enhance soil nutrients. Soil and water conservation (SWC) refers to activities that reduce water and nutrient losses and maximize their availability in the root zone of crops: rainwater and therefore nutrients are conserved where it falls, *in-situ*. This distinguishes SWC from rainwater

Table 9. Summary of main features of clay pot (pitcher) irrigation

Uses	Precise application of water to plant root zone
Necessary conditions	Dry area or growing season and relatively small amounts of water available Local availability of clay (or at least not too distant from place of manufacture)
Advantages	Very high productivity of water, land and labor; reduces water losses Low cost—can be used for kitchen gardens or production for the market Less sensitive to clogging than drip irrigation kits (minimal maintenance required) Less vulnerable to damage from animals than drip irrigation kits No pressurized water is needed Therefore, cost effective and easy-to-implement alternative to bucket and drum drip irrigation kits Especially good for fruit trees, vegetables and flowers Often can be made locally Pots can be used for storing seeds, cool drinking water In a wet period can be used for drainage by emptying pots
Disadvantages	Not much experience with this technology in SADC region Not easily available at the moment—effort is required Clay may not be easily available locally

harvesting (RWH), which seeks to transfer run-off water from a "catchment" to the desired field or a storage structure (Mati 2006). SWC therefore includes techniques like terracing, ditches, stone and vegetative bunds, mulching, conservation tillage and more broadly "conservation agriculture." RWH includes a range of micro-catchment systems, earthen bunds and other structures to capture and store run-off from elsewhere (hence, *ex-situ*) for use when needed. As Mati (2006) notes, the line between SWC and RWH technologies is very thin—indeed some of the examples in her section on RWH are really *in-situ* techniques such as pits. There is a very wide range of both SWC and RWH technologies in use around Africa; what specific techniques or combination of techniques is appropriate depends on local climate, soil, social and economic and other factors. The reader is referred to Mati (2006) and Ngigi (2003) for a detailed description of those technologies most commonly used in Eastern Africa (Ethiopia, Kenya, Tanzania, Uganda). Many are also applicable in specific Southern African circumstances (Beukes et al., eds. 2003). In this section we provide a more detailed discussion of techniques that come under the heading of "conservation agriculture."

Conservation agriculture[17]

FAO has proposed the term "Conservation Agriculture" to replace the widespread use of "conservation tillage" to describe farmer's adoption of new tillage/seeding systems (Clayton et al. 2004). The FAO rationale is that agricultural production technologies geared towards resource conservation involve more than tillage as seems to be implied by the use of "conservation tillage." FAO suggests defining conservation agriculture as:

> "Involving a process to maximize ground cover by retention of crop residues and to reduce tillage to the absolute minimum while exploiting the use of proper crop rotations and rational application of inputs (fertilizers and pesticides) to achieve a sustainable and profitable production strategy for a defined production system."

In practical terms, examples of conservation agriculture techniques include the following (Steiner 2002, reproduced in de Lange 2006a; see also Mati 2006 and Beukes et al., eds. 2003 for specific descriptions):

- Ripping only the planting line using a tractor or animal-drawn 'rippertine', rather than normal plowing;
- Tied ridges, for holding water and facilitating infiltration in low rainfall areas (there are a variety of types of ridges;
- Mulching using both crop residue and material from non-cultivated areas, for holding water, returning nutrients to the soil, and in some cases reducing the temperature of the soils;
- Assuming hand-hoe farming: a variety of techniques referred to as pot holing, pitting, trenching (ridges and furrows);
- Where erosion control is important, various techniques such as contour ridges, storm drains, grass strips, etc. and
- Agroforestry and green manure or cover crops, many of which contribute to nitrogen fixation.

According to the African Conservation Tillage Network (ACT, www.act.org/zw), the rapid spread of conservation agriculture in Latin America was mainly because this production system reduces production costs significantly. But even though African farmers face a similar scenario to their Latin American counterparts in terms of rising costs and diminishing returns, conservation agriculture has not developed as rapidly as its proponents wish. There are many reasons: low soil fertility combined with unreliable rainfall make agriculture risky and limited access to markets make it unprofitable; and traditional communal land tenure systems which limit land use rights to the growing season discourage investment in for example green manure or cover crops. Further, the very diversity of agricultural environments and economic conditions make selection of appropriate mixes of cost effective and appropriate technologies rather difficult. The situation is compounded by the lack of clear policy and institutional support. Although in

[17] This section is adapted from de Lange (2006a).

the long run conservation agriculture is expected to save labor, during the transitional stage, i.e., the first 1-5 years, labor costs are often higher. Conservation agriculture is a long-term investment in improved soil fertility and water holding capacity, but initially the returns compared to the costs may discourage many small farmers.

Our partners described conservation agriculture practices in Botswana, Malawi, Namibia, Tanzania and Zambia. Permanent strip farming is practiced in Gaborone, Botswana at Sanitas Farm. Very promising yields are achieved at very low plant populations (up to 5t/ha at 10,000 plants/ha). This is ascribed to deep ripping in permanent strips, adequate oxygen to the roots and water harvesting by permanent profiling of the fallow strips between the Permanent Strips or ripped planting areas (de Lange 2006b).

In Malawi, these practices include contour ridging, minimum tillage and planting pits (Mloza-Banda 2006). Remaking ridges every season on the contour is a conventional land preparation practice in Malawi; plant residues are covered, removed, or burnt and growth of all vegetation is prevented, except for the desired crop. Elsewhere, this has been termed clean tillage. The effect of this tillage systems on crop yield is not uniform with all crop species, in the same manner as various soils may react differently to the same tillage practice. Invariably however, it is argued that, over time, the practice of ridge tillage, which moves soil from the old ridge to the furrow and back, seasonally, may have led to the development of a soil pan that effectively prevents infiltration and encourages runoff.

Various modifications of surface land configuration have been attempted for rainwater management in different rainfall regions of the country. These include *chololo* pits and tied ridges (see Mati 2006 for descriptions). The aim has been to increase storage of water in the soil profile and to increase runoff collection, storage, and use to offset water deficit periods. Ridges are constructed across the slope to contain surface runoff and control excess runoff rates at non-erosive velocities. It is this impact that ridges achieve, for which their continued use is advocated in Malawi where most of the country lies on moderate to steep slopes.

Research has shown that contour farming alone can reduce erosion by as much as 50% on moderate slopes. However, on slopes steeper than 10%, other measures should be combined with contour farming to enhance its effectiveness. In some agroecological areas, soils are predominantly clay having very low infiltration rates. In such cases the depth of water infiltration is very small and water may remain (ponding) at the soil surface or in the upper layer of the sol profile if ridges are tied or pits are made.

In Tanzania, conservation agriculture, i.e., minimum or no tillage, is seen as ultimately labor-saving while improving household food security and incomes. It makes use of tools and implements such as the jab planter and the animal drawn ripper or no-tillage planter, in combination with agronomic practices that have the potential to suppress weeds through soil cover and introduction of cover crops form a set of possibilities (SWMRG 2005). HIV/AIDS and other diseases such as malaria as well as urban migration and education are reducing the labor availability in rural households and increasing the burden of labor-intensive activities on women and children. Minimum tillage reduces labor requirements especially in peak seasons for land preparation and weeding, and potentially contributes to household food security by making more efficient use of rainwater and increasing soil fertility through the introduction of nitrogen fixing cover crops. Minimum tillage reduces expenditure on hiring farm power services and purchase of fertilizers, whilst generating additional revenue through the production of fodder and cash cover crops, and reduces production costs by reduced use of expensive fuel. Results from on-farm trials show minimum tillage combined with cover crops leads to maize yields of 4.7-5.5 tons/ha, five times the yield with conventional tilling; and the labor requirements is reduced from 67 days to 37 by the fourth year (SWMRG 2005).

The Golden Valley Agricultural Research Trust (GART) in Zambia and RELMA, among others have been promoting ripper-based conservation tillage (Samazaka et al. 2003). The Magoye ripper is an animal-drawn one developed and promoted in Zambia. Samazaka et al. (2003) report overall positive but not spectacular results: while there is a saving on land preparation costs (and spreading of the labor because ripping can be done during the off season) it did not necessarily lead to higher yields except for deep-rooted crops like cotton. Weed control costs apparently increased however, and availability of the technology remains a problem (viewed by the authors as a market opportunity).

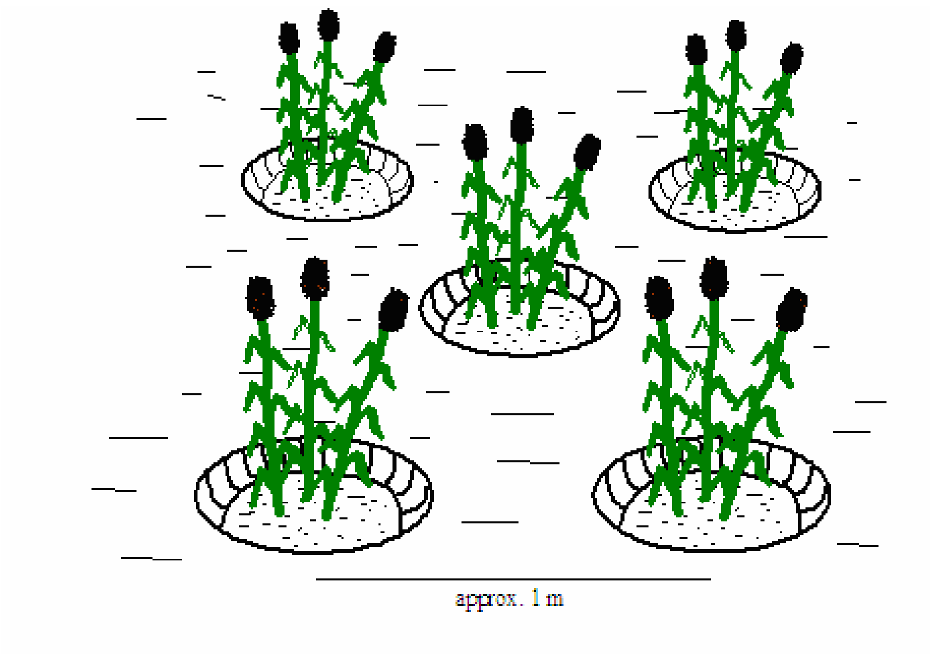
Daka (2006) says that in Zambia micro-basins prepared by hand hoes to capture and store rainfall lead to a doubling of maize yields to 3 tons/ha. This performance has led to accelerated adoption such that small farmers cultivating an estimated 200,000 ha of rainfed land have adopted such conservation technologies. Micro-basin sizes are about 35 cm X 15 cm X 15 cm, and are illustrated in his report. They have the additional advantage of allowing precision planting and fertilizer applications. Haggblade and Tembo (2003) view precision and timeliness as a requirement for successful use of conservation agriculture methods. They report that Zambian cotton farmers, who are used to the strict regimes associated with cotton cultivation, have fared best at successfully adopting conservation agriculture. Mulching between planting rows reduces soil moisture loss and suppresses weeds as well as adding organic matter to the soil[18].

In Namibia, the Agronomic Board promotes conservation tillage, especially in the form of planting pits dug with a hoe (de Lange 2006c); the main cost to the farmer is her own labor in the first year, but the Board claims this work can be spread over a long time period in small steps, and the work load diminishes in subsequent years through fewer weeds and higher yields. The principle of ‘manageable increments’ is also advocated by the Water for Food Movement in Lesotho and South Africa, which facilitates households to develop ‘five-year food security plans’ whereby the household prepares its homestead yard over time with multiple permanent planting trenches 1-5 m^2 in size for highly intensive food production. These trenches are laid out to channel run-off for absorption into the 0.6-1.0 m deep organic planting beds.

[18] Marques (2006), our Mozambique partner, uses the term “micro-basins” for plots ranging in size from 100-250 m^2 for growing rice. Small earthen bunds are rebuilt every year to capture and hold rain water. This practice is found in other SADC countries as well, in flat areas with heavy clay soils and 1,000 mm or more of rainfall annually.

The Namibian and Zambian examples are forms of what Mati calls "pitting systems" (Mati 2006: section 3.3), which capture and store rainwater and build up soil fertility. In East Africa such systems are usually used for special crops like banana and fruit trees; their use for maize as in Zambia and Namibia is considered novel. She describes and illustrates a variety of types of pits: *zai* (adapted from West Africa), *chololo*; "five by nine;" as well as a variety of "basins:" T-basins, V-basins and root zone basins. An example, *zai* pits, is illustrated in Figure 12.

Figure 12. *Zai* pits for water harvesting and conservation



Source: Mati 2006: Figure 3.6.

Conclusions

It is clear there is a rather large menu of technologies and practices, and these can be packaged to create synergies among them and to adapt them to specific contexts. For example, combining various types of reduced tillage systems or pits with mulch, and combining contour ridges or basins with mulch seems to provide very positive results (see Botha et al. 2003 on the positive interactions of mulching with such land management systems). Several researchers emphasize the critical importance of *combining* water and soil nutrient management (Twomlow and O'Neill 2003; Stroosnijder 2003)—indeed water conservation without combining with nutrient management often leads to no positive impact. This also suggests the importance of paying attention to agronomy and soils as well as water technology and markets.

