Irrigation Techniques for Small-scale Farmers

KEY PRACTICES
for DRR Implementers

Humanitarian Aid
and Civil Protection

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Irrigation Techniques for Small-scale Farmers: Key Practices for DRR Implementers

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This brief is part of the series, *A Field Guide for Disaster Risk Reduction in Southern Africa: Key Practices for DRR Implementers*, coordinated by the FAO Subregional Office for Disaster Risk Reduction/Management for Southern Africa. This series has been produced with contributions from COOPI, FAO, OCHA and UN-Habitat, and comprises the following technical briefs:

- Information and Knowledge Management (COOPI)
- Mobile Health Technology (COOPI)
- Safe Hospitals (COOPI)
- Disaster Risk Reduction for Food and Nutrition Security (FAO)
- Appropriate Seed Varieties for Small-scale Farmers (FAO)
- Appropriate Seed and Grain Storage Systems for Small-scale Farmers (FAO)
- Farmer Field Schools (FAO)
- Irrigation Techniques for Small-scale Farmers (FAO)
- Management of Crop Diversity (FAO)
- Community-based Early Warning Systems (OCHA and FAO)
- Disaster Risk Reduction Architecture (UN-Habitat)

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Humanitarian Aid and Civil Protection

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Foreword by ECHO

The southern Africa and Indian Ocean region is extremely vulnerable to cyclones, floods, droughts and tropical storms. These recurrent climate-related shocks negatively affect the highly sensitive livelihoods and economies in the region, and erode communities' ability to fully recover, leading to increased fragility and vulnerability to subsequent disasters. The nature and pattern of weather-related disasters is shifting, becoming unpredictable, and increasing in frequency, intensity and magnitude as a result of climate change. Vulnerability in the region is further compounded by prevailing negative socio-economic factors, such as high HIV rates, extreme poverty, growing insecurity and demographic growth and trends (including intra-regional migration and increasing urbanization).

The European Commission's Office for Humanitarian Affairs (ECHO) has actively engaged in the region through the Disaster Preparedness ECHO (DIPECHO) programme since 2009, supporting multi-sectorial disaster risk reduction interventions in food security and agriculture, infrastructure and adapted architecture, information and knowledge management, water, sanitation and hygiene, and health. This programme operates with two objectives, notably:

- Emergency preparedness by building local capacities for sustainable weather-hazard preparedness and management, including seasonal preparedness plans, training, emergency stocks and rescue equipment, as well as Early Warning Systems.
- Empowering communities through multi-sectorial and multi-level approaches with DRR mainstreamed as a central component and improved food and nutrition security as an outcome.

This is done in alignment with national and regional strategies and frameworks.

For DIPECHO, one of the main measures of success is replicability. To this end, technical support through guidelines established for DRR implementers is a welcome output of the DIPECHO interventions in the region. ECHO has supported regional partners, namely COOPI, FAO, UN-Habitat and UN-OCHA, to enhance the resilience of vulnerable populations in southern Africa by providing the funding to field-test and establish good practices, and to develop a toolkit for their replication in southern Africa. It is the aim of the European Commission Office for Humanitarian Affairs and its partners to fulfil the two objectives sustainably and efficiently through the practices contained in this toolkit to ensure the increased resilience of the most vulnerable populations in the region.

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Foreword by FAO

The southern Africa region is vulnerable to a diverse array of hazards, largely linked to environmental causes (such as drought, cyclones and floods); human, animal and plant diseases and pests; economic shocks; and in some areas socio-political unrest and insecurity, among others. The region's risk profile is evolving, with new factors becoming gradually more prominent, including a trend towards increased urbanization, migration and mobility, among others. Natural hazards will be progressively more influenced by trends in climate change. Disasters in the region are often composite and recurrent, and have a dramatic impact on livelihoods and on southern African countries' economy and environment, often undermining growth and hard-won development gains.

Increasing the resilience of livelihoods to threats and crises constitutes one of the Strategic Objectives of FAO's Strategic Framework (Strategic Objective 5, or SO5). FAO specifically aims at building resilience as it relates to agriculture and food and nutrition security, which are among the sectors most severely affected by natural hazards. The impact of shocks and disasters can be mitigated and recovery can be greatly facilitated if appropriate agricultural practices are put in place; improving the capacity of communities, local authorities and other stakeholders is therefore central to resilience building.

Together with partners, FAO is undertaking intensive work in southern Africa to consolidate the resilience of hazard-prone communities; this is leading to an improved knowledge base and to documentation of good practices. This toolkit purports to disseminate improved methods and technologies on key aspects of agriculture, such as appropriate seed varieties, irrigation, storage systems, land and water use and Farmer Field Schools, in the hope that they may serve different stakeholders to improve their resilience-building efforts. A multi-sectoral approach and solid partnerships are seen as key to the success of resilience-building work. For this reason, this toolkit also includes non-agricultural aspects of good resilience practices, contributed by FAO partners: the UN-OCHA, UN-HABITAT and COOPI, which certainly strengthen this collection.

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Acronyms and Abbreviations

DRR/M .... disaster risk reduction/management
IPM .... integrated pest management
FAO .... Food and Agriculture Organization of the United Nations
FFS .... farmer field school
FWM .... farm water management
GO .... governmental organization
NGO .... non-governmental organization
NRL .... FAO Land and Water Division
O&M .... operation and maintenance
PEP .... polyethylene pipes
PT&E .... participatory training and extension
PVC .... polyvinylchloride
SPFS .... Special Programme for Food Security
ToT .... training of trainers
US$ .... United States Dollar
WUA .... water users association

1. Introduction

Background and justification

The recurrent emergencies in southern Africa[1] caused by natural and biological hazards, such as floods, drought, cyclones, pests and diseases have exposed an important segment of the population to high levels of vulnerability. This is sometimes further aggravated by civil strife, HIV/AIDS and economic set-backs. Climate change, and the expected increase in the frequency and severity of extreme weather events, will affect the agriculture sector, thereby increasing the risks faced by the rural populations, the majority of which are dependent on agriculture for their livelihoods and food security.

International emergency programmes have done much to overcome the immediate shocks of extreme events and emergencies by providing immediate food and shelter needs and to redress the negative impacts on people's lives and their livelihoods.

There is a need to not only focus on response, but to also increase the resilience[2] of vulnerable communities through prevention and reduction of the impact associated with disruptive events and increasing people's preparedness for response in order to reduce their vulnerabilities. Disaster risk reduction/management (DRR/M) and climate change adaptation have been assigned a high priority in the FAO corporate strategy in order to support governments to better respond to natural disasters with adequate policies, institutions and coordination mechanisms, and to strengthen capacities at national and local levels to assess, reduce and adapt to climate and disaster risks.

To build the resilience of hazard-exposed small-scale farmers to recurrent natural disasters, the FAO's interventions promote the spread

1 Angola, Botswana, Comoros, DR of Congo, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.
2 The ability of a household to keep within a certain level of well-being (i.e. being food secure) by withstanding shocks and stresses.

of improved DRR methods and technologies on key aspects of agriculture and food security sectors, including conservation agriculture, crop production, appropriate seed varieties, land and water use and management, agricultural inputs supply, insurances, environmental rehabilitation, protective afforestation and irrigation, among others.

Objective and justification

To re-establish food production and create a farming system that provides for better food security and assurances for sustained production and income, the FAO aims to build upon its experiences over the past years in their DRR/M programmes and to provide practical guidance in the introduction of effective techniques and technologies that can assist hazard prone communities to overcome recurrent threats.