Helping poor farmers to improve their productivity and profitability requires participatory approaches, emphasizing capacity building in terms of both providing new information to farmers, but no less important, promoting innovation by farmers (Twomlow and O'Neill 2003; Mati and de Lange 2003). Because of the complexity and diversity of most African farming systems, there is no monolithic package of technologies that can be replicated *en masse*. Rather, farmers must be encouraged, assisted and sometimes supported to try new ideas (often new to them, but actually already used by others) and combinations in order to find the optimum mix given their conditions. Table 10 summarizes the advantages and disadvantages of conservation agriculture.

Table 10. Summary of main features of 'conservation agriculture'*

Uses	Improving soil fertility Improving water retention in the root zone
Necessary conditions	Match the right package of practices to the land, soils, climate, and water regime Combining appropriate practices is critical
Advantages	Many practices reduce labor costs in the long run (less weeding, less land preparation) Reduced need to purchase fertilizer in the long run (cost-reducing) Increase and stabilized yields as a result of higher fertility, less erosion and better water management Some practices, such as planting pits, can be implemented incrementally over time
Disadvantages	Many practices are high-cost to implement in the initial stages Returns may be low in initial years Some practices require special tools to implement Lack of institutional and policy support

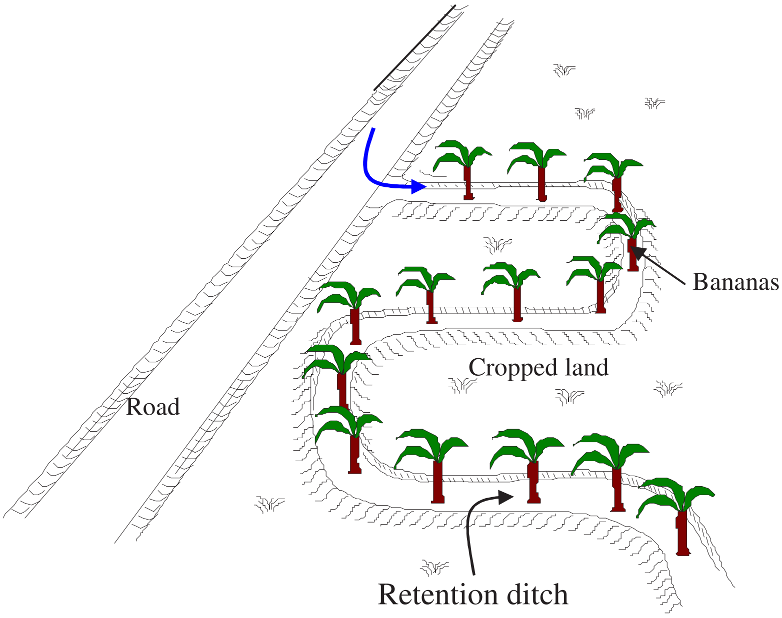
* Note: 'Conservation agriculture' includes a very wide range of practices and technologies, so this is a very general overview. In general, the defining feature is that *both* water and soil or nutrient management in integrated; but given the diversity of farming systems, creativity and innovation is important for long term success.

Ex-situ water harvesting and storage

Mati (2006: sections 3.1, 3.4) describes a variety of technologies for harvesting rainwater from roads, foot-paths and household compounds; she notes these are easily replicable but not commonly used in Eastern and Southern Africa outside Tanzania. Separately, she describes a number of technologies for storing harvested water (Mati 2006: section 3.7). Many of these water run-off harvesting systems have been developed by farmers themselves, for example those capturing "sheet and rill" runoff generated by compacted surfaces like roads, paths and household compounds. Water is harvested and directed either directly onto cropped fields, or into various types of natural or man-made storage structures. An example of a method of road runoff harvesting developed by a Kenyan farmer that is now used as a textbook design is provided in Figure 13. Water is diverted into a channel that zigzags through the farm across the predominant slope, carrying water to crops.

In this section we provide examples of small storage dams, shallow wells and boreholes, roof top water harvesting, and above- and below-ground storage tanks.

Figure 13. Road runoff harvesting into a channel for crop production



Source: Mati (2006: Figure 3.9).

Small storage dams

A large variety of storage technologies are used in Eastern and Southern Africa. Our partners reported with varying degrees of detail on such technologies from Botswana, Malawi, Namibia, Tanzania, Zambia, and Zimbabwe. Many are described and illustrated in Mati (2006) and Ngigi (2003). In Zambia and Zimbabwe (among others), NGOs like CARE have also promoted small dams that are to be managed by communities, with mixed results (SIWUP PCR no date; CARE small dams 2003; CARE et al. 2004). We discuss here a few types that require minimal engineering and are potentially important in the SADC region.

Mati (2006: section 3.7.5) describes *charco* dams as small excavated pits or ponds constructed in relatively flat topography, and requiring minimal engineering. They are generally about 3 m in depth, and take advantage of areas where water collects naturally. They are used for multiple purposes including livestock water and to supply domestic water to villages and small towns. The technology can serve up to 500 households or 4,000 livestock units in semi-arid areas (SWMRG 2005). The technology is being promoted by the government for improved livestock production. The government consulting agency (Drilling and Dam Construction Agency) or private consultancy firms design and supervise the construction of the *charco* dams, depending on whether the project is funded directly by the central government or local governments. But in some instances where communities get assistance from external donors (government agents or NGO), private consulting firms design and supervise the construction as directed by the financiers. Generally where the dam construction is for a village community, the community contributes about 20 % of the capital cost plus other labor inputs which may be needed during the survey and planning phases. Because of the high capital costs (20 - 50 million Tanzania shillings, US$18,000-45,500), *charco* dams are generally community property or properties of estate farms (e.g., sugar plantations and modern large livestock ranches).

Local communities are responsible for the management of village dams. For the dams to be successful, the village communities must participate in the planning and construction of the dams and accept responsibility for their operation and management. Normally the village governments form dam management committees with operation and maintenance responsibilities for the dams. Additionally, the committees are expected to come up with by-laws and measures that are acceptable and implementable by the local communities within the catchment areas of the dams.

In Botswana, the government provides assistance to improve existing small animal watering ponds by excavating them to increase their capacity, fencing them to protect them from contamination and collapse, and installing a hand pump and watering trough. However, de Lange (2006b) reports that farmers cut the fence to allow their animals direct access to the ponds, as the daily labor requirement to pump for the animals is high. The government has also constructed about 120 small dams (average 160,000 m^3) since 1989, for both livestock and irrigation. For participation in these dams, farmers must tender in writing to use them, and prospective users' plans for their use are rigorously assessed (de Lange 2006b).

Hand dug shallow wells

Our partners in Botswana, Namibia, and Malawi reported on hand-dug shallow wells. In Botswana, traditional wood-lined wells with wooden windlasses, are improved through installation of concrete rings, backfilling to ground level on the outside of the rings and installation of a hand pump on the improved well. During installation of the improved well, the original vertical wooden supports for the old windlass are left intact. Thus, in the event of a pump breakdown, farmers are able to revert to the traditional technology while the hand pump is being repaired. This is done by reinstalling the wooden windlass and removing a loose concrete slab on the well opening to gain access to the water. The main advantage is seen as the reduction in labor for pumping water for animals and people. De Lange (2006b) provides illustrations and cost data. In Namibia, shallow wells are constructed in valley bottoms between sand dunes and equipped with "bush pumps" or other manual technologies. The water is used for human use, livestock and some supplementary irrigation during dry spells. These are largely privately constructed (de Lange 2006c).

Boreholes

In most SADC countries, small-bore wells (boreholes) are drilled and equipped to supply community water for domestic use and animal watering. However, in dry areas of South Africa, the development of community food gardens has been based almost exclusively on borehole water. Boreholes for food production are mostly equipped with diesel or electric-powered pumps. Electric pumps are preferred, because both the operation costs and the maintenance requirements and costs are less than those for diesel motors.

In both Botswana and Namibia, livestock farmers and remote rural communities are highly dependent on borehole water, which is often their only water source. Both countries have developed effective programs for the provision of water supply based on boreholes. In Namibia, a comprehensive capacity building process engenders community organizations to ensure user responsibility for operation and maintenance of their own water points (de Lange 2006c, 2006b). Our Malawi partner reports there were over 50,000 boreholes in that country by 2003 (Mloza-Banda 2006). In a questionnaire on micro-AWM technologies filled by country representatives at the SARIA workshop in January 2006, most countries indicated the importance of boreholes, but we did not gather very much information on this technology.

Rooftop rainwater harvesting and above ground storage tanks

Harvesting rainwater from roofs of buildings features in our partners' reports for Lesotho, Zambia and Zimbabwe, usually combined with either storage or in Lesotho, with drip irrigation kits. They are also increasingly common in Eastern Africa (Mati 2006: section 3.7.1). The most detailed discussion is in the Zambia report (Daka 2006). Despite relatively high rainfall, the level of activity in rainwater harvesting in Zambia is very low and isolated. The most common type of rainwater harvesting is the traditional one, where families catch water falling from rooftops in drums of 200-210 liters capacity for short term use. This is usually done without their even realizing that they are practicing rainwater harvesting. The technology is quite novel in its formal state but it has existed for a long time. A similar type of system involves the use of gutters on buildings like schools and hospitals. Though with limited application, the system referred to as 'institutional rainwater harvesting' is quite effective and uses ferrocement tanks, sized between 10 to 20m^3, which collect rainwater from roof tops via gutters. The collected water is used by the concerned communal institutions. Such interventions are currently pilot projects by the Zambia Rain Water Harvesting Association. Daka (2006: Figures 5a, 5b) provides photographs of this technology.

While the collection of rainwater by a single household may not be significant in the larger scheme of things, the impact of thousands or even millions of household rainwater storage tanks can be enormous. In some cases, the harvested rainwater may be filtered, and even disinfected. Storage structures for roof catchments include surface tanks like ferrocement tanks (Daka 2006) and commercially available plastic tanks. In Lesotho, drip kits are promoted by some NGOs in combination with rooftop water harvesting, but the need for gutters and a collector tank is seen as raising the cost significantly (IWSD 2006c). Mloza-Banda (2006) says in Malawi a roof top harvesting system with an above-ground tank having a capacity of 50 m^3, costs approximately US$1,860 to construct; Mati provides lower cost figures from Kenya, working out to US$150 per person or $0.07 per liter assuming 20 liters consumption per person per day (Mati 2006: section 3.7.2).

Underground tanks to catch surface run-off

Underground rainwater tanks are a cheaper alternative than above-ground tanks because construction costs less; however it is then necessary to lift the water. Another problem is higher likelihood of contamination and sedimentation. The main problem, however, is lack of expertise at local level to design and construct underground tanks that are safe and functional (Mati 2006: section 3.7.2). Nevertheless, underground rainwater storage tanks (cisterns) are being aggressively promoted by several African governments, for example Ethiopia, and material on their design is available through SEARNET. IDE has been testing various low-cost underground storage systems using plastic bags at a cost of $40 for 10,000 liters (0.40 US cents/liter) (Polok et al. 2004).

In South Africa, underground tanks are currently being promoted to enable food insecure households to become more resilient against hunger. With an average rainfall of 450 mm/year (roughly half the world average), the increased run-off available from the homestead yard, adjacent roads and fields as compared to rooftops, is an important potential water source. In hilly areas it is possible to channel surface run-off into above-ground tanks, but otherwise, underground tanks (cisterns) are preferred (de Lange 2006a). De Lange (2006a: Table 10) provides estimates of the collection area and water storage capacity required in different areas of South Africa for a 100 m^2 trench garden.

A wide range of building materials can be used, with the most popular currently being self-made cement-blocks and ferrocement. Rammed earth is being investigated as an affordable alternative, while geofabric with a bitumen coating has also been tried. A variety of plastic linings are being investigated for their durability and ease of installation and maintenance by households – they are said to be already in use in parts of Kenya because they are easy to construct and more affordable (Mati 2006). However, this depends greatly on the types of plastic available in any particular country. In South Africa, nine types of plastic lining are currently being investigated to identify the most suitable for specific applications. Mati quotes figures of US$ 190 to construct a cylindrical underground tank with 15 m^3 capacity and Ngigi (2003:149-150, 169) provides similar figures; Mloza-Banda (2006) estimates the cost of a 10 m^3 tank in Malawi at $670 using conventional bricks and waterproof cement.