The introduction of appropriate agricultural water management techniques, including irrigation, would provide an attractive way to rapidly re-establish production and income, and to increase significantly the resilience of the local population to overcome subsequent emergencies.

Although responses in each type of emergency will be different, introduction of irrigation techniques will be, in most cases, a viable option:

- After floods and cyclones that occur in the rainy season, the introduction of irrigation in the subsequent dry season will allow farmers to grow an additional crop and facilitate an early recovery.

- In drought conditions, when irrigation will help to overcome shortages in precipitation and crop production can be substantially increased as a result of stable access to water.

A range of irrigation technologies have proved their effectiveness for different conditions related to climate, soil and available water resources. Selection of the appropriate technology according to the given agro-ecological context is a key to success or failure.

The introduction of new technologies to small-scale farmers has often failed, as both farmers and aid organizations have limited experience and technical knowledge to ensure the proper selection, installation and management of irrigation equipment and facilities in a given social and agro-ecological environment. This leads to inefficiencies, wastage of resources and/or technical failures of the provided equipment.

Intended application

This brief provides key practices for implementers and field staff engaged in various DRR and aid programmes as an initial introduction to the various irrigation techniques that have proved successful for small-scale farmers in southern Africa.

Practical examples of common irrigation technologies are provided with relevant illustrations, design concepts, technical requirements, as well as common constraints experienced in the introduction of the technologies. An indication of investment and operational costs is also provided for each irrigation technique. Principles and key steps required in the field to ensure the successful introduction of irrigation techniques are provided with steps and procedures for field based implementation.

These guidelines are based on extensive review of the successes and failures of irrigation techniques introduced under the Special Programme for Food Security (SPFS)[3] over a period of more than 15 years, mainly in Africa. These experiences demonstrate that the process of introducing and familiarizing farmers to the irrigation techniques from the planning phases is central to their success or failure. In this regard, due attention must to be given to the socio-economic context, as well as the tools and practices, such as the farmer field school (FFS), to assist farmers in adopting and adjusting to new technologies. Access to credit and markets must also be carefully considered for the long-term viability of the technology (see bibliography for further reading on these topics).

3 The FAO Special Programme for Food Security (SPFS) was launched in 1996 in the wake of the World Food Summit of 1996 with the specific aim of increasing food security and reducing hunger. Over a period of more than 15 years, the programme introduced new and improved technologies that would lead to a rapid increase in agricultural production and farm income in more than 100 countries. Water control technologies formed a key element in the set of technologies introduced. The review can be downloaded from the FAO website: http://www.fao.org/docrep/014/i2176e/i2176e00.pdf

2. Practical Examples of Common Irrigation Technologies

This section outlines a range of common irrigation technologies. Each technology is accompanied by:

- relevant illustrations
- design concepts
- technical requirements
- common constraints
- indication of investment and operational costs.

Figure 1: Vegetable irrigation by watering can

Watering can

The watering can provides a simple and accessible irrigation technique that is understandable and widely practiced by small-scale farmers for vegetable production. The technology requires low investments, but is labour intensive and allows irrigation of only a small garden/area (50 to 100 m^2.)

Table 1: Watering can conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Water source (rivers, streams, canals, drains, open shallow wells) in immediate vicinity (< 50m)	• Watering cans commercially available • Access to local market for horticultural products	• High labour input • Access to a nearby water source

Irrigation by watering can or bucket (Figures 1 and 2) provides many small-scale farmers with a simple way of growing irrigated crops. In some cases, locally sourced natural materials (e.g. bottle gourds) are used, but in most cases the watering can is locally produced from galvanized iron or plastic. Carrying the cans from the water source to the crop is labour-intensive and daily watering is required. In general, the water source should: not be more than 50 m away from the area to be irrigated; not be too deep; and allow easy access for filling the watering can.

A reservoir filled by small pump is sometimes constructed to facilitate access (Figure 3). Normally, irrigated gardens are found along rivers and streams or where surface and groundwater can easily be reached. The amount of labour required to carry water from source to field limits the area that can effectively be irrigated by a household, which is typically between 50 and 100 m^2.

Watering cans have been supplied in many emergency interventions, usually for small-scale vegetable production in groups – often women's groups. To help generate additional income, nearby markets are important for the sale of the vegetables; therefore, most irrigated vegetable gardens are usually found around urban centres and settlements.

Costs

It costs US$5 or less for a watering can that irrigates around 100 m^2, i.e. US$500 per hectare (ha). Sometimes additional costs are incurred when a water source has to be made accessible, for instance via a pump, reservoir or open well.

Labour costs are more substantial, however, and depending on the distance of the water source to the field, can vary between

Figure 2 (left): Watering with a bucket

Figure 3 (right): Using a watering can to access water from a concrete reservoir

US$1 200 and 1 500/ha per season (assuming US$1/workday and a crop with a water requirement of 3 000 m^3/ha).

Treadle pumps

Originally developed in Asia, the treadle pump has been extensively introduced in many African countries, and is promoted by several international agencies and specialized NGOs to show its potential. This micro-irrigation technique, which requires a relatively modest investment of around US$100, allows the small-scale farmer to irrigate a more substantial area than is possible with the traditional watering can method. Lifting water from up to a maximum depth of 7 m, the use of the treadle pump permits a typical area of 2 000 to 3 000 m^2 to be irrigated with at least four hours' daily pumping for an output of around 1L per second.

Treadle pump technology has been evaluated substantially since its first introduction in the 1970s, and a range of models has been developed by various organizations, including the FAO, using different materials and improving design and manufacturing. Two main types can be distinguished by the way the outlet operates: the pressure treadle pump and the gravity treadle pump (Figure 4). The pressure pump has proved more successful, as it can be connected to a flexible hose that allows direct watering of the crop (Figure 5).

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Figure 4 (left): Concrete gravity treadle pump

Figure 5 (right): Watering with pressure treadle pump

The spread of the technology was facilitated by promoting local manufacturers, often through separately financed projects and with the assistance of specialized international NGOs.

Yet the initial enthusiasm for the treadle pump has been tempered, as the technology showed a number of setbacks and limitations in several programmes, and proved less sustainable for a number of reasons. These constraints included:

- Poor quality of local manufacturing and frequent breakdowns;
- Inadequate technical advice for installation and operation of the equipment;
- Considerable daily labour required to pump water;
- Limitations, in particular of the gravity model, as the small volume of water cannot be transported over any distance to the crop;
- The high position needed for operating the treadle pump, in particular in the early models, causing discomfort to women; and
- Sharing of the treadle pump among a group of users proved less successful.

The treadle pump has been more successful in wetland development projects where groundwater can be found at a shallow depth (<3 m). When combined with well development, the pressure treadle pump can be connected via a set of low-pressure pipe distribution system and flexible hoses to distribute the water by sprinkling.

Table 2: Treadle pump conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Appropriate water source (surface or groundwater) should be close to irrigated area • Water lift not more than 7 m • Extension of existing irrigated garden area	• Farmers familiar with garden irrigation and access to market • Capacity for local manufacturing and after service • Demonstration and advisory services for improved field irrigation system	• Labour intensive and restricted to 3–4 hours/day • Area limited to 200–3,000 m^2 • Poor quality of local manufacturing • Inadequate field irrigation system

Costs

The investment for the pressure treadle pump, including a set of flexible hoses for intake and output, is around US$120 per treadle set irrigating 2 500 m^2, which means around US$500/ha; and labour costs to operate the treadle per season are estimated at US$150 per set or US$600/ha.

Motorized pumps

Motorized pumping has revolutionized irrigated agriculture and made an important contribution to securing food production and income for small-scale farmers in many countries.

These small low-cost motorized pumps (Figure 6), make attractive and successful technology suitable for an individual farmer or a group of small-scale farmers. Individual farmers may extend their garden plots to irrigate a larger area as a result of the motorized pump, while groups of farmers can irrigate a common or collective area. Equipment has proved reliable provided that adequate maintenance is undertaken and spare parts are available. However,

Figure 6: Small 1.5 hp petrol motor pump

fuel costs and access to fuel constitute a constraint for small-scale farmers. Larger pumps often pose management problems, as the larger irrigated areas require good conveyance and distribution systems, preferably with lined canals or low-pressure Polyvinylchloride (PVC) pipe and flexible hose outlets for smaller pump systems.

Table 3: Motorized pump conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Adequate surface or groundwater sources available in the vicinity of irrigated areas • Water level not to exceed 7 m at pump site • Opportunity for extension of irrigated area for single farmers • Assurances for good management and cooperation of farmers in pump users group	• Motor pump commercially available with maintenance services and spare parts available • Access to regular supply of fuel at affordable price • Access to markets for produce • Advisory services on selection, installation, field irrigation practices and maintenance • Adequate attention to conveyance system (canal lining or low-pressure pipe system)	• High investment costs • Availability fuel • Operational costs • Management problems in larger pump schemes • Low irrigation efficiencies due to unfamiliarity with water conveyance and field irrigation practices

Many small-scale and village irrigation schemes have been equipped with motorized pumps for areas of 5 to 200 ha, but organizing farmers into water users associations (WUA) to ensure adequate operation and maintenance (O&M) has been difficult: many pump schemes have failed due to poor cooperation among farmers.

Costs

The small low-lift motorized pumps driven by small petrol or diesel engines (Figure 7) with a capacity of 2 to 5 horsepower (hp) and a typical discharge of 2–15 L/second have proved cost-effective. The price of this centrifugal pump has substantially decreased as the result of imports from China and India, and is typically between US$200 and US$500, which more established small-scale farmers can afford, and allows them to irrigate a substantial area of 1 to 5 ha. The operational costs are mainly fuel costs, which are estimated at US$500/ha per season.

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Figure 7: Small motopump suitable for 2.5 ha of irrigated area

Solar pumps

Solar pumps allow users to avoid the constraint of the high fuel costs for motorized pumps. The electric pumps linked to the solar energy units have proved reliable and have low maintenance costs. Energy outputs of solar panels are limited, however, and in most cases a solar-driven electric pump may irrigate only a small garden area of 0.3 to 1 ha.

The solar pump unit (Figure 8) includes solar panels, a battery pack with current regulator unit for energy storage, and an electric motor linked to the water pump. To irrigate effectively, water needs to be stored in a water reservoir or tank and connected to a low-pressure pipe system or drip system.

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Figure 8: Solar panels, pump and reservoir for drinking water and garden irrigation

Table 4: Solar pump conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Water source (river, wells) with limited depth (<10 m) • Tube well development in case of groundwater • Adequate sunshine (8 to 12 KWh/m^2/day)	• Panels and suitable pumps commercially available • Construction of reservoir for 2 to 3 days storage to increase discharge and periods of low sunshine • Low-pressure pipe system or drip irrigation • Competent technical advisory services for design and installation	• High investment costs • Low discharge • Only small garden areas (of 0.3–1 ha) can be irrigated

Costs

Initial investment is very high and often difficult to justify economically. Estimates for the cost of batteries and electric regulators, electric motor pumps and a water reservoir are between US$10 000 and 15 000/ha. There are also extra costs to be taken into account if connected to either a low-pressure pipe system or drip irrigation system, which are most suitable for efficiently conveying the low pump discharges to the crop.

However, operational and maintenance costs for a solar system are relatively low at 50–100 US$/ha; therefore it may be worthwhile for farmers to consider the long-term investment benefits of using solar energy to pump irrigation.

Shallow wells

Groundwater has proved a reliable and accessible water source for irrigation. Several low-cost technologies have been developed including open well lining and shallow tube wells to improve access to groundwater for irrigation or drinking water. Water depth and variability in depth and quantity can be constraints as the common pump systems do not allow water to be pumped from a depth of more than seven metres.

Capacity building to train local drilling teams and provision of technical advice on suitable sites and procedures need to be ensured. Some international NGOs in southern Africa are now successfully engaged in the promotion of shallow well technologies and capacity-building of local craftsmen.

Figure 9: Open well development

Open wells

Traditionally, farmers have developed open wells, up to 15–20 m in depth (Figure 9), for drinking water and for garden irrigation using buckets (Figure 2). Open well development is most common, particularly in the bottoms of valleys and wetlands where groundwater is at a shallow depth and farmers dig open pits for bucket irrigation. Because in unstable and sandy soils shallow pits collapse easily, well construction techniques have been improved: the pits are lined with concrete rings (Figure 10), bricks or stone masonry, allowing groundwater to be sourced from greater depths.

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Figure 10: Open well lining

Table 5: Well conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Groundwater depth up to 15–20 m • Stable soil structure for wells without lining • Sandy soils require lining of the well for depth > 2 m	• Local artisans with traditional experience in well digging • Well stabilization by lining required for unstable soils (sand) • Technical advice manufacturing concrete rings and installation procedures	• Low discharge • Small area to irrigate • Technical knowledge for lining and manufacturing of concrete rings • Protection and visibility to avoid accidents

Costs

The costs for open wells can vary considerably depending on the well's depth and the equipment required for drilling; costs may vary between US$500 and 1 500 per open well fitted with concrete lining. Traditionally, open well digging carried out by local craftsmen (with or without brick lining) is a cost-effective option.

Shallow tube wells

Shallow tube well drilling is a relatively new and promising technique for southern Africa that has proved particularly effective with PVC tubing, which is now widely available, even in rural areas. Several new and cost-effective techniques for tube well drilling have been developed for different hydro-geological conditions, which allow drilling in various soil conditions, such as sand and hard stone layers.

Shallow well development techniques include:

- Augering of tube wells
- Rota sludge drilling for tube wells
- Percussion drilling
- Jet wash boring
- Stone hammer drilling
- Rotary rigs.

Specialized international NGOs have played an important role in the introduction of shallow tube wells and in training local entrepreneurs in new well development techniques, such as the rota sludge technology. Through the training of local drillers the technologies can be made available for farmers at affordable costs.

Costs

Shallow tube well drilling implemented by locally trained drilling teams fitted with 150 mm PVC pipes, may be as low as US$300–400 per unit, typically irrigating 1 ha of vegetables with a motorized pump (±US$250). Deep tube wells beyond 30 m require specialized drilling equipment and multiple stage pumps, thus the price of such a deep well pump can exceed US$10 000 per unit.

Canal and pipe conveyance systems

Water conveyance from intake to crops is an essential element of the irrigation system, in most cases done via a simple earthen gravity canal. Water losses in such a system can be quite considerable due to evaporation and seepage through the canal bottom, particularly in sandy soils. Moreover, if water regulating structures are absent or inadequate, water distribution will be uncontrolled, leading to possible canal breakages and water losses. Open gravity systems are usually about 40 percent effective, pump energy is wasted, and less area than planned is irrigated.

Providing farmers with an irrigation pump but no further technical advice on how to distribute water to the fields and crops, has frequently led to high water losses, disappointing performance, salinity and frequent failures overall.

It is therefore important in any irrigation system to pay adequate attention to the layout and design of the canal system In order to determine which system should be used, where improvements should or can be made, and which regulating structures should be included.