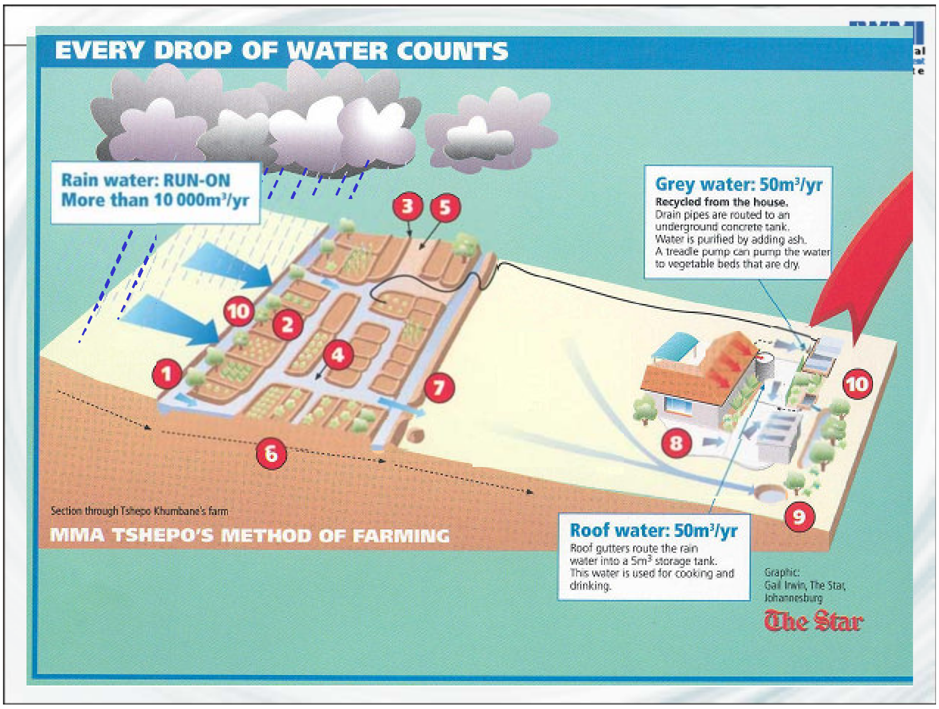
> In South Africa the migrant labour system during apartheid degenerated the rural family's traditional livelihoods. People became dependent on wage labour as their only survival strategy and this left them vulnerable when unemployment hit hard (Khumbane and Andersson 2006, in de Lange 2006a).

The legacy of apartheid, which led to loss of traditional knowledge, adds to the challenge of overcoming apathy and hopelessness of the food insecure in South Africa. Therefore, the implementation of the Department of Water Affairs and Forestry (DWAF) subsidy for rainwater harvesting tanks will attempt to transfer the 'mind mobilization' technique of the Water for Food Movement to implementing agents in the DWAF pro-poor RWH program (DWAF 2005). The Water for Food Movement, led by a grassroots activist, has demonstrated the very high productive potential of harvesting the rainfall as well as gray water on a 45 m by 45 m household small holding, at minimal cost (Figure 14). By one calculation, 220 m3 was used to produce over a ton of vegetables in the winter (dry season) of 2002 at the activist's homestead outside Pretoria, South Africa (de Lange 2006a: Table 11).

Conclusions

Clearly, again, there is a large range of potential small scale technologies for capturing water and directing it either onto crops or into storage facilities for later use. Many of them are quite low-cost and easily constructed by local people from local materials, with minimal technical assistance; and many of them provide water than can be used for many purposes, not just agriculture. As with other small-scale technologies, combining different ones to capture, store, and apply water is often synergistic: a small amount of water captured and stored can be used very productively and with minimal labor cost by combining with drip kits or treadle pumps. But adaptation to local conditions, with poor farmers empowered to make their own decisions, rather than being passive recipients is critical to success (see Table 11). Currently, several organizations are testing alternative technologies to find ways to reduce costs and optimize outcomes; these include RELMA (www.relma.org), IDE (www.ideaorg.org), and South Africa's DWAF (www.dwaf.gov.za).

Figure 14. Schematic diagram of household water harvesting



Source: Marna de Lange Power Point for Addis PanAfrica Water Conference, December 2003.

Other opportunities

Our coverage in this report is not comprehensive; it is selective and focused on what we believe are especially promising interventions. But here we draw attention to two agro-ecologies deserving special attention in some of the SADC countries: flood recession agriculture, and wetland (*dambo*) cultivation. Flood recession agriculture, i.e., cultivation of flood plains as flood waters recede, is mentioned by our Mozambique and Zambian partners. In Zambia, Daka (2006) describes 'flood plain recession irrigation' on a small area around Lake Kariba; crops are grown on residual moisture after the rain season, with supplemental irrigation as necessary to complete the crop. In Mozambique, flood recession irrigation is more developed and sophisticated, using systems of canals and dikes, and is largely for growing rice (Marques 2006). Two key adaptations have made the system effective: smallholders limit the size of their holding to match labor availability (usually around 0.5 ha); and they use different planting methods and varieties based on the variable topography, soils, etc. These systems have been in operation for more than 25 years. Productivity is low (<1.0 ton/ha) but the potential to increase this by improved land management, better seeds and the like is tremendous.

Table 11. Summary of main features of *ex-situ* water harvesting and storage*

Uses	To capture and store rain water for use when needed, for productive and domestic purposes
Necessary conditions	Large variety of technologies for capturing and storing water, each adapted to specific conditions
Advantages	Storage: water is available when needed in a dry spell Rainwater harvesting technologies can direct water falling on small holding or garden to where it is needed Some technologies are relatively low cost Can be constructed from local materials Can be combined with water-application technologies to minimize labor and enhance productivity Some technologies lend themselves to use at household level—can be used as part of a program to empower poor women and men farmers Rooftop systems can capture and store water that is clean and useable for domestic purposes Potentially very high returns in terms of household production, nutrition, health status
Disadvantages	Underground tanks cheaper, but water must be lifted and these are more vulnerable to contamination Above-ground tanks are more expensive but lifting water further may not be needed, and contamination more easily avoided Low-cost plastic linings still vulnerable to puncture Not cost-effective where large amount of water is needed

* As for *in-situ* rainwater harvesting and conservation agriculture, this category also includes a very wide range of practices and technologies, this table is very general.

Cultivation of inland valley lowlands which are seasonably saturated with water and retain a high water table even during the dry season (*dambos*) is reported by our partners for Malawi, Mozambique, Namibia, and Zambia (Table 1) but is even more widespread, being common in Tanzania, Swaziland and Zimbabwe as well. The total area of *dambo* cultivation in the SADC countries is not known but likely over two million ha; Daka (2006) says Zambia alone has 100,000 ha. *Dambos* are often exploited using the technologies discussed above—treadle pumps, shallow wells, etc. IWMI currently is leading two major projects with national and regional partners in the SADC region to identify how to optimize the benefits that can be derived from specific wetlands in an equitable manner, including through sustainable agricultural use. McCartney et al. (2005) provide a framework and pragmatic approach to identifying the trade-offs among different uses as a means to identify those wetlands where agriculture has a high and sustainable potential.

Costs and Economic Benefits of Selected Micro-Agricultural Water Management Technologies

Analysis of unit costs of selected Micro-AWM technologies

Data on unit capital and O&M costs of micro-AWM technologies in southern Africa are scant. The limited available data are usually calculated based on experimental information or data collected from a few pilot farmers. In this report we present the indicative unit capital and O&M costs for some of the AWM technologies identified in the region based on the results of our AWM technology inventory and literature review. For ease of presentation the unit cost of the four groups of AWM technologies discussed above are treated under separate headings here. Detailed pricing structure and mark-ups for the treadle pump technology is also presented.

Appendix 3 provides some comparative cost data from India. The Indian government pursues a deliberate policy of promoting water saving technologies through targeted subsidies and encouraging private enterprise in the entire supply chain. This is in contrast with most African countries, where NGOs have played a primary role in disseminating micro-AWM technologies. Another important difference is that there is far greater investment in adaptive research in India, leading to considerable innovation.

Water lifting or pumping technologies

The costs for the most common smallholder water lifting technologies in the region are presented in Table 12. Treadle pumps are relatively new but are becoming increasingly important in some regional countries. A minimum of 44,251 treadle pumps have been disseminated in the region since the mid-1990s by governmental and non-governmental organisations (see Appendix 1). It is important to note that the unit cost varies among and within countries, often depending on the nature of the promoting institution. The costs presented in Table 12 do not include the cost of promotional activities. For instance, the Malawian government has distributed treadle pumps freely to some farmers in response to the food insecurity situation of the country.

The precise per ha cost of a treadle pump is difficult to determine because of the often large divergence between the specified technical capacity and the actual farmers' experience. An area of land that can be irrigated with a treadle pump ranges from 0.1-1.0 ha. However, the cost may be significant enough to hinder adoption at least among some poor farmers. For instance, farmers in Mozambique query why they are offered such a technology for the same amount as for small petrol engines which they prefer.

Because of the attention governments and NGOs are giving to this technology, its price structure is presented here based on Tanzanian and Kenyan experience (Table 13). In Kenya, the estimated manufacturing cost for the treadle pump in 2003 was US$ 36 per unit, plus US$ 6 for various sub-assemblies such as valve plates, piston cups and rubbers. The manufacturer was allowed a 33% mark up on the basic cost, resulting in a total ex-factory cost of US$ 54 per unit. The NGO, acting as wholesaler, added a mark-up of 26% and sold the pump on to the retailer at a price of US$ 68. The retailer then added a mark-up of 18% before selling the pump to the end-user at a retail price of US$ 80.

Table 12. Unit costs of some smallholder water lifting technologies

Lifting (pumping) technologies	Capital cost (US$/Pump)	Capital cost (US$/ha)	O&M cost (US$)
Treadle pumps [a]	71.2-315.6	237.3-605.6	80/ha
Motorized pumps	NA	NA	NA
Bush pump "B"	2500	NA	NA
Rope and washer pump	100-200	100-200	NA
Bucket pump	1000	NA	NA

Note: NA=Not Available. Source: Partners' reports and inventories.
[a] There are different makes and models of treadle pumps currently being promoted in SADC countries. Treadle pump costs may also include additional costs for pipe, which is about US$ 86/0.25 ha, not included in the values reported in the table.

Table 13. Price structure for 'Super-MoneyMaker' treadle pumps in Kenya and Tanzania (US$)

Item	Kenya	Tanzania
Basic manufacturing cost	36	42
Manufacturers mark-up	12	5
Ex-factory price to wholesaler (KickStart)	48	47
Cost of sub-assemblies	6	-
Total ex-factory cost to wholesaler (KickStart)	54	-
Wholesaler's mark-up	14	9
Wholesale price to retailers	68	56
Retailer's mark-up	12	9
Retail price*	80	65

*Mid-2003 USD. In 2006, KickStart reports the Super-MoneyMaker pump costs US$ 90 in Kenya, while the original MoneyMaker pump costs $55, and the MoneyMaker-Plus $52.
Source: Adapted from Peacock (2005).

Out of its 33% mark-up, the manufacturer was to finance its working capital, overheads and profits, with a cash flow guaranteed by the NGO, which undertook to buy all pumps produced. Out of its 26% mark-up, the NGO had to finance its working capital to pay for and maintain all stock, plus its overheads, as well as storage and transport costs of about US$ 3 per unit. It also, significantly, met almost the entire cost of marketing the pumps.

In Tanzania, the basic manufacturing cost of the treadle pump was US$ 42 per unit, on which the manufacturer was allowed a mark-up of only 11%, resulting in an ex-factory price of US$ 47 (compared with US$ 54 in Kenya). The wholesaler (commercial operators in Tanzania) then added a mark-up of 20%, resulting in a wholesale price to the retailer of US$ 56 per unit, to which the retailer added a further mark-up of 17% before selling to the end-user at a retail price of US$ 65 per unit.

In the Tanzania case, out of its 11% mark-up, the manufacturer had to finance its working capital, which had to cover the cost of credit supplied to wholesalers. It appears that, out of its 20% mark-up, the wholesaler had merely to cover its overheads and profits (in Kenya, the wholesale function had been undertaken by the NGO, which employed donor funds for this purpose). As in Kenya, out of its 17% mark-up the retailer had to cover only its overheads and profits. Remarkably, the treadle pump was 23% cheaper in Tanzania than in Kenya, apparently because of lower margins for each of the actors in the supply chain as well as lower manufacturing costs.

As has already been noted, the treadle pump costs presented in Table 13 do not include dissemination costs. Mangisoni (2006) has estimated the dissemination cost of treadle pump in Malawi (Table 14) at about US$ 57.70 per treadle pump. Taking the mean treadle pump price in the SADC region as US$ 111.3, the total investment cost is therefore on the order of US$ 169.0 per pump, which also represents the cost per irrigating beneficiary household. However, as in other forms of irrigation investment, the number of direct beneficiary households may far exceed the number of irrigator households, through incremental wage employment and group ownership.

At a unit cost of US$ 169.0, the investment cost per hectare for a treadle pump, at an assumed irrigation capacity of 0.25 ha per unit, is US$ 676, excluding any other investment by the user (e.g., for fittings and a distribution system). However, because some of the costs were met by the government (in Malawi for example), the investment cost to the end-user amounted to only US$ 445.2 per hectare (US$ 111.3/0.25 ha). Annual maintenance costs are normally negligible and labor for pump operation is included in crop production costs. Thus, provided a convenient source of water is available, the annualized investment cost would represent total annual costs.

Table 14. Average cost of disseminating treadle pumps in Malawi, 2005

Cost category	**Amount (US$)**
Hiring a truck to delivery 100 treadle pumps from supplier in Lilongwe to Mchinji Rural Development Project office/from supplier in Blantyre to Blantyre Rural Development Project Office	327.9
Loading and off-loading costs	49.2
Storage cost	82.0
Hiring a truck from Mchinji/Blantyre Rural Development Office to a field office (Extension Planning Area)	286.9
Loading and off-loading costs	49.2
Storage costs	82.0
Farmer training	215.6
New adopters field support visits	3,196.7
Old adopters field support visits	1,475.4
Total cost (100 treadle pumps)	5,764.8
Cost per treadle pump	**57.7**

Source: Mangisoni (2006).