Pipe distribution systems are very efficient, but require significant investment and energy. Some basic principles of lay-out and main technical characteristics are elaborated below, but design and installation of both systems require adequate technical advice and support to be tailored to the specific situation.

Open gravity canal system

In an open canal system, water is taken in through a diversion structure or from pumps. For larger areas where water is to be carried over several kilometres, a network of secondary and tertiary canals is required. These canals require proper layout and design, taking into account regulating structures to control water flow and levels in the canals and the distribution of the appropriate quantity of water to each canal segment, field channel and field outlet. To reduce water losses in the canal and to prevent erosion, particularly in sandy and unstable soils, canal lining (Figure 11) should be considered for at least part of the canal system. Canal regulating structures (Figure 12) include flow and water level regulators, drop structures, inlets and outlets, as well as bridges and siphons for road and drain crossings.

Given these technical requirements, adequate technical support is required to ensure the proper design and installation of an irrigation canal system, even for small irrigated areas of less than one hectare. Besides the layout and construction of the canal system, farmers need to receive O&M training of the system, as well as advice regarding when and how much water needs to be applied to the various crops.

Figure 11 (left): Brick masonry lining of irrigation canal

Figure 12 (right): Canal regulation with drop structure and field inlets

Table 6: Canal system conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Reliable intake structure available (pump, dam, source, diversion) • Adequate water supply for irrigated area • Good potential for expansion of irrigated area • Low water efficiency of the actual conveyance system	• Adequate funds available for construction • Adequate technical assistance for design and technical advisory services for farmers • Local masons to be trained in small regulating structures • Motivated water users group prepared to substantially contribute to excavation and construction works	• High investment costs • Poor motivation of WUA members to pay fees for O&M • Conflicts in water use between upstream and downstream users • Complexity of water distribution • Lack of competent technical support services for O&M

Construction of a canal system involves excavation work for the secondary and tertiary irrigation and drainage canals as well as the flow-regulating structures. In addition, part of the earthen canal system may need to be lined in order to reduce losses and convey water over difficult canal stretches (Figure 13).

Costs

With basic assumptions of excavation costs of US$4 per m^3, concrete work at US$150 per m^3 for lining and cost of regulating structures, canal construction costs may amount to US$600–800/ha including partial lining (10 percent) and small regulation structures. To reduce the costs, local contractors should do as much of the work as possible. When large national or international contractors undertake the design and construction, costs are likely to be substantially higher and investment costs can range from US$3 000 to 8 000/ha.

Low-pressure pipe system

The low-pressure pipe distribution system (*système Californien*) has proved to be an effective and efficient irrigation technology for small-scale farmers and small farmers' groups for conveying water efficiently to fields and crops (Figure 14). In general, most materials (PVC or Polyethylene (PEP) pipes, flexible hoses) are locally available and farmers can install the system with minimal technical assistance, or with help from locally trained private irrigation technicians.

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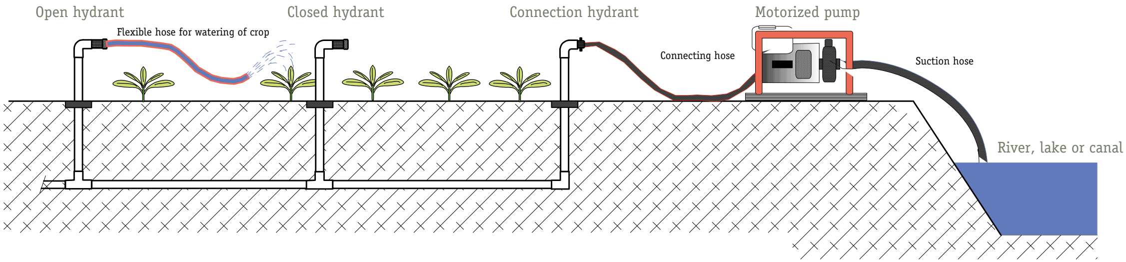
Figure 13: Canal erosion at motorized pump outlet



Modified from original drawing by M Smith

Figure 14: Layout of low-pressure pipe system

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Figure 15 (left): Buried PVC pipe system and outlets connected to flexible hose

Figure 16 (right): Watering by flexible hose

Table 7: Low pressure pipe system conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Water supply available from water lifting device (treadle pump, small motor pump) or small reservoir • Irrigated area some distance from water source • Extent of irrigated area >5,000 m^2 with possible extension • Suitable to be combined with dry-season irrigation in rice fields	• Treadle pump or motor pump available • PVC pipes and fittings locally available • Technical advice on design, installation and operation of system	• High Initial investment costs • Breakage of riser pipes

Used in combination with a small motorized pump, a pressure treadle pump, or gravity from an elevated small reservoir, the system efficiently is able to convey and distribute water directly to the irrigated areas (> 0.5 ha) and fields, rotating irrigation between the different pipe outlets. Pipe outlets or hydrants are placed at a regular distance (±20 m) on a fixed underground PVC system. The outlets can be opened directly to the field or connected to a flexible hose that can be dragged around to irrigate individual fields and crops (Figure 15). Low-pressure pipe systems have been successfully introduced in several African countries, mostly with assistance from technical agencies.

Costs

The investment required for low-pressure pipe systems is still high at around US$1 000 to 1 500/ha, but can easily be recovered as water allocation and easy operation ensure more accurate and efficient water application, resulting in higher yields, water savings and larger irrigated areas.

Sprinkler irrigation systems

Sprinkler irrigation has been widely introduced into communities and in individual schemes for both small and large areas. The technique includes a complete irrigation system with pump, distribution pipes and mobile laterals on which the sprinklers are placed. The system has high water efficiency, is easy to install, and the equipment is readily available on the market. However, high investment costs, as well as high fuel costs for the operation of the pressure pumps, have been a major constraint and are often a reason why the implementation of the technology failed or has been abandoned.

Table 8: Sprinkler system conditions, requirements and constraints

Technical conditions	Requirements	Constraints
• Adequate water supply from river, lake, reservoir or groundwater source • Mobility of irrigation system required • Supplemental irrigation • Low wind conditions	• Equipment commercially available • Pressurized pump system (2–3 bar) • Cheap energy available • Technical advice on design, installation and operation of the system	• High energy costs • High investment cost • Labour costs in moving laterals

In sprinkler irrigation, a pump takes up water from a water source (river, lake, canal or well) and conveys the water under considerable pressure (2–3 bar) through a lateral pipe system (partially underground, partially above ground), of quick-coupling light-weight tubes, which can be moved over the field to the crops (Figure 17). The sprinklers are fitted to the pipe system, and (Figure 18) water is sprinkled down through spray heads onto the crops in circular patterns. Water losses are low (<30 percent) and the system can be moved easily. No field levelling is required and limited labour is required to move the mobile pipelines along the field and connect the hydrants to the underground main-lines.

The system is used in a range of different sizes and designs and has also been used by small-scale farmers. Because of the mobility of the equipment, sprinklers systems have been applied successfully as supplemental irrigation in locations where rainfall is irregular or inadequate, which may save or boost crop production during dry spells.

Major constraints of the irrigation system are the considerable investment and operational costs. In particular the high fuel costs and energy requirements of the pressurized system make it one of the more expensive options and it has often proved to be uneconomical for most of the food crops cultivated by small-scale farmers.

Costs

Investment costs for the sprinkler system include a motorized pump with the capacity to provide sufficient pressure, as well as

Figure 17 (left): Moveable lateral aluminium sprinkler line

Figure 18 (right): Rotating sprinkler head the quick-coupling laterals, with sprinkler risers and the pressurized pipe system. Estimated investment costs of the sprinkler systems are around US$3 000–5 000/ha. Due to the amount of fuel required for this high-pressure system, operational costs are high, amounting to US$800–1 000/ha per season.

Drip irrigation systems

In drip irrigation, water is applied directly along the crop rows through small drippers fitted on flexible polyethylene tubes. The system can be very efficient in terms of water usage, reaching up to 90 percent, and it applies the water very accurately to the crop, which results in optimal crop yields. Drip irrigation is applied successfully in most high-level commercial fruit and vegetable farms and greenhouses.

Family drip irrigation and bucket drip irrigation systems have been commercially developed and introduced in southern Africa specifically for small-scale farmers. A 10–15 L bucket reservoir or 200–300 L fuel drum is placed at an elevated height (1–2 m) above the field and is connected to the small tubes and drippers (Figure 19) to irrigate a small vegetable garden area of 50 m^2 in the case of a bucket reservoir or 250–500 m^2 in the case of a drip irrigation with a larger reservoir.

Although an effective technology, drip irrigation systems for small-scale farmers have failed in several cases, as farmers have not been adequately familiarized with the operational aspects of

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Figure 19 (left): Installation of drip irrigation lines

Figure 20 (right): Filter in drip system the technology. Difficulties including the frequent filling of the bucket or reservoir; access to the water source; unfamiliarity with the frequency of water application; water not clean enough or with sediments; and failure to clean the filter system regularly (Figure 20), have been the cause of disappointing performance and failure of small-scale drip systems.

Table 9: Irrigation technology conditions, requirements and constraints

Irrigation technology	Technical conditions	Requirements	Constraints
Family drip kits	• Optimizing the available scarce water resources (dry season or arid region) • Water supply available from open well, hand pump or other water source • Good water quality (clean)	• Dripper equipment commercially available • Water reservoir of sufficient size available • Adequate provisions for lifting water in reservoir (treadle pump) • Technical advice on operation of drip system and frequency of irrigations	• Small area to irrigate (< 500 m²) • Labour to fill water reservoir • Clogging of drippers • Cleaning of filters • High investment cost • Unfamiliarity with dripper system (soil remains dry)
Bucket drip irrigation	• Small vegetable garden (50–100 m²) • Water from well or drinking water source	• Equipment fabricated from local materials • Technical advice on operation of the system	• Very small irrigated area (50 m²) • Frequent filling of the bucket • Unfamiliarity with dripper system

Costs

Commercial drip systems are around US$8 000–10 000/ha with energy costs estimated at US$500–700/ha.

The investment for a bucket or family drip irrigation system is considerable. Even though the costs of a bucket drip unit (US$50) and family drip unit (US$300) are relatively modest, the investment costs per hectare are still substantial (US$10 000–12 000/ha), as the area covered is quite small (50–250 m^2). Also the labour costs to refill the bucket and water tank regularly are quite significant and estimated at US$500–700/ha.

Small-scale and community irrigation systems

Small-scale and community irrigation systems have been widely introduced in southern Africa to promote irrigated agriculture for small-scale farmers. Systems may vary in size from 5 to 200 hectares and may include river diversion, small dams or pump schemes. Results have not always been positive due to lack of ownership and inadequate involvement of the community in planning. Operation and maintenance have proved a major challenge, and operational costs were often too high for the cultivation of food crops by small-scale farmers.

Three basic types of small-scale or community irrigation schemes can be distinguished, depending on how water resources are mobilized for irrigation, namely river and spring diversion schemes; pump schemes and small dam schemes.

Each system has specific design and operational characteristics, which will be outlined in the following sections.

Table 10: Irrigation schemes conditions, requirements and constraints

Irrigation system	Technical conditions	Requirements	Constraints
River or spring diversion	• Adequate water supply for two seasons • Reasonable distance (<2 km) from intake • Existing WUA	• Motivated WUA, prepared to substantially contribute in rehabilitation works and carry out O&M • Adequate funds available for diversion • Adequate technical assistance for design and technical advisory services • Intensive participatory training and extension (PT&E)	• Rehabilitation costs • Motivation of WUA members to pay fee for O&M • Tendering construction works • Support services to be provided for at least two years
Small earth dams	• Small streams • Favourable land formation (rolling) suitable for dam site • Suitable area (2–5 ha) to be irrigated near the dam site • Suitable soils for dam construction in vicinity	• Motivated water users group, prepared to substantially contribute in construction works • Adequate funds available for dam construction • Adequate technical assistance for design and technical advisory services to farmers • Specialised contractors for proper design and contractors with earth moving equipment experience	• High investment costs • Limited duration of water availability • Siltation • Flood damage risks • High maintenance • Motivation and capacity of WUA members to pay fee O&M • Support services to be provided for at least several years
Pump scheme	• Adequate water supply • Functioning main structural works • Existing WUA	• Motivated WUA, prepared to substantially contribute in construction works and carry out O&M • Adequate available funds for rehabilitation works • Adequate technical assistance from technical advisory services • Intensive farmers training (PT&E)	• Rehabilitation costs • Motivation of WUA members to pay fuel costs and O&M • Support services to be provided for at least two years

River and spring diversion

Farmers have traditionally erected small stone or pole and brush weirs in the riverbed to make simple diversions in rivers and streams. Groups of farmers sharing an inlet excavate the gravity canals and construct the simple structures. The inlet canal often runs over several kilometres before reaching the valley where the irrigated lands are situated.

These traditional structures require significant maintenance, and they are easily destroyed by floods, needing partial or full reconstruction almost annually. In addition, water control is difficult, resulting in large fluctuations in water supply at the inlet and canals. Many government and donor sponsored small-scale irrigation programmes have improved the construction by using concrete or masonry weirs and inlet structures. Stone-filled wire baskets (gabions) are examples of low-cost and durable weirs that can be constructed by farmer communities (Figure 21).

A typical diversion structure (Figure 22) includes a weir body with one or two inlet gates and a stilling basin to dissipate hydraulic energy. In most small-scale irrigation projects the main and secondary canals with regulating structures are included in the design of the project. Most gravity channels are unlined, except for fragile stretches (sand, unstable waterlogged soils).

Replacement of traditional weirs with a proper intake structure constructed of durable materials is a first step towards enhancing

Figure 21 (left): Improved diversion weir structure with stone-filled wire baskets (gabions)

Figure 22 (right): Diversion weir with stilling basin, sluicing gate and inlet canal water control, reducing annual reconstruction and water losses, and allowing larger areas to be irrigated.

Rainfall determines the level of discharge in the river and stream diversions. The design of the diversion structures must consider the (often substantial) fluctuations in discharge over the dry and wet seasons. Special precautions in dam design are required to manage extreme floods, heavy siltation and reduced water supply in the dry season. Moreover, several irrigation schemes may be constructed along the same river and conflict situations can develop when upstream users divert water at the cost of downstream use.

To support governments and implementing partners with the more technical aspects of the small-scale irrigation schemes, specialized consultancy firms are often engaged to carry out the studies and establish the design of the structures, while contractors carry out construction. Farmers' involvement in the design and concept of the works is often minimal. Although it is generally accepted that farmers contribute to part of the costs of the works (15–20 percent) by providing labour (earth works) or building materials (e.g. sand, gravel), their limited consultation from the beginning of the project can result in a lack of ownership and a weak WUA.

Operation and maintenance by the WUA is a major factor for success of the scheme. To succeed, WUA require assistance in areas such as building capacity, in setting rules and regulations on water distribution, in water use, maintenance of structures, and collection of water fees for maintenance works.