Water application technologies

Water application technologies are primarily promoted to save water. However, these technologies offer more than just water savings. Asian experience shows that these innovative water management technologies can have the following benefits:

- Significant improvement of crop yields and thus improved water productivity;
- Reduction of the negative impacts of rainfall variability and unreliability;
- Reduction in the cost of production;
- Improve household food and nutritional security;
- Positive environmental externalities such as reduced erosion; and
- Positive human health effects through effects on human diseases causing vectors.

Until quite recently, these systems appealed only to the rich commercial farmers (Table 15). But the technologies have been significantly remodeled by international NGOs like IDE to make them affordable by poor farmers as well.

Drip irrigation kits have been promoted for individual households, particularly rural and urban poor families, and female and child headed households. One major aim in promoting the kits has been the desire to alleviate the effects of HIV/AIDS. A major drawback to accelerated uptake of the low cost bucket/drum kit drip irrigation in SADC is the lack of manufacturing capacity in the countries. IDE sporadically supplies drip kits to communities, while World Vision sometimes supplies bucket kits as a one-off program to its recipients. The system greatly reduces irrigating and weeding labor, potentially important for the disadvantaged vulnerable populations that are aged, disabled, or weakened by the impacts of the HIV-AIDS pandemic.

Table 15. Unit costs of agricultural water application technologies

Water Application Systems	Capital cost (US$/ha)	O&M (US$/ha)
Commercial drip (dripper lines)	4098-5028	250
Low cost bucket/drum kit drip irrigation[a]	560-4894	480-1840
Clay pot subsurface drip irrigation[b]	NA	NA
Pressure sprinkler systems	6556.5-8500	198.5-500
Center pivot[c]	131130.4	NA
Hill spring water gravity head sprinkler irrigation	1000	20
Low pressure gravity feed sprinkler	203.3	2458.7
Semi-portable sprinkler (communal schemes)	491.7	NA

NA= Not applicable/not available.
[a] The per ha cost of low cost drip systems is misleading and it is difficult to assess the precise unit cost for such systems because they vary greatly in size and models. The farmers have installed different family drip system, sizes ranging from systems covering 100 m^2 to 2000 m^2.
[b] See Table 8, above, for unit costs of clay pot irrigation "per 800 plants."
[c] The per hectare cost of center pivot technology, which was reported from Swaziland (IWSD 2006c) seems to be extreme.

In-situ soil and water conservation technologies

Indigenous and introduced soil and water management technologies include long-used practices, innovations introduced from elsewhere, and farmers' own improvisations. There is some confusion regarding the nomenclature of these systems as the same practice can have different names in different countries or communities. Their major cost component is labor. These systems at best enable mitigation of the frequent seasonal dry spells observed in the region, enabling a reasonable harvest. For instance, *negarims*[19] are

[19] Small semi-circular bunds; see Mati (2006).

used for the establishment of fruit trees in arid and semi-arid regions where seasonal rainfall can be as low as 150 mm. But they may not help farmers in the case of severe drought, a frequent reality in southern Africa. Among these technologies, conservation farming has considerable potential for improving the productivity of maize, the main staple cereal of the region in rain-fed systems. Most of these systems presume the availability of reliable water at some time within the season and may not be effective in areas where there is an acute water shortage.

Tables 16 and 17 provide what cost data we were able to obtain for some of these technologies. Those systems that require permanent structures such as stone bunds and *fanya juu*[20] usually have higher establishment but lower maintenance costs than other non-permanent structures. This high cost at the initial stage and uncertain benefits discourage farmers from adoption (Ellis-Jones and Tengberg 1999).

Another important cost relates to land lost from the construction of some types of systems. This can range from as low as 4% for small "trash lines"[21] in Kenya to as high as 13% for *fanya juu* in Tanzania (Table 18). The basins, pits, bunds, and all other water harvesting systems that get their run-off from small areas are usually within-field systems and generally have a ratio of catchment to cultivated area ranging from 1:1 to 5:1. These systems usually give significant yield increases on the area receiving the runoff, but farmers are often not willing to sacrifice this land and therefore do not adopt them.

Table 16. Unit costs of selected indigenous soil and water conservation technologies

***In-situ* SWC/Conservation Agriculture**	**Capital cost (US$/ha)**	**O&M cost (US$/ha)**
Conservation farming	135.4	NA
Minimum tillage	NA	83.8
Contour cultivation	369	63.3
Mulching	NA	25.1
Ridging	50-80	41.9
Paddy field bunding	NA	83.8
Tied ridging	NA	7.9
Micro-catchment systems	500	77
Micro basin water harvesting	94	14
Fanya juu terraces	54	8.4
Ladder rerracing	NA	83.8
Chololo pits	NA	83.8
Ngoro pits	45-60	167.6
Debushing for aquifer recharge and improved grazing	24.6-49.2	8.2
Silted sand valley farming (*Kilimo cha mchangani*)	NA	41.9

NA = not available. Source: Partners' reports. We list only those technologies for which we have some data. See Mati (2006) for descriptions and in some cases illustrations of technologies.

[20] Kenyan term for narrow contour terraces made by throwing earth upslope to form an embankment; see Mati (2006: section 2.1.4)
[21] Contour strips using the previous years' crop residues; see Mati (2006: section 2.1.3).

Table 17. Unit costs of selected soil and water conservation technologies in Tanzania, Kenya and South Africa

System type	Crops	Capital cost (US$/ha)	Total annual costs (US$/ha)[a]
Majaruba basins	Paddy	94	14
Negarim micro-catchments	Fruit trees	500	77
Contour ridges	Field crops	369	57
Trapezoidal bunds	Sorghum	750	116
RELMA sub-surface storage tanks	Vegetables	5000	659
Silanga storage tanks	Vegetables	667	103

Notes: [a] Includes annualized capital and maintenance costs.
Source: van Koppen et al. (2005).

Ex-situ rain water harvesting, storage and diversion systems

Historic data on rainwater harvesting, storage and diversion system costs are not readily available in Southern Africa. Old cost figures presented by FAO tempts one to conclude that the capital costs of irrigation in sub-Saharan Africa are higher than in "most other regions" of the world although recent figures tend to challenge this claim (Inocencio et al. forthcoming, 2006).

Multipurpose dams and boreholes, which are used mainly for human and livestock consumption and less often for fishing and irrigated crop production, have helped pastoralists, farmers and other rural dwellers of the southern African region, specifically in Botswana and Namibia, to survive under extreme drought conditions. The cost of a small earth dam is about US$ 30,000 in Zambia and Botswana. However, these figures are planned figures and often these are far less than the actual cost. Often, dam construction, for instance in Zambia, is marred with technical problems; constructed dams do not function as designed (SIWUP PCR no date). Table 19 provides data on some ex-situ rainwater harvesting and storage systems from our partners.

The unit costs of other selected agricultural water management interventions in a few southern African countries are presented in Table 20. These calculations are mainly based on the figures reported in project completion reports. Unit costs vary from US$ 440/ha in Madagascar to US$ 82,400/ha in Zimbabwe for an earth embankment dam storage. The estimated annual O&M cost of the Madagascar schemes reflects their low capital costs. Annual maintenance costs for the distribution system and basins are considered to be included in the crop budgets. In contrast, the high annual O&M cost for the Zimbabwe earth embankment scheme reflects its extremely high capital cost.

Table 18. Resource requirements for conservation technologies

Country	**Technology**	**Life span (years)**	**Land lost (%)**	**Labor (man days/ha)**		**Cost (Us$/ha)**	
				construction	**Maintenance**	**Construction**	**Maintenance**
Kenya	Large fixed trash lines	1-2	7	0	10-20	0	10-20
	Large fixed movable trash lines	1-2	7	0	10-20	0	10-20
	Small trash lines	1-2	4	0	10-20	0	10-20
	Small double-spaced trash lines	1-2	8	0	10-20	0	10-20
	Large stone bunds	10	7	62	12	62	12
	Small stone bunds	10	5	36	12	36	12
	Fanya Juu	10	13	54	18	54	18
Tanzania	*Ngoro*	2	0	45-55	15-20	45-55	15-20
	Matuta[a] with organic	1	0	0	25-30	0	25-30
	Matuta without organic	1	0	0	8-10	0	8-10
Uganda	Trash lines-annual crops	1-2	10	0	25-35	0	25-35

[a] A Tanzanian term for ridge systems of two kinds, one incorporates organic matter on annual crops, the other does not.
Source: Ellis-Jones and Tengberg (2000).

Table 19. Unit costs of selected RWH, storage and diversion systems

Ex-situ RWH/storage	Unit cost (US$)	O&M cost (US$)
Underground tanks	395.4-5,000	23.7
Small dams: livestock watering and multipurpose	31,600[a]	NA
Small earth dams: crop production	30,000	NA
Small earth dam (*Ndiva)*	58663.1	12.6
Charco Dam	16,760.9-41,902.4	NA
Boreholes, water points [d]	26,226.1[b]	163.9-573.7/year[c]
Improved hand dug wells for livestock watering	11,200-15,250[a]	NA
Shallow wells	79.1	15.8/year
Underground water springs	11,862.4	23.7
Retention ditches/infiltration pits	23.7/ha	NA
Stream or flood diversion	1,186.2/ha	NA
Roof harvesting with above ground tank [e]	209.5-1,824.2	27.7
Household RWH storage tanks in South Africa [f]	835-1,700	NA

Notes: [a] Includes salaries and allowances for technicians and other workers for a maximum of 45 days per well. [b] For boreholes run with diesel engines; however there are also windmill and hand pump run boreholes. [c] Depending on whether the borehole is operated with diesel, windmill or hand pump. For windmill-operated boreholes the cost is about US$ 245.9 per annum. For hand pump operated boreholes the cost is US$163.9 per annum. [d] The boreholes are mainly mean for livestock and human drinking and domestic use. But farmers communally produce some vegetables to cover the fuel cost of the diesel engine associated with the boreholes. [e] The cost depends on the capacity of the tank. For instance, in Malawi, for a 50 m^3 tank the cost is about US$ 1824.2 and for 10 m3 capacity tank the cost is US$ 656.4. [f] A tank able to irrigation a 100 m^2 garden, about 5 kl, is estimated to cost between Rand 5,000-10,000 (US$ 835-1,700). Pilot studies are underway to determine the costs and benefits of various types, and then to finalize the amount of government subsidy to be provided.
Source: Partners' reports; for the South Africa case DWAF (2005; no date).

Another way of assessing costs is to determine the unit cost per cubic meter of water harvested (Table 21). For instance, the volume of earthen dams range from hundreds to tens of thousands of cubic meters. Reservoirs with volumes less than 5000 m^3 are usually called ponds.

In Kenya, a range of low-head drip irrigation kits is available at prices ranging from US$ 15 for a 20-liter bucket kit to US$ 125 for the 200 liter mini-tank/drum kit. These are often combined with water harvesting and storage structures. Table 22 provides estimated investment costs for a farm pond rainwater harvesting system for supplemental irrigation using low-head drip irrigation.

Costs generally higher in Africa than in India

A comparison of the cost data presented above with the Indian cost data summarized in Appendix 3 demonstrates that prices in India are generally substantially lower, and indeed the Indian data are not useful for estimating costs in Africa. There are many reasons for this: differences in government policies; the existence of well-developed agricultural markets in India and the high degree of competition among manufacturers and retailers of AWM technologies; the much greater scale of the market in India compared to African countries; and the far higher investment in applied research. The high cost of equipment imported from India to Africa has often been noted. Table 23 illustrates why this is using data on the cost of selected micro-irrigation technologies imported into Eritrea: bucket and drum irrigation kits cost 2.5 times the price *ex factory* in India.

Benefits of AWM technologies

Productivity changes

There are four fundamental routes through which AWM technologies may bring about desirable welfare changes for farmers or rural households. These are:

- Improved productivity of water and land
- Improved cropping intensity
- Stabilizing output and
- Multiple use or multi-functionality as for boreholes and dams.

Table 20. Unit cost of some small scale irrigation systems in Southern Africa

Country	**Technology**	**Scale**	**Capital cost (US$/ha)**	**O&M Costs (US$/ha/ year**
Madagascar	Run-of-river; concrete/masonry diversion structure; gravity-fed; partially lined main canal; unlined secondary canals; field to field distribution; basin irrigation.	Medium	440	4
Tanzania	Low, earth embankment dam storage; gravity-fed; lined main canal, unlined secondary canals; field to field distribution; basin irrigation.	Small	3679	37
Tanzania	Run-of-river; gabion diversion structure; gravity-fed; unlined main canal; unlined secondary canals; field to field distribution; basin irrigation.	Medium	1066	16
Zimbabwe	Large, earth embankment dam storage; gravity-fed piped main; lined secondary and tertiary canals; furrow irrigation.	Small	82400	487
Zimbabwe	Pumped groundwater from electrically powered boreholes; piped main; concrete lined secondary and tertiary canals; border strip irrigation.	Medium	10940	95
Zimbabwe	Run-of-river; gravity-fed piped main line; piped distribution; drag hose sprinkler irrigation	Small	7829	98

Source: Van Koppen et al. (2005).