Costs

The investment in gravity diversion schemes can vary from country to country, and will depend on the complexity of the weir, the materials used and on the length and complexity of the inlet canal.

Table 11: Water diversion schemes, stakeholders and costs

Type of diversion weir	Design	Construction	Cost US$/ha	Remarks
Spring diversion	(N)GO agency	Small contractors	500–1 000	Simple inlet structure, small
New construction of diversion weir	Consultants	Contractors	6 000–15 000	Including canal excavation, regulating structures, fields
Reconstruction of traditional weirs	Consultants	Contractor	4 000–6 000	Standardized quality structures
Reconstruction of traditional weirs	Consultants (N)GO agency	Small contractors WUA	1 500–2 500	Local materials, lower quality structures
Rehabilitation of existing weirs	Consultants	Contractors	2 000–3 000	Standardized quality structures
Rehabilitation of existing weirs	Consultants (N)GO agency	Small contractor WUA	600–1 500	Simple local materials

Giving farmers greater responsibility and involving them in the design and construction of the irrigation system can result in much lower costs and significantly increase farmers' involvement in O&M of the system. This approach has proved successful when adequate and regular technical assistance is provided to farmers throughout the design and implementation phases. It is also important to follow a flexible timeframe that is adapted to include farmers, and takes into account their pace in adopting new technologies.

The life span of a diversion structure executed in concrete or solid masonry should be at least 10 years, while many structures may last as long as 30 years. Good maintenance and timely repairs are key factors in the durability and lifespan of the structure.

Pump schemes

Pumps for irrigation can simplify design and construction, eliminate the long intake canals of diversion schemes, and provide greater flexibility in scheme size and in selection of a suitable location near the area to be irrigated. The energy costs of running the pumps, however, off-set the reduced investment costs and prove a major constraint in many small-scale pump schemes.

With the installation of the pump, water can be pumped from a nearby source, such as surface water or groundwater. Surface water includes rivers, canals, streams and lakes. An advantage of pumps is their mobility and ability to easily adapt to varying water depths. In the case of groundwater, the pumps are placed on tube wells that can go to great depths, using multiple stage pumps driven by diesel engines or submergible electrical pumps.

Over the past 30 years, pump irrigation has significantly developed in several African countries, particularly along the main rivers in West Africa (Niger, Senegal River), as well as the rivers, lakes or reservoirs in East Africa and southern Africa.

The depth of the water source is a main factor when selecting this method and the type of pump to be used. Linked to this selection are the investment and operational costs of the pump and the motor connected to the pump, which is driven in most cases by diesel engine. If an electric grid can be reached, electrically driven engines are a more viable option.

Costs

The installation costs of a pump scheme are generally considerably lower than those of a diversion intake with a long head canal, but the fuel and repair costs are often constraints in many small-scale irrigation schemes and need to be carefully considered in close consultation with the farmers.

Operational costs will vary according to the elevation to which the water is to be pumped, and will determine the capacity of the pump as well as the fuel costs per hectare.

Estimated investment costs of pump schemes are around US$1 500–4 000/ha. Larger schemes are more expensive as the regulation structures in the canal system become more complex and require higher quality work and more skilled technicians for the installation of the system.

Depreciation of investment costs is not a major constraint, but fuel costs are a heavy burden and will demand US$300–500/ha per season.

Small earth dams

The construction of small dams may be an attractive solution to retain water from the rainy season into the dry season for drinking water, in particular for cattle, but also for irrigation. The small dams (Figure 23) are common in semi-arid and arid regions, which receive annual rainfall between 600 and 1 200 mm and have a landscape featuring rolling or hilly land. These areas are suitable for the construction of small dams in the valleys where small natural streams provide water to fill the reservoir formed behind the dam.

The length and height of the dams as well as the particular shape of the landscape determine the volume of water that can be stored. In general, the amount of water that can be stored and carried over into the dry season is limited, due to evaporation from the reservoir as well as underground seepage, which will result in considerable water losses.

A small dam with a length of 20 m long by 2 m high will generally irrigate 0.5 ha, while a dam 100 m long and 5 m high will irrigate 20–25 ha.

The dam body is constructed from earth that is excavated at a nearby location with the proper texture and structure and that

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Figure 23 (left): Small earth dam

Figure 24 (right): Spillway in masonry badly eroded by floods will compact well in order to assure dam stability and to minimize water seepage.

Special attention is to be given to the size and construction of the concrete or masonry spillway in order to provide an outlet for excessive floods. This is the weak spot in the structure of the dam, and is often subject to severe damage that can result in the collapse of the dam.

The risk of dam failure and the serious threat of a destructive flood wave should be taken into account particularly when the height of the dam exceeds 5 m. Therefore, the design of the dam requires specialized knowledge and skills to determine its proper siting, design and construction in order to minimize the risk of collapse.

The life span of the dam is determined by the risks of dam failure and siltation, as eroded soil from the catchment area will be deposited and slowly fill the dam reservoir, thus reducing the volume and effective life of the reservoir. Erosion control of the catchment could be a remedy to reduce siltation, but this is not an economical solution.

Costs

The construction costs of a dam can be substantial and are determined by many factors. A small farm reservoir may be constructed using simple excavation materials, with costs around US$2 500, while a larger construction could cost around US$50 000–100 000.

3. Key Principles and Practices for Selection and Installation

Key principles and key steps required in the field to ensure successful implementation of irrigation techniques

The following questions can help guide the selection of the irrigation technologies for field implementation:

Is water available for irrigation? Diagnosis of the environment and assessment of available water resources for irrigation development, with information to be collected on the following aspects:

- Description of climate and rainfall during the year
- Available surface and groundwater resources
- Distance of water source to fields to be irrigated
- Variability of water resources (fluctuations in depth and quantity).

Which areas can be irrigated with the available water resources? Delineation of the area that can be irrigated, taking into account:

- Suitable soils and land to be irrigated in terms of levelness and fertility
- Distance and level of water resources to the land to be irrigated
- Landscape, field lay-out and slope of the fields
- Quantity and availability of water that can be used for irrigation.

Which irrigation techniques are relevant? Assessment of the kind of irrigation techniques, as described in Section 2, which can be successfully introduced in the given environmental conditions (climate, soils, landscape) and agricultural context, taking into account:

- Water resources (quantity, quality, fluctuations)
- Access, distance and height from water resources to the field
- Costs and complexity of installation
- Operating costs (labour, fuel costs)
- Technical equipment and support services locally available.

What kind of crops can we irrigate? Assessment of potential, traditional knowledge and markets for irrigated crops

- What crops are traditionally grown by the farmers?
- Is irrigation practiced in the area, for which crops, in which season?
- Can irrigation readily be introduced in the dry season, in the wet season?
- Are irrigated crops used for self-sufficiency, and what percentage is sold?
- Is there a market for irrigated crops?

What is the social and economic context? Participatory diagnosis of the interest, motivation and capacity of hazard-prone farmers to adopt irrigation techniques, based on which an action plan can be prepared jointly with the farmers for the introduction of most suitable irrigation techniques. The following aspects should be taken into account:

- Are farmers already familiar with irrigation?
- Which irrigation techniques (and drainage and flood control practices) are currently being used?
- Which irrigation techniques are farmers most interested in and give priority to?
- What is the capacity of local farmers to successfully adopt the new techniques?
- Which materials and inputs do farmers require to install and operate the new technologies?
- Which training programmes need to be developed to overcome farmers' lack in knowledge and experience?