Table 21. Typical costs for some rainwater harvesting technologies

Technology	Specifications	Unit cost (US$/m^3)
Underground tanks	Concrete dome shaped tank	7
	Brick dome shaped tank	9-14
	Bottle shaped tank	4
	Ferrocement tank	12-15
	Ball shaped plastic tank	160
Above ground tanks	Brick tank	93
	Ferrocement tank	30-70
	Plastic tank	130
Runoff open reservoirs	Plastic lined	3
	Cement lined	5
	Unlined	100[a]
	Lined oval tank	8
Runoff closed reservoirs	Concrete dome-shaped underground tank	7
	Brick dome shaped underground tank	9-14
	Bottle shaped underground tank	4
	Ferrocement underground tank	13
	Hemi spherical underground tank	23
	Sausage shaped tank with cement lining	16
In Situ	Human land preparation	113[a]
	Draught animal power land preparation	53[a]
Sand or sub-surface dams	Sand dam	0.8
	Sub surface dam	0.7
Rock catchments	Open rock dam with stone gutters	71
	Closed rock dam with stone gutters	89
	Open rock dam with tank	110
	Rock catchment tank with stone gutters	46
	Stone gutters	2[b]

Notes: [a] The figures are in man days per ha. [b] The value is in US$ per meter. Source: Mati (2006).

Table 22. Cost-benefit analysis of farm pond water management using simple drip irrigation technology

Item	Cost (US$)
Construction of farm pond (20 man-days @US$1.5)	30
Seepage control UV resistant plastic lining sheet (100 m^2 @ US$ 2.7/ m^2)	270
Low-head drip irrigation system (i.e. for two 200-l kits @ US$ 125)	250
Fencing and roofing	100
Total investment cost	650
Recurrent cost (labor and farm inputs) per season	100
Expected seasonal returns @ US$ 0.15 per kg of cabbage	300
Net benefit on investment per season	200

Source: Nigigi, et al. 2004.

Table 23. Cost components of selected micro-irrigation technologies in Eritrea (US$)

Item	Bucket Kit	Drum Kit	Sprinkler Kit
Price at manufacturer's door in India	5	16	21
Plus service charge in India, 10% of net price	0.5	1.6	2.1
Shipment costs (in the actual case with air flight, 60% of net price)	3	9.6	12.6
Custom clearing in Eritrea including transport costs (10% of net price)	0.5	1.6	2.1
Cost of locally available bucket	4.1	18.5	-
Total cost per set in USD	13.1	47.1	37.6

Source: CDE 2001.

Indicative productivity and cropping intensity changes following the adoption of AWM technologies are shown in Table 24. In line with general observations, particularly Asian experiences, the productivity gains for some of the technologies are quite substantial. However, these figures need to be assessed carefully as they are often from experimental plots or based on the experience of innovative pilot farmers. Output stabilization effect (reduction in the vulnerability of people to rainfall unreliability or drought) of the technologies is obviously very important. Boreholes, river diversions and dams may substantially reduce the vulnerability of people to drought, provided the water source is dependable. However, the various indigenous and introduced soil and water management technologies that mainly rely on farmers' own investments may at best help to withstand the often pervasive dry spells of the region; the drought mitigation impacts of such technologies are open for further exploration.

Net income/gross margins

The country partners were requested to develop a prototype enterprise budget for each of the micro-AWM technologies identified in their respective mandate countries. The results for only three countries, Malawi, Tanzania and Zambia are presented here because of their relatively good analytical procedure (Table 25). The table reveals striking preliminary results. When family labor is valued at the going wage rates, farmers using the contour ridge technology in Malawi operate at a loss (this practice is widely used in Malawi). Similarly, farmers using motorized pumps for lifting water to grown beans operate at a loss. This is due to a recent increase in operating costs of motorized pumps following a fuel price hike (Mangisoni, personal communication). Though the returns do not look impressive, the assured harvest in semi-arid areas where harvest failures for rainfed crops is common is an advantage that farmers consider in their AWM technology adoption.

Except in Malawi, farmers use treadle pumps mainly for high value crops. Thus the returns to treadle pumps in Malawi are lower than in Tanzania and Zambia. In conclusion, micro-AWM technologies tend to be rewarding when they are used for cultivating high value crops. Can smallholders successfully compete with the established medium and large scale commercial farmers of the sub-region? This seems to be one of the challenges which policy makers have to address, if the objective of extricating the poor smallholders out of poverty is to be achieved.

Table 24. Expected productivity gains of selected micro-AWM technologies

AWM technology	Country	Crop	Yield increase (t/ha)	Cropping Intensity
Treadle Pumps*	Malawi, Zambia	Maize	3-5	2-3
	Zambia	Tomato	2.5-35	
	Zambia	Cabbage	5-29	
Drip kits	Tanzania	Watermelon, tomato, onion	1000%	1-3
	Zambia	NA	300-400%	
Commercial drip (dripper lines)	Swaziland	Sugarcane	98-102[a]	
Clay pot subsurface drip irrigation	Zambia	Maize	13 (9.3)	NA
	Zambia	Rape leaf vegetable	33 (27)[b]	
	Zambia	Tomatoes	42 (40)	
	Zambia	Cauliflower	22 (16)	
	Zambia	Beans	5 (4.7)	
Sprinkler irrigation system	Malawi	Maize, okra, leaf vegetables	0.6	3
Hill spring water gravity head sprinkler irrigation	Zambia	Orange	70[a]	Perennial
	Zambia	Pineapples	60[a]	NA
	Zambia	Banana	100[a]	Perennial
Permanent strip farming	Botswana	Maize	6	2-3
Conservation farming	Malawi	Maize	2.5-4.0	1
Minimum tillage	Malawi	Maize	4.5	1
	Tanzania	Maize	0.9-5.4	
Contour cultivation	Malawi	NA	1.5	1
Tied ridging	Malawi	Cotton, sorghum, millet, sweet potato	1.0-1.3	1
Micro-catchment systems	Mozambique	NA	0.7-1	1
Small earth bunds/raised footpaths	Malawi	Rice	1.0-1.4	2
Micro basin water harvesting	Zambia	Maize	1-4	1
	Zambia	Soybean	0.3-8	
Stone lines	Malawi	Maize, beans, vegetables	1	1
Chololo pits	Tanzania	NA	1	1
Planting pits	Malawi	NA	2	1
Residual moisture	Malawi	NA	1.6	2
River flood plain irrigation/wet season	Mozambique	Rice	1.2-1.8	2
Swamp irrigation/fresh water swamps	Mozambique	Rice	1.9-2.8	3
	Mozambique	Lettuce, sweet potato	20	
	Mozambique	Cabbage	10-15	
River flood plain irrigation/dry season/ Cegonha	Mozambique	Rice	2.5-5.0	3
Silted sand valley farming (*Kilimo cha mchangani*)	Tanzania	NA	2.5	1
Small earth dams	Malawi	Maize	3	1-2
Hill irrigation	Mozambique	NA	200%	2-3
Retention ditches/infiltration pits	Malawi	Maize	1.4	1
Stream or flood diversion	Malawi	Maize	1.1-1.4	1-2
River diversion irrigation system	Malawi	NA	3-7	
Roads/footpath runoff harvesting	Malawi	Cotton, rice, maize	1.25-1.4	1

Notes: [a] The yield values are in absolute figure, not increment. [b] The values in parentheses are for the counterfactuals or the base technologies/practices. [c] Boreholes though mainly intended for livestock and domestic uses, are sometimes used for irrigating vegetables, primarily to recover the operation and maintenance cost of motorized pumps as in Namibia. NA: data not available. Sources: Partners' reports. Technologies for which no data are available are not listed.

Table 25. Estimated net benefits of selected AWM technologies

Technology	Countries/Net benefits (US$/ha)		
	Malawi	**Tanzania**	**Zambia**
Contour ridging [a]	(51.6)	NA	NA
Minimum tillage [a]	443.3	335.2	NA
Treadle pump [b]	78.4	NA	1800-2100
Watering can(bucket) [b]	7.6	NA	NA
Treadle pump (beans)[c]	364.9	NA	NA
Motorized pump (bean) [c]	(139.7)	NA	NA
Watering can (bean) [c]	214.9	NA	NA
Gravity irrigation (bean) [c]	1156.8	NA	NA
Residual moisture cultivation [c]	76.8	NA	NA
Treadle pump (onion)[d]	NA	942.0	NA
Treadle pumps (lemon grass essential oil extraction) [e]	NA	NA	3852.3
Treadle pump (lemon grass herbal tea production) [e]	NA	NA	878.3
Paddy bunding (bean) [c]	NA	586.6	NA
Drip system	NA	3466.1	NA
Drip kits (watermelon, tomato, onions)	NA	754.2	NA
Stream or flood diversion (maize)	118.6-158.2	NA	NA
Sprinkler irrigation system	47.5	NA	NA
River impounding/weirs	1502.6	NA	NA
Small earth dams (maize)	563.8	NA	NA
Inland valley swamp irrigation (rice)	NA	NA	363.3-499.7
Hill spring water gravity head sprinkler (oranges, pineapples, and bananas)	NA	NA	66931.2[d]
Mulching (banana, coffee)	NA	754.2-838.0	NA
Ngoro pits	NA	83.8	NA
Chololo pits	NA	83.8	NA
Silted sand valley farming (*Kilimo cha mchangani*)	NA	251.4	NA
Ladder terracing, cabbage	NA	293.3	NA

Sources: [a] Valencia and Nyirenda (2003); [b] Shigemichi and Shinohara (2004); [c] Kadyampakeni (2004). [d] The value is for an area of land that can be irrigated with 10 sprinkler heads.

Gender differentiated impacts

Another important observation is the difference in realized economic benefits between male and female farmers (Figure 15). Except for irrigation with watering cans and motorized pumps, in all other forms of micro-AWM technology, female farmers realize substantially lower economic benefits than male farmers. The specific reasons behind this gap are not clear, but it may indicate that ensuring access to technology alone is not enough to empower disadvantaged people.

Overview of Key Actors in SADC Countries

This section is drawn largely from the country reports prepared by our partners. It is not complete by any means, but gives a flavor of the diversity and large number of actors promoting or supporting micro-AWM technologies and practices. Table 26 provides a list, by country, of government institutions, NGOs, private sector firms, and donors involved in micro-AWM. In all the countries studied, governments and NGOs are working to promote micro-AWM, usually with donor support; and in most countries there are active private firms as well. In some countries—especially Malawi, Mozambique, Tanzania, ands Zimbabwe—there are multiple government institutions involved, raising the question of how much inter-departmental and inter-ministerial coordination exists. Malawi, Zambia and Zimbabwe have a relatively large number of NGOs operating in the sector as well; and Malawi seems to have a large number of private firms (it is likely this is the case for Zambia as well).

We have no information on the degree of coordination among NGOs or between the NGOs and government institutions; and only limited evidence on the relative effectiveness of the various institutions. For example, evidence from the country reports suggests that International Development Enterprises (IDE) in Zambia and Zimbabwe and KickStart (Tanzania) are relatively effective[22]. World Vision and CARE are very active in several countries, but we have less information on their effectiveness. The report on Malawi (Mloza-Banda 2006) and impact assessment of treadle pumps (Mangisoni 2006) suggest that government institutions, NGOs and private firms are active and fairly effective given some of the limitations under which they operate. The data on donors is likely to be especially incomplete, making it difficult to offer any comments. USAID and FAO are both very active in many of the countries. The effectiveness of government institutions is given mixed reviews: while in Botswana, Malawi and Tanzania they seem to be somewhat effective, in Zambia, Mozambique, Swaziland and Zimbabwe they seem to need considerable strengthening.

Based on this rather extensive (but not intensive!) overview, we have made some recommendations, included in the recommendations section below.

[22] See also Mudenda and Hichaambwa (2006) and SIWUP PCR for Zambia, and Van Koppen et al. (2005) for KickStart in Tanzania.

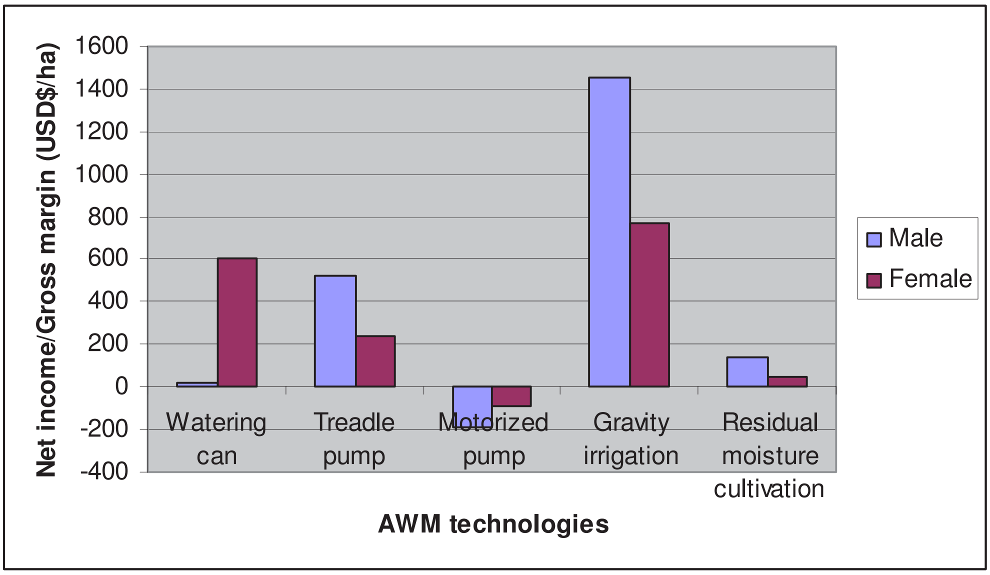
Table 26. Overview of key actors in micro-AWM, SADC countries*

Country	Government Institutions	Non-Government Organizations (non-profit)	Private Sector	Donors
Botswana	Ministry of Agriculture Dept. of Water Affairs District Councils	Botswana Rain Harvesting and Utilization Association (BORHUA) Permaculture Trust Botswana (allied to PELUM) Somarelang Tikologo Kalahari Conservation Society	Sanitas Farm	SIDA SADC Land and Water Management Unit with EU funding DANIDA
Lesotho	Ministry of Agriculture and Food Security (various divisions) Lesotho Highlands Development Authority (LHDA)	World Vision Lesotho Save the Children Save the Children (UK) Farmer Associations Rural Self-help Associations CARE++; Helvitas	Matsieng Development Trust (MDT)	DFID++ USAID IFAD
Malawi	Ministry of Agriculture Ministry of Irrigation and Water Development Department of Irrigation Department of Land Resources Conservation Smallholder Floodplains Development Project Rainwater Harvesting Project-Bunda College Malawi Social Action Fund (MASAF) Malawi Environmental Endowment Trust (MEET) Agricultural Marketing and Development Corp (ADMARC)+ Malawi Industrial Research and Development Centre (MIRTDC)	CARE Action Aid OXFAM Concern Universal Concern Worldwide Sasakawa Global 2000 Total Land Care World Vision Civil Society Network on Agriculture (CISANET) Association of Smallholder Seed Multiplication Groups (ASSMAG) National Smallholder Farmers Association (NASFAM) Catholic Development Commission in Malawi+ Malawi Red Cross+	Treadle pump manufacturers: APED Engineering VICS Delt-Tech Engineering Ltd+ Agricultural Trading Company+ Agri Hort+ Pipeco+ Agricultural Equipment Ltd+ Valiant Glass Works Ltd+ Saifro+ Lilongwe Mechanical Development+ Shire Litd+ Agro-engineering+ Indigo Business Directory: about 20 companies providing irrigation equipment Malawi Rural Finance+	EU Public Works Programme FAO Chinese Technical Mission Royal Norwegian Embassy UNICEF USAID JICA DFID World Bank CIDA

Country	Government Institutions	Non-Government Organizations (non-profit)	Private Sector	
Mozambique	Ministry of Agriculture: National Directorate for Agricultural Hydraulics (DNHA) PRONIPE, National Small Scale Irrigation Program (within DNHA) FDHA-Fund for Agricultural Hydraulics Development (within DNHA) Ministry of Public Works and Housing: National Water Directorate (DNA) 5- Regional Water Administrations (ARAs)** National Water Council (CAN)	Sasakawa Global 2000 AFRICARE CARE Adventist Development Relief Agency (ADRA) World Vision National Farmers Union (UNAC) Helvettas		USAID FAO World Bank World Food Programme African Development Bank Government of Italy GTZ SIDA Spanish Cooperation
Namibia	Ministry of Agriculture, Water and Forestry	Agronomic Board of Namibia Desert Research Foundation of Namibia Lihepurura NGO, Rundu RISE, Windhoek	Lund Consulting Ralf Hoffmann Namibia Resource Consultants	USAID WWF Life Plus Funds mainly for Rural Water Supply: Govt of Germany Govt of Finland Govt of Netherlands Govt of France Govt of China Govt of India UNICEF Red Cross AfriCare Nolidep
Swaziland	Ministry of Agriculture and Co-operatives Swaziland Water and Agricultural Development Enterprise (SWADE) Swaziland Development Finance Corp. (FINCORP)	World Vision African Cooperation Action Trust Swaziland Farmer's Development Foundation (SFDA) Farmers' Associations Farmers' Cooperatives Lutheran Development Services	Swaziland Industrial Development Company (SIDC) SWAZI Bank Imhlanyelo Fund	FAO IFAD USAID DFID

Country	**Government Institutions**	**Non-Government Organizations (non-profit)**	**Private Sector**	
Tanzania	Ministry of Water and Livestock Development (Drilling and Dam Construction Agency) Ministry of Agriculture and Food Security (Irrigation Department) District Livestock and Development Officer (DALDO)	KickStart (formerly ApproTEC) Mbezi Enterprise Sokoine Agriculture University (Soil and Water Management Group) Traditional Irrigation and Environmental Development Organization	Balton Tanzania Ltd Karam Engineering Works Ltd	Rural Water Supply and Sanitation Programme (Netherlands Govt., World Bank, others) USAID DANIDA GTZ UNDP Netherlands Japan Novib-Oxfarm Netherlands

Figure 15. Gender differentiated benefits of micro-AWM technologies



Source: Kadyampakeni (2004).

Conclusions: Major Issues Emerging from the Study

This study has probably raised more questions than it has answered. Nevertheless, in this section we highlight what we see as the key conclusions and issues emerging, while the next section makes specific recommendations.

1. Low average rainfall that is seasonal, highly variable in time and space, and increasingly unreliable is the major impediment to farm households increasing their production of food, cash crops, and livestock products in Southern Africa. The impacts of this unreliable and inadequate water supply are compounded by many other problems, both natural (for example poor soil fertility) and human-created (for example lack of support services and infrastructure and deteriorating health status of people). Improving the reliability of water supply for agriculture is therefore a necessary though not sufficient condition for reducing poverty and malnutrition and generating faster agricultural growth.

2. There is reasonable though not conclusive evidence that some of the micro-AWM technologies reviewed in this study, under the right conditions, do lead to substantial improvements in households' food security and incomes, and that they do so in a cost-effective manner. This is especially true for treadle pumps, but there is enough case study and anecdotal evidence to suggest that the statement also applies to low-cost drip irrigation kits, clay pot irrigation, conservation farming practices that integrate nutrient and water management, and a variety of *in-situ* and *ex-situ* water harvesting and storage technologies.

3. There are many actors and many projects involved in studying and (especially) promoting a large number of different micro-AWM technologies and practices in Southern Africa. However, there has been little or no systematic analysis of their effectiveness, impacts and sustainability, or attempts to understand what strategies work and why, and what does not work and why. Undoubtedly the same mistakes are being repeated needlessly throughout the region. While a multiplicity of effective local and international NGOs is to be encouraged, it would be useful to find out systematically what are the main strengths and weaknesses (comparative advantages) of each, and develop mechanisms for better coordination and sharing of experiences and lessons learned. For example, IDE and KickStart have specific models for trying to establish viable micro-AWM technology supply chains and in IDE's case, linkages of smallholder farmers to profitable output markets. Perhaps other NGOs who at the moment focus largely on provision of technologies could learn from their experiences and thereby improve their long term developmental impacts.

4. The tremendous diversity of conditions in the SADC region must be acknowledged. Even within districts, there is such diversity in soils, micro-climate, cultures, and access to markets that what works on one farm may not be appropriate next door. This means there is no possibility of generalizing, no cook book approaches or sure-fire universal panaceas that will work everywhere. Unfortunately, it appears that there are cases where micro-AWM technologies not really appropriate to local conditions and needs are promoted (and rejected). Further, there has been a failure to take an integrated approach, in several senses: recognition of the multiplicity of household water needs given the diversity of livelihoods (for example integration of livestock, crops, brick making, etc.); recognition of the potential synergies of integrating micro-AWM technologies, for example combining treadle pumps with efficient application technologies with soil conservation practices; integrating water and nutrient management; and pursuing implementation strategies that integrate attention to support services (inputs), attention to production processes, and to outcomes on the demand side in terms of both household food security and nutrition and access to ell-functioning markets.

5. Following from the diversity of the region, it is no surprise that there are no cases of successful massive scaling up and out of specific micro-AWM technologies and practices. Adoption, adaptation, or rejection decisions are a function of many factors including lack of information or access, lack of fit between the technologies on offer and the capacities and needs of households, inefficient promotion strategies, flawed assumptions about households' needs and capacities and the real costs and benefits from their perspectives (for example the assumption of surplus labor availability), ineffective targeting, lack of capacity to manage projects offering a large array of small-scale technologies to thousands of poor households, and lack of credit.

6. An issue that already requires attention in some areas and will become increasingly critical is the potential mismatch between the supply of water resources and demand, especially on small watersheds and *dambos* during the dry season. With increasing intensity even of the use of small treadle pumps, communities may need assistance to develop appropriate mechanisms for regulating equitable access to diminishing water supplies. This problem will be compounded in future by the spread of motorized pumps.

7. Government policies are often either unfavorable or contradictory vis-à-vis micro-AWM technologies. On the one hand, there is a tendency of governments to favor large-scale infrastructure investments, especially when there are pressures to spend –and be seen to be spending—large budgets on time. In some cases policies are contradictory: for example, in Malawi while some institutions have promoted programs to encourage local manufacture of treadle pumps and provided subsidies or credit for small farmers to purchase them, more recently the government has initiated a program to hand out thousands of such pumps (mostly imported) free of cost. Such a policy may undermine efforts to develop an effective and sustainable market-based supply chain (including local manufacturing) for pumps and spare parts. This reduces the potential synergies from linkages between agricultural growth and the growth of agri-based industries. On the other hand, a case can be made for a *consistent* limited-period policy to kickstart such industries by making large numbers of technology available at a subsided rate, then encourage local support services and manufacturing for replacement pumps.

8. The SADC region is highly inequitable in terms of distribution of income, with evidence that the poor are getting poorer (for example declining levels of calorie consumption). This state of affairs is compounded by the impact of the HIV/AIDS pandemic, high rates of malaria and other illnesses, all further compounded by malnutrition, especially among small children. In many rural areas of the region, there is currently a vicious cycle underway which is undermining resilience, creativity, and labor availability, leading to long term deleterious impacts on the potential to achieve the Millennium Development Goals in the region. Indeed, most observers now agree SADC cannot meet the MDGs. There is a quiet crisis underway whose long term consequences will be immense unless concerted efforts are made to reverse these trends.

Recommendations

Throughout this paper we have made specific suggestions and recommendations. Here we try to focus on a selected number of key generic recommendations that we believe will help improve the effectiveness of micro-AWM programs in Southern Africa. In an earlier section we focused our attention on a small number of technologies and practices that we believe are most promising “best bets” to the extent such generalization is possible. We briefly reinforce these recommendations here before finishing with eight more strategic recommendations.

Recommended micro-AWM technologies and practices

1. In many regions in southern Africa where there is a water source no more than 6-7 meters below the surface or 200 m away from where the water is needed, treadle pump offer a potentially high-return and high-impact intervention. The pumped water can be used for many domestic and productive purposes, not only irrigation. The evidence from Malawi, Tanzania and Zambia demonstrates the potentially very high impact on food security and incomes. We therefore recommend this technology for widespread promotion where the conditions are favorable.

2. The evidence we have shows that many individual farmers have benefited from low-cost drip irrigation kits, even though they have not been implemented on a large scale as yet in Southern Africa. Nevertheless, under the conditions discussed in the relevant section of this report, they hold a great deal of promise, and we therefore recommend their promotion under the specified conditions.

3. Like low-cost drip irrigation kits, although so far clay pot irrigation has not been implemented on any scale, we believe this is also a low-cost technology that can result in a very high level of water and labor productivity under the same conditions as for drip kits. We therefore recommend further adaptive research and if the results are favorable, wider promotion of clay pot irrigation.

4. The term "conservation agriculture" covers a large range of *in*-situ water and land management technologies and practices, some of which require large initial investments to implement. But some of the practices described under this heading are relatively low-cost, with very high potential returns. The critical issue is that many interventions have failed to address the necessity of integrating water and nutrient management: adding water by itself can actually lead to more rapid depletion of nutrients, while soil nutrients cannot be efficiently used by plants without water. Because of the complexity and diversity of most African farming systems, there is no monolithic package of conservation agriculture technologies; rather, we recommend that farmers be supported and assisted to try new ideas and combinations of practices that work under their conditions.

5. As with *in-situ* water and land management practices, there is a wide range of low-cost and easy-to-construct *ex-situ* water harvesting and storage practices that under specific conditions are effective and can have large impacts on food security and livelihoods. As is the case for others, adaptation to local conditions with poor people empowered to make their own decisions rather than being passive recipients is critical to success. We therefore recommend wider dissemination of these practices.

Strategic recommendations

1. Following from the observations above regarding the diversity of conditions and situations and the fact that no single micro-AWM technology or practice can be a panacea, we strongly recommend that supporting the creativity of the user is

essential if people are going to improve their food security and escape from poverty. Therefore, participatory approaches that encourage and support creativity and innovation, for example by offering choices and menus that can be adapted and combined as needed, participatory approaches that empower users to make their own decisions, and provision of support services that reduce risk and makes available resources that are not otherwise at hand.

2. Effective targeting of the poorest and most food-insecure is a huge challenge, but absolutely essential to achieve the MDGs. It is food-insecure households, not government, NGOs, donors, or wealthy people, who will achieve the MDGs (or not achieve them). Specifically, we recommend focusing on supporting those who are most hungry and risk-averse; living with HIV/AIDS; relying on rainfed agriculture with little prospect of getting access to irrigation plots in the near future; and need access to sufficient staple foods and sources of nutrition especially for young children and pregnant women. In many cases this will be households headed by women or at least in which women play the critical role in producing and providing food.