Based on the answers to these contextual questions, actions and programmes can be formulated with farmers, including:

- Action plan for installation and operation of the irrigation techniques, setting priorities, calendar and defining responsibilities of the community and aid organizations
- Programme for training and capacity-building and the possibilities of implementation of a farmer field school.

What support services are available? Assessment of public and private agencies that can assist farmers in the introduction of the new techniques:

- Which government agencies can assist farmers in the introduction of the new technologies (agricultural services, extension, irrigation departments)?
- Can NGOs and/or agencies specialized in rural development and irrigation technologies be mobilized to assist in the capacity building programme?
- Is irrigation equipment (e.g. pipes, irrigation equipment, pumps, well development) available on the local market?
- What capacity building and training is required for the government and NGO agencies to carry out the farmer training and to establish the necessary support services for farmers with local aid organizations and the private sector?
- Is credit available for farmers to install, operate and maintain the irrigation equipment?

Technical considerations and specifications

Introduction of irrigation is a complex process with a range of factors that determine the initiative's success or failure. These factors can be technical, agricultural, social or economic; they can also relate to the typical conditions of climate and environment that need further consideration.

To ensure the viability of irrigation technologies a feasibility study needs to be undertaken that includes a cost-benefit analysis of crops to be produced under irrigation, taking into account the investment and operational costs of the irrigation technologies, as well as the costs of agricultural inputs and market values of the crops to be produced.

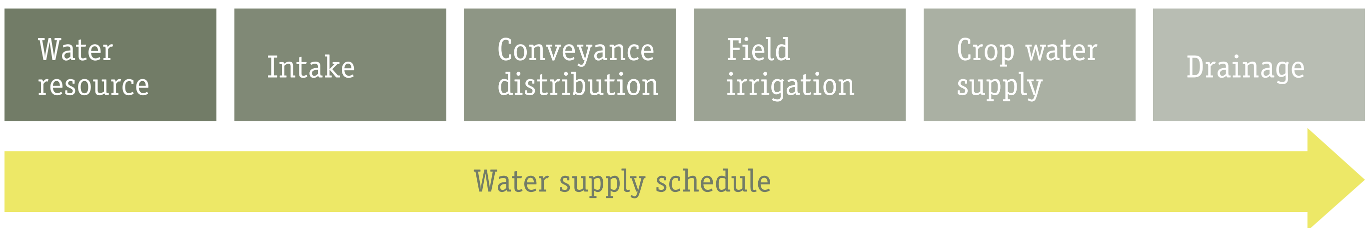

Figure 25: Schematic analysis of water supply system

Table 12: Main elements and techniques to be considered in typical irrigation systems

Irrigation system	Water resource	Intake	Conveyance & distribution	Field Irrigation	Crop water supply	Drainage flood control
Vegetable garden irrigation	River	Treadle pump	Low-pressure pipe system	Flexible hose	Irrigation calendar	Natural drains
Smallholder irrigation scheme	River	Diversion weir	Partial lining Offtakes and inlets	Basin and furrow irrigation	Rotational supply	Secondary drains
Dam scheme	Small Earth Dam	Motor pump	Lined canal	Furrow irrigation	Rotation and Calendar	Natural drain
Sprinkler irrigation system	River	Motor pump high pressure	Buried PVC pipes, hydrants, mobile lightweight laterals	Sprinklers	3–6 day rotation	Natural drains

In order to ensure that the irrigation techniques are successfully introduced it is essential to evaluate the full cycle of the water supply system from the water source to the irrigated field (Figure 25).

Providing farmers, for instance, with an irrigation pump without adequate provisions for the effective conveyance and distribution of the water through an appropriately designed canal or pipe distribution system has often led to high water losses, poor performance, and much smaller areas than planned being irrigated.

Similarly, consideration should be given to introduce more efficient field irrigation methods. These would include, for instance, the introduction of furrow irrigation, the levelling of farm plots for a more regular and efficient water distribution in the field, as well as introduction of flexible hoses for field sprinkling and drip irrigation systems.

Providing the crop with irrigation at the appropriate time and in the appropriate quantity requires experience and will depend on climate, rainfall, soil and crops stage, as well as the field irrigation system and irrigation technology used. Special computerized irrigation programmes such as the FAO CROPWAT[4] programme may be used to advise farmers about efficient water supply and schedule for the given climatic conditions, crop, soil and field irrigation method.

Drip irrigation systems, despite their potential for high irrigation efficiency and high production capacity, may perform

4 FAO CROPWAT is a computerized irrigation management program for the calculation of crop water consumption and irrigation requirements based on soil, climate and crop data. The program allows the development of irrigation schedules for different management and water stress conditions and the calculation of water supply for varying crop patterns. The programme can be downloaded from the website of the FAO Water Service: http://www.fao.org/nr/water/infores_databases_cropwat.html

poorly if farmers are unfamiliar with the importance of respecting the correct timing, frequency of irrigations and cleaning of filters.

To illustrate the main elements to be considered in an irrigation water supply system, the following tables provide examples of the various techniques used from water source to drain.

An overview of the main technical conditions, requirements and constraints of the main irrigation techniques are given in Table 13.

Table 13: Overview of technical conditions, requirements and constraints to be considered for the various irrigation techniques

Irrigation techniques	Technical conditions	Requirements	Constraints
Watering can	Which water source (river, open shallow wells) is in walking distance	Minimal investments Watering cans commercially available	High labour input
Treadle pump	Water source not deeper than 7 metres	Capacity building for local manufacturing Development market	Labour costs
Motor pump	Available surface and groundwater sources Financing of fuel costs	Motor pump commercially available Access to markets for produce	Investment costs Operational costs
Low-cost well development	Favourable hydro-geological conditions	Training of local drilling teams Development market	Well development costs
Solar pumps	Water source not too deep Construction of water reservoir	Commercially available and local services	Low discharge, small areas High investment
Low-pressure pipe distribution system	Motor pump or treadle pump available Small reservoir	Assistance for installation by local technicians	Installation costs
Drip irrigation	Limited water resources available Reservoir and pressure height	Trained staff for installation and management advice Availability of spare parts in the local market	Installation costs Efficient operation
Sprinkler irrigation	Pumping from nearby water source (surface or groundwater)	Commercially operated farm Supplemental irrigation	High installation and operational costs

Agricultural considerations

To ensure that the introduction of new irrigation techniques will create the potential to successfully produce a good crop and optimal crop yield, adequate attention needs to be given to: the selection of the crops and their appropriate varieties; the cropping calendar; agricultural practices; and the conditions under which the crops are grown. Moreover farmers need to have access to agricultural inputs, such as quality seeds, fertilizers, pesticides and tools, as well as the credit to buy the necessary inputs. Specific agricultural aspects to be considered and elaborated are shown below.

Selection of suitable crops for irrigation, taking into consideration:

- Cropping calendar of present common crops grown in the area during the wet and dry seasons, indication of seasonal hazards (drought, floods, pests and diseases)
- New crops with good potential to be introduced under irrigation
- Crops for self-consumption and food security
- Crops destined for the market
- Experience, motivation and priorities given by farmers in selection of the crops.

Suitable agricultural practices and inputs, taking into consideration:

- Present agricultural practices of common crops grown in terms of inputs, labour and tools

- New or improved agricultural practices to be introduced for the irrigated crops in order to ensure optimum production levels
- Assessment of inputs required for optimal production in terms of quality seed, organic and inorganic fertilizers, tools, availability of inputs, and access to credit.