3. The previous recommendation creates a dilemma: there is currently much emphasis on improving access to markets, and focusing on production for markets as a way of generating profits and promoting agricultural growth. This is indeed important, but in the short to medium term at least, does little to help the poorest and hungriest people. We therefore recommend that far more resources be allocated to targeting and assisting the very poor. Helping them achieve basic food sufficiency (in terms of calories and nutritional balance) will make it possible for many of them to take the next steps into market-oriented commercial production; for others it will make it possible to use income generated from off-farm employment for essential needs like school expenses; and for all it will improve their health and labor productivity, enabling them to participate more effectively in productive and educational pursuits and lead better lives.

4. While supporting the need to invest in major water (and indeed other) infrastructure at a far greater scale than seen so far in Southern Africa, we strongly recommend scaling up investments in micro-AWM technologies and practices as well, because this offers a relatively faster and more cost-effective way to achieve the MDGs than for example major irrigation investments. Global experience demonstrates that it takes decades to achieve the full benefits of large irrigation investments; and that it is relative expensive on a per hectare as well as (and more importantly) a per-household basis. Many micro-AWM technologies are far less expensive per household than formal irrigation, their benefits begin immediately upon acquisition, and they are not plagued by all the management problems, transaction costs and negative externalities often characterizing formal irrigation. Of course, for poor people living in areas where there is no adequate source of water, or where there is a high risk of major drought, infrastructural development is necessary to bring water close to the people in need.

5. Micro-AWM technologies are "divisible"; i.e., can be used by individuals or small groups directly. They also lend themselves to provision by the private sector, unlike large water infrastructure projects with large public good and common property characteristics. But most SADC countries by themselves have too small a local market for a competitive micro-AWM industry to develop. Therefore, we recommend that governments examine how to make their policies more conducive to encouraging private sector firms to manufacture, supply, and even experiment and innovate micro-AWM technologies; and that at the SADC level, an effort be made to encourage a regional market in this sector. India provides a model in this regard—there is a healthy competitive and profitable industry catering to a large and diverse market, providing low-cost micro-AWM technologies, and that is also innovating to improve quality and lower costs. This industry contributes to improving the productivity and profitability of agriculture and itself creates jobs and contributes to overall economic growth. Governments can also consider "kickstarting" the micro-AWM industry by a limited-term consistent policy of providing large numbers of subsidized units to create a market for support services including repair, spare parts, and future replacement.

6. We recommend that governments re-examine their policies toward micro-AWM and clarify and streamline them to be directly supportive. In some countries there are too many government institutions involved, often with different and even contradictory policies. We therefore also recommend that countries explore mechanisms for coordination, and even consider identifying a "lead institution" at government level. The proposed SADC Agricultural Water Management for Food Security Program can provide an effective mechanism for helping governments clarify their policies, and assisting in the creation of a larger SADC market for micro-AWM technologies.

7. We recommend that NGOs and governments currently promoting micro-AWM technologies as part of their relief efforts move away from short term relief to long-term development. We have found cases where well-meaning provision of technologies like bucket and drip kits has had no impact, because of the lack of longer term service provision and training. This is not a good use of scarce resources. It is clear that the most successful programs are those that take a longer term integrated perspective toward creating the conditions conducive to sustainability.

8. Finally, we strongly recommend more investment in monitoring, impact assessment, pilot testing of innovations, and sharing the lessons learned widely among governments, investors, donors, private firms and farmers. Creating "learning alliances" among interested partners to collaborate in these endeavors is one effective way to achieve this. In line with this, we recommend support for exchange of experiences and lessons learned, comparative analysis, and partnerships among African countries and between Africa and Asia, especially India. We also recommend supporting programs where post graduate students are

supported both financially and in terms of methodology to carry out in-depth independent studies whose results can be widely disseminated.

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Appendices

Appendix 1

Table a. Agricultural water management technologies and practices in the SADC region: lifting and field application technologies

AWM technology or practice	**Countries**	**Source**	**Year**	**Beneficiary Households**	**Area in ha**	**Profile of Beneficiaries**	Proportion of women beneficiaries
Lifting (pumping) technologies							
Treadle Pumps* *There are different makes and models of treadle pumps available in Southern Africa.	Lesotho, Zimbabwe, Zambia, Malawi, Tanzania, Mozambique	Imported	1996-2000	44251	4020-9020	Ultra-poor, poor, non-poor	30-50
Motorized pumps	Mozambique	Imported	1940		10000.00	Non-poor	30
Bush pump "B"	Zimbabwe	Indigenous	1933	250.00			
Rope and washer pump	Zimbabwe	Imported				Poor, non-poor	
Bucket pump	Zimbabwe	Indigenous	1983			Poor, non-poor	
Shallow well and hand pumps	Namibia	Imported					
Field application systems/technologies							
Drip systems							
Drip irrigation system	Malawi	Imported	2003	19.00		Poor, non-poor	10-50
Drip kits	Lesotho, Zimbabwe	Imported	2000	200.00	13.00	Ultra-poor, poor	
Commercial drip (dripper lines)	Swaziland	Imported				Non-poor	
Clay pot subsurface drip irrigation	Zambia	Indigenous	1995	50.00	0.50	Poor, non-poor	60
Low cost bucket/drum kit drip irrigation	Zambia	Imported	1999	440.00	13.00	Ultra-poor, poor, non-poor	
Drip irrigation	Tanzania	Imported	2005	15.00	3.75		
Sprinkler systems							
Sprinkler irrigation system	Malawi	Imported		192.00		Poor, non-poor	40.8
Hill spring water gravity head sprinkler irrigation (?)	Zambia	Indigenous	1980	100.00	20.00	poor	90
Low pressure gravity fed sprinkler	Malawi	Imported	1980	5.00	7.00	Poor, non-poor	
Semi-portable sprinkler (communal scheme)	Swaziland	Imported		NA	NA	NA	
Direct applicator hose pipes	Swaziland	Indigenous					
Bag gardening	Malawi	Imported	2003	4.00	4.00	poor	
Micro jets	Swaziland	Imported					
Center pivot irrigation	Swaziland	Imported					

Table b: Agricultural water management technologies: In-situ SWC/conservation agriculture

In-situ SWC/Conservation Agriculture	Country	Source	Year	No. beneficiaries	Area (ha)	Profile of Beneficiaries	Proportion of women
Conservation Agriculture							
Permanent strip farming	Botswana	Imported				Poor	
Conservation farming	Malawi	Imported	2004	300.00	60.00	Poor, non-poor	35
Minimum tillage	Tanzania	Imported	1991			Poor, non-poor	50
Erosion Control							
Contour cultivation	Malawi	Indigenous	1964	4237.00	1113.00	Poor, non-poor	50
Gully control	Malawi	Indigenous		6000.00	140.00	Poor, non-poor	40
Vegetative Cover							
Vegetative Cover	Malawi	Imported	1990	679.00	369.00	Poor, non poor	40
Mulching	Tanzania	Indigenous	1900			Poor, non-poor	50
Ridging and Bunding							
Ridging	Tanzania	Indigenous				Poor, non-poor	50
Paddy field bunding	Tanzania	Indigenous	1950			Poor, non-poor	70
Tied ridging	Malawi	Indigenous		2938.00	5000.00	Poor, non- poor	20
Micro-catchment systems	Mozambique	Indigenous		250.00	300.00	poor	80
Water seeding (rainwater harvesting) half moon	Zimbabwe	Indigenous					
Small earth bunds/raised footpaths	Malawi	Imported	1970	1100.00	800.00	Poor, non poor	20
Micro basin water harvesting	Zambia	Imported	2000	250000.00	300000.00	Ultra-poor	80
Terracing							
Fanya juu terraces	Malawi	Imported	1973, 2005			Poor, non poor	80
Stone lines	Malawi	Indigenous	2001			non-poor	100
Terracing	Malawi	Imported	1970	500.00	800.00	Poor, non-poor	20
Ladder terracing	Tanzania	Indigenous	1920			Poor, non-poor	50
Planting Pits							
Chololo pits	Tanzania	Indigenous	1989				50
Ngoro pits	Tanzania	Indigenous				Poor, non-poor	50
Planting pits	Malawi, Namibia	Indigenous	2003	18	4.00	Non-poor	50
Nombete (planting beds)	Namibia	Indigenous	2000	6.00	9.00	Ultra-poor	
Debushing for aquifer recharge and improved grazing	Namibia						

Swamp/Flood Recession							
Residual moisture	Malawi	Indigenous		30.00	60.00	poor	50
Zilili River flood plain recession irrigation	Zambia	Indigenous	1960	500.00	50.00	poor	80
Inland valley swamp irrigation (*dambos*)	Zambia	Indigenous	1960, 1975	400000.00	100100.00	poor	80
River flood plain irrigation/wet season	Mozambique	Imported	1950	1000.00	3000.00	poor	60
Swamp irrigation/fresh water swamps	Mozambique	Indigenous	1950	350000.00	465000.00	Poor, non-poor	60
River flood plain irrigation/dry season/ Cegonha	Mozambique	Indigenous		150.00	200.00	Poor, non-poor	45
Omarumba: valley bottom cultivation	Namibia	Indigenous				Poor, non-poor	
Silted sand valley farming (Kilimo cha mchangani)	Tanzania	Indigenous				Poor, non-poor	50

Table c: Agricultural water management technologies/practices: Ex-situ RWH/storage

Ex-situ RWH/Storage	**country**	**Source**	**year**	**No of beneficiaries**	**Area (ha)**	**Profile of beneficiaries**	Proportion of women
Water Storage and Control							
Low-cost gutter technique using waterproof shade	Zimbabwe	Indigenous	1998			Poor, non-poor	
Under ground tanks	Malawi	Imported	2005	250.00	600.00	Poor, non-poor	50
Small dams	Botswana	Imported				poor	
Small earth dams	Malawi	Indigenous	2001	100.00	5.00	Poor, non-poor	40
Small earth dam (*Ndiva)*	Tanzania	Indigenous		50.00	15.00	Poor, non-poor	50
Charco dam	Tanzania	Imported	1930	500.00	2.00	Poor, non-poor	50
Hill irrigation	Mozambique, Zimbabwe	Indigenous	colonial time	8500.00	2100.00	Non-poor	40
Pond improvement	Botswana	Indigenous				poor	
River impounding	Malawi	Indigenous				Poor, non-poor	80
Groundwater							
Boreholes, water points	Namibia	Imported	1993		6877	poor	50
Improved wells	Botswana	Indigenous				poor	
Shallow wells	Malawi	Indigenous	2005	200.00	400.00	poor	60
Underground water springs	Malawi	Imported	1991	40.00	25.00	Poor	20
Diversions							
Retention ditches/infiltration pits	Malawi	Imported	2004	15.00	36.00	poor	20
Stream or flood diversion	Malawi	Indigenous	2004	1500.00	400.00	Poor, non-poor	56
River diversion irrigation system	Malawi	Indigenous	2004	48.00	8.00	Poor, non-poor	42

Harvesting/storage							
Roof harvesting with above ground tank	Malawi, Tanzania	Imported	2005	510.00	540.00	Poor, non-poor	70
Roads/footpath runoff harvesting	Malawi		2004	300.00	450.00	poor	30

Sources: Partners' reports and inventories.

Appendix 2: List of Reports Prepared under this Project

Note: All these reports are available from IWMI, and are contained on the CD.

Daka, A. 2006. Micro-irrigation and water harvesting technologies: Experiences and their contribution to poverty alleviation in Zambia. Report written for IWMI. Pretoria, South Africa: IWMI. [and Inventory]

De Lange, M. 2006a. A literature study to support the implementation of micro-AWM technologies in SADC. Report written for IWMI. Pretoria, South Africa: IWMI.

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De Lange, M. 2006c. Report on experiences with micro irrigation technologies: Namibia. Report written for IWMI. Pretoria, South Africa: IWMI. [and Inventory]

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IWSD. 2006d. Experiences with micro irrigation technologies and practices: Zimbabwe. Report written for IWMI. Pretoria, South Africa: IWMI. [and Inventory]

Mangisoni, J. 2006. Impact of treadle pump irrigation technology on smallholder poverty and food security in Malawi: A case study of Blantyre and Mchinji Districts. Report written for IWMI. Pretoria, South Africa: IWMI.

Marques, M. 2006. Inventory of agricultural water technologies and assessment of poverty impacts: Mozambique. Report written for IWMI. Pretoria, South Africa: IWMI. [and Inventory]

Mloza-Banda, H. 2006. Experiences with micro irrigation technologies and practices: Malawi. Report written for IWMI. Pretoria, South Africa: IWMI. [and Inventory]

Soil and Water Management Group (SWMRG). 2005. Experiences with micro irrigation and rainwater harvesting technologies: Tanzania. Report submitted to IWMI. Morogoro, Tanzania: Soil and Water Management Group, Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture. [and Inventory]

Appendix 3: South Asia Experience—Costs and Benefits of Selected Micro-AWM Technologies

There has been widespread use of micro-irrigation technologies in Southern Asian countries, specifically India, Bangladesh and Nepal. The motivation for adopting the technologies varies among these countries. In India, even with full utilization of the water potential, a little less than 50% of the cultivated area will remain rain-fed (Sivanappan 1988, 1994).Thus more efficient use of available land and water resources is considered to be an important means to expand irrigation benefits (Government of India 1995, Dhawan 1995, Saleth 1996). In Bangladesh, the abundance of shallow groundwater necessitated the use of various forms of motorized and manual pumps. In Nepal the focus is on reducing poverty in hill and *terai* (plains) areas through on-farm income generation, enabled by the introduction of appropriate irrigation technologies and the development of integrated agricultural markets. Thus the experiences from these countries are relevant to the diverse needs of the southern African countries.

In India, drip irrigation (in its various forms – conventional drip systems, indigenous pot drips, sub-surface drips, bucket drip kits, micro-tubes, easy drip, family drip kits and locally manufactured and assembled kits like *Pepsee*[23]) is the dominant mode of micro-irrigation since the 1970s. These technologies enjoy significant government and NGOs research and development support. Micro-irrigation adaptation and dissemination efforts started with preliminary research studies by National Committee on the Use of Plastics in Agriculture (NCPA), Indian National Committee on Irrigation and Drainage (INCID), Mahatma Pule Agricultural University (MPAU), Tamil Nadu Agricultural University (TNAU), Haryana Agricultural University (HAU), etc. This is in contrast to the situation in Africa where the dissemination efforts are not well supported by adaptive research. The results of these adaptive research activities in India are summarized in the Tables 1 to 4.

Table 1 compares yields and water supplied for eight crops under drip and conventional irrigation systems. The data show 23-88 percent increase in crop yields and 36-68 percent saving in water supplied.

Table 1. Yields and water use for selected crops under conventional and drip irrigation systems in India

Crop	Yield (kg/Ha)			Water Supplied (cm)		
	Conventional	Drip	% Increase	Conventional	Drip	% Saving
Banana	57500.0	87500.0	52	176.00	97.00	45
Grapes	26400.0	32500.0	23	53.20	27.80	48
Sugarcane	128000.0	170000.0	33	215.00	94.00	65
Tomato	32000.0	48000.0	50	30.00	18.40	39
Watermelon	24000.0	45000.0	88	33.00	21.00	36
Cotton	2330.0	2950.0	27	89.53	42.00	53
Chillies	4233.0	6088.0	44	109.71	41.77	62
Papaya	1340.0	2348.0	75	228.00	73.30	68

Source: Compiled by Verma 2003 based on *NCPA,* 1990

Tables 2 and 3 are compilations of results from various research publications and compare water saving, yields and water productivity under drip and traditional methods of irrigation for ten

[23] Pepsee is basically a disposable drip irrigation system consisting of a lateral with holes.

crops in India (Sivanappan et al. 1987; Agarwal and Goel 1981; Sivanappan and Padmakumari 1980; Sivanappan 1977; Muralidhara et al. 1994; Paul and Sharma 1999; Narayanamoorthy 1999). The results in Table 2 show 13.5-69.5 percent increase in yields and 25.0-79.3 percent water saving.

Table 2. Water saving and yields for various crops under drip irrigation relative to conventional systems

Crop	% Water Saving	% Increase in Yield
Cotton	66.27	25.00
Sugar beet	25.05	17.09
Sweet potato	60.06	38.73
Beetroot	79.34	55.34
Radish	75.72	13.49
Papaya	67.89	69.47
Mulberry	60.00	3.03
Coconut	48.00	19.00
Mango	25.00	33.00
Sapota	25.00	31.00
Banana	29.16	29.10
Grapes	37.28	19.07

Source: Verma 2003.

Table 3 shows the water productivity of the drip and conventional irrigation methods for different crops. For all of the crops considered, the drip method of irrigation resulted in a significant higher water productivity as compared to the conventional methods of irrigation.

Table 3. Water productivity for various crops under different irrigation methods

Crop	Water Productivity (kg/m^3)	
	Conventional	Drip
Cotton	3.1	11.6
Sugar beet	85.0	132.0
Sweet potato	6.7	23.4
Beetroot	0.7	5.0
Radish	2.25	11.0
Papaya	0.06	0.32
Mulberry	138.6	375.0

Source: Adapted from Verma, 2003.

Table 4 is a compilation of similar results from different research stations in India for sixteen crops and shows yield benefits of up to 77 percent and water saving of up to 80 percent through the adoption of drip irrigation systems.

Table 4. Comparative advantage of drip irrigation over flood irrigation: Results from different research stations

Research Institute	Crop	% Water Saving	% Yield Increase
MPAU, Rahuri	Sugarcane	30.0	20.0
TNAU, Coimbatore	Sugarcane	47.0	29.0
MPAU, Rahuri	Cotton	43.0	40.0
TNAU, Coimbatore	Cotton	79.0	25.0
MPAU, Rahuri	Tomato	30.0	5.0
TNAU, Coimbatore	Lady Finger	84.0	13.0
MPAU, Rahuri	Brinjal	47.0	-
MPAU, Rahuri	Chili	62.0	44.0
TNAU, Coimbatore	Radish	77.0	13.0
TNAU, Coimbatore	Beet	80.0	56.0
TNAU, Coimbatore	Sweet Potato	61.0	40.0
HAU, Hissar	Potato	-	46.0
HAU, Hissar	Onion	-	31.0
TNAU, Coimbatore	Banana	77.0	-
TNAU, Coimbatore	Papaya	68.0	77.0
Jyoti Ltd., Vadodara	Lemon	81.0	35.0
Jyoti Ltd., Vadodara	Groundnut	40.0	66.0
Jyoti Ltd., Vadodara	Coconut	65.0	12.0

Source: Verma 2003.

Costs

The cost of micro-irrigation technologies in South Asia is influenced by many factors including the nature of the technology (i.e., conventional micro-irrigation vs. low cost micro-irrigation), crop type, spacing, and type of supplier. The results of the numerous studies on the initial investments required for micro-drip and sprinkler systems, and the benefit-cost (B-C) ratios for the investment are presented in Tables 5 to 7. Table 5 lists the capital costs and B-C ratios for nine different crops with varying spacing for conventional drip irrigation systems. The costs range between US$352.0 and 1075.3 per hectare. The B-C ratios vary from 2.78 to 32.32.

Table 5: Benefit cost ratio of different drip irrigated crops

Crop	Spacing (m x m)	Capital Cost (US$/ha)	Benefit Cost Ratio
Coconut	7.62 x 7.62	352.0	1.41
Grapes	3.04 x 3.04	605.7	13.35
Grapes	2.44 x 2.44	734.7	11.50
Banana	1.52 x 1.52	1075.3	1.52
Orange	4.57 x 4.57	632.5	1.76
Pomegranate	3.04 x 3.04	608.6	1.31
Mango	7.62 x 7.62	352.0	1.35
Papaya	2.13 x 2.13	747.3	1.54
Sugarcane	b/w bi-wall 1.86	1002.9	1.31
Vegetables	b/w bi-wall 1.86	1002.9	1.35

Sources: Narayanamoorthy 1999, compiled from INCID 1994.

Table 6 provides capital costs and B-C ratios for twelve horticulture crops and here the costs are much higher. The per ha capital costs range between US$ 1995.4 and US$ 9347.0. The B-C ratios range between 1.08 and 4.23.

Table 6: Benefit cost ratio of various horticultural crops under trickle irrigation system

Crop	Spacing (m x m)	Capital Cost (US$/ha)	Benefit Cost Ratio
Mango	10 x10	2138.5	1.30
Oil Palm	9 x 9	2557.3	1.72
Coconut	8.2 x 8.2	2129.0	1.08
Sapota	7.6 x 7.6	1995.4	2.07
Guava	6.1 x 6.1	2297.2	1.55
Ber (an indigenous fruit)	6.1 x 6.1	2138.2	1.56
Citrus	6.1 x 6.1	2414.1	1.99
Grapes (Anab-e-shahi)	4.6 x 4.6	7972.9	1.68
Grapes (Thompson Seedless)	4.6 x 4.6	9347.0	1.57
Pomegranate	4.3 x 4.3	2691.1	4.23
Coccima India	3 x 3	4221.3	1.11
Rose	1.2 x 1.2	5363.1	3.08

Source*:* Reddy and Reddy 1995.

Table 7 compares the subsidized and unsubsidized investment costs for different micro-irrigation systems and crops. It can be concluded that the farmers enjoy substantial privileges and incentives to adopt water saving technologies.

Table 7. Comparison of subsidized and unsubsidized investment costs for selected micro-irrigation technologies in India

Crop	Micro-irrigation technology	Investment cost (US$)	Subsidized investment cost (US$)
Banana	Low cost drip	626.1	313.0
	Conventional drip	1258.6	629.3
Groundnut	Micro-sprinklers	508.9	254.5
	Conventional sprinklers	686.5	343.2
Cotton	Low cost drip	230.7	115.4
	Conventional drip	1048.6	524.3

Source: Namara et al. 2005.

Clearly, the conventional systems may be beyond the financial reaches or the land sizes of many of the small-scale farmers in the region. Thus efforts have been made by both government and private agencies to reduce the initial investments required. Especially, the government of India, realizing the yield and water saving potential of the technologies, has provided numerous subsidies to allow poor farmers to adopt these technologies. The government released Rs. 11.96 Crores (=US$2,736,842) to state governments under centrally sponsored schemes between 1982-83 and 1991-92, for the promotion of drip, sprinkler and other water saving irrigation systems and practices (Narayanamoorthy and Deshpande 1997, 1998).The subsidy rates are based on criteria that include the socioeconomic status of the farmer, the type of micro-irrigation and crop (Namara et al. 2005). For instance, for sericulture, the subsidy was fixed at 50% for general farmers, 70% for women and 90% for scheduled castes and scheduled tribes; for horticulture, it was 30% for general category farmers and 50% for the scheduled castes and scheduled tribes.

The subsidy has attracted a large number of companies into micro-irrigation business. All in all, there are over 75 companies in India manufacturing and selling drip irrigation systems (Namara et al. 2005). Some of these market players supply unbranded products to farmers offering substantial opportunities for economizing on capital investment. Consequently, for instance farmers in Maharashtra India were able to install drip systems at US$323.8-US$397.9/hectare by assembling them with gray market material. The Indian Standard Institute-approved products could cost them about US$710.5/hectare (Shah and Keller 2002).

Several NGOs have also done their bit in promoting drip technologies, micro-sprinklers, low cost pumping and storage technologies in Southern Asian countries and in India in particular. International Development Enterprises (IDE) has developed low cost drip irrigation systems (drum kits, bucket kits, etc) for poor farmers which cost less than US $250 per hectare (Polak et al. 1997a, 1997b). The unit and per ha costs of some of these technologies compiled from different sources is presented in Table 8 below.

Table 8. Investment costs for low cost drip and sprinkler systems

Micro-irrigation technologies	Price per unit (US$)	Cost (US$/ha)
Pepsee[1]	0.01/ m^2	98.8
Easy drip[1]	0.04/m^2	400
Bucket kit[2]	6	1500
Drum kit[2]	20	1666.7
Tank kits[2]	63	-
Customized systems[2]	190	470
Micro-tube drip, IDE, Horticulture[3]	-	397.9-454.8
Micro-tube drip, IDE, Mulberry, paired row system[3]	-	1136.9-1421.2
Micro-tube drip, IDE, Mulberry, pit system[3]	-	1136.9
Drip system, 125m^2, 80 drippers[4]	14	1120
Drip system, 250m^2, 160 drippers[4]	21	840
Drip system, 500m^2, 320 drippers[4]	35	700
Micro-sprinklers, 2 heads, 125m^2 area[4]	7	560
Micro-sprinklers, 4 heads, 250m^2 area[4]	10	400
Micro-sprinklers, 8 heads, 500m^2 area[4]	15	300

Source: [1]Keller and Keller, 2003; [2]ITC et al., 2003; [3]Shah and Keller, 2003; [4]Siminet, 2005

In addition to drip and sprinkler systems, water lifting technologies such as treadle pumps are also widely used in Southern Asian countries, particularly in Bangladesh, Nepal terai and eastern India. In Bangladesh 1.3 million units have been sold since the technology was introduced in the mid-1980s. In Eastern India and the Nepal Terai, there is an ultimate market potential of 10 million treadle pumps (Shah et al. 2000). The ever increasing fuel prices may even further enhance the demand for treadle pumps at the expense of diesel pumps. In Bangladesh, the cheapest bamboo treadle pump costs around US $12. The more expensive metal and concrete pumps cost between US $25 to $35 dollars.

IDE Nepal has been developing markets for agricultural inputs, including micro irrigation technologies since 1993, which includes a foot-powered treadle pump for pumping ground water in the plains region, and local versions of drip, micro-sprinkler and mini-water storage systems for upland farmers in the hills. The mini-water storage systems are for storing upland water/rainwater for micro-irrigation of high value crops during gaps in rainfall. The unit cost of the different sizes and models of these storage structures are shown in Table 9.

Table 9. Unit cost of low cost water storage systems introduced by IDE in Nepal

Type	Size (l)	Cost per unit (US$)
Cement Mortar Jar	500	29
Cement Mortar Jar	1000	40
Modified Thai Jar	1500	54
Modified Thai Jar	3000	100
Ferro Cement Lining	6000	153
Ferro Cement Lining	10000	196

Source: Siminet, 2005

In Nepal, IDE has been supporting the production of vegetable crops to increase the cash income of small farm units. The goal has been to transform farmers from subsistence to micro-enterprise market production orientation. IDE has worked with over 27,000 farmers who have increased their annual net income, on average, by more than $100. The majority of these farmers were not commercial growers prior to involvement in IDE programs.