Economic considerations

To ensure sustainability of the irrigation technologies, there should be a sound economic basis for the introduction of the new technologies and equipment in relation to investment as well as O&M costs. Although purchase of the equipment could be facilitated and partly or fully covered by a grant or gift, expenditures for the operation of the irrigation equipment should be covered by the small-scale farmers from the sales of the agricultural produce. It makes little sense, for instance, to provide subsistence farmers with a motor pump if they have no access to a market to sell their produce and are unable to pay for the fuel costs of the pump.

In the introduction of irrigation technologies, due consideration should be given to the following economic aspects.

Investment costs

In the description of the irrigation techniques in Section 2, indicative figures are given for the investment costs of the various technologies; these are summarized in the following table and, for reasons of comparison, expressed as investment costs per hectare.

Table 14: Indicative investment costs of equipment

	Irrigation technology	Indicative investment costs in US$/ha	Life span in years
1	Watering can	500	2
2	Treadle pump	600–750	4–5
3	Motorized pump	200–400	5–8
4	Solar pump	10 000–15 000	8–12
5	Gravity canal system	600–800	10–15
6	Pipe distribution system	1 000–1 500	8–12
7	Open well lining	500–1 500	10–15
8	Shallow tube well	300–500	8–12
9	Sprinkler irrigation	3 000–5 000	5–8
10	Family drip irrigation	10 000–12 000	4–6
11	Small-scale irrigation schemes	3 000–8 000	10–12

Depreciation costs relate to the annual savings put aside for the replacement of equipment; these are estimated as investment costs calculated according to the potential lifespan of the equipment, as indicated in Table 14.

Operation and maintenance costs

Energy costs are operational costs related to *fuel or electricity* for the operation of pump systems and requiring cash payments.

Labour costs are operational costs related to the handling of equipment, such as the watering can or treadle pump, but also the costs of filling a reservoir (bucket drip irrigation) or moving sprinkler lines. For many small-scale farmers they concern opportunity costs and involve availability of own or family labour. In the case of hired labour cash or produce is to be provided as compensation.

Maintenance costs relate to regular maintenance and repair costs of the irrigation equipment, e.g. seasonal cleaning and repair of the canal system; lubricants, filters and spare parts for motor pumps. In general, annual maintenance costs are around 15 percent of the investment costs.

Table 15: Indicative operational costs

	Irrigation technology	Indicative operational costs in US$/ha
1	Watering can	1 200–1 500 (labour)
2	Treadle pump	600–800 (labour)
3	Motorized pump	500–700 (energy)
4	Solar pump	50–100 (labour)
5	Open canal system	120–160 (maintenance)
6	Pipe distribution system	20–40 (maintenance)
8	Sprinkler irrigation	800–1 000 (energy)
9	Family drip irrigation	500–600 (labour)
10	Small-scale irrigation schemes	400–1 000

Access to markets

In order to be able to pay for the (often considerable) O&M costs of the irrigation equipment, farmers should be able to access markets and be able to sell their produce at adequate prices to cover those costs. For that reason most irrigation schemes can only be economically viable for high-value crops, such as fruit and vegetables or cash crops such as sugarcane, cotton, tobacco, etc. Other than in traditional farmer gravity scheme production, full irrigation of food crops such as maize, rice and beans have seldom proved economically viable for small-scale farmers.

Access to credit

In order to cover the purchase costs of agricultural inputs and to finance operational costs of the irrigation equipment, farmers need to have access to credit. Although consideration can be given to initial subsidies in post-emergency situations, micro-credit institutions should be involved in establishing a sound rural credit system to make irrigated agriculture economically viable.

Social and cultural considerations

Experience has demonstrated that the introduction and adaptation to new technologies with small-scale farmers is a complex process in which adequate attention needs to be given to familiarize farmers with the installation, the operation of the equipment, and the production and marketing of their crops. Social considerations play an important role in this and require that, through a participatory approach, farmers are fully involved and cooperate in the selection, design and installation of the equipment. A follow-up programme must also be set up to ensure that O&M of the equipment is properly done, that crop cultural practices are aimed at optimal production (economically optimal rather than just maximum production) and that farmers have access to markets for their produce.

Participatory appraisals of the social and cultural aspects and consultative planning have proved to be the best approach to get farmers fully engaged in the selection, design and installation of the equipment. A proper training and capacity building programme is to be set up as elaborated in Section 4, to ensure that O&M of the equipment is carried out correctly.

Social norms and local customs in crop production and land use must also be considered. Due attention needs to be given to gender issues in the introduction of irrigation technologies, as both men and women farmers will have specific responsibilities in agriculture and irrigation. When selecting technologies and suitable crops, planning and operations and maintenance personnel should take traditional knowledge of water management and crop production fully into account.

Climate and environmental considerations

Agricultural production and food security in southern Africa is to a large degree determined by climatic conditions and extreme weather events and is significantly impacted by natural and biological hazards, such as floods, drought, cyclones, pests and diseases. In particular, rain-fed production may vary considerably from

year-to-year and depends on fluctuations in precipitation, where dry years may follow years of heavy rainfall. Climate change, and the increase in frequency and severity of extreme weather events, has affected the agriculture sector which is particularly sensitive to extreme weather events and will increase the risks faced by the rural populations, the majority of which are dependent on agriculture for their livelihoods and food security.

Analysis must be made of the climate in terms of variability in rainfall and temperatures, and its impact on crop production of both rain-fed and irrigated crops must be evaluated. The impact of drought on crop production and irrigation requirements of crops can be estimated with the help of special computerized crop models such as the FAO CROPWAT programme. Historical climate data can be obtained through local meteorological records or from available climate databanks such as the FAO Climwat[5] programme.

Aspects of food security and local preparedness for natural hazards and disasters in both drought and floods are therefore to be seriously considered in the action plan to be prepared with farmers for the introduction of irrigation technologies and irrigated crop production.

Environmental aspects in relation to the consequences of increased water use by irrigation and more intensive agriculture should be given due consideration and should be closely monitored.

Introduction of irrigation implies increased water use from surface or groundwater resources. The reduced flow of rivers or lowering of the groundwater is likely to affect downstream users and may cause valuable natural resources in wetlands and valley bottoms to decline. Drinking water provision for humans and animals may also be affected and may cause conflicts among different users of the natural resource base.

Intensified agricultural production under irrigation may increase the use and abuse of agricultural chemicals, which may have severe environmental and health impacts.

5 The FAO Climwat database can be downloaded from the website of the FAO Water Service: http://www.fao.org/nr/water/infores_databases_climwat.html

4. Farmer Training and Demonstrations

Demonstrations and training need to be included in the DRR/M programme and are most effective if implemented over an extended period, spanning a full agricultural calendar, for example, and in groups where farmers have ample opportunity to assess the benefits of the new technologies jointly. Training in groups builds on existing knowledge and experience, and strengthens cooperation among farmers in the use of the equipment and in the sustainable management of water resources. A participatory planning from problem analysis to solution identification is a successful approach.

Figure 26: A farmer participates in farmer field school training

The farmer field school approach[6]

Developed originally under the integrated pest management (IPM) programme in Asia, the concept of the FFS approach is a successful farmer training and extension methodology because of its focus on consultation and participation when introducing new practices or technologies to farming communities.

An FFS (Figure 26) typically consists of a group of 25 carefully selected farmers, who will follow an intensive training programme that lasts an entire cropping season, wherein improved agricultural practices and technologies are demonstrated. During weekly sessions, progress in crop development is observed and closely followed from planting until harvest, with results and constraints extensively discussed and reported. The FFS methodology builds on farmers' existing knowledge, observation, experience, and learning-by-doing. The FFS training sessions are facilitated by technical extension staff (Figure 27), who have undergone an intensive season-long training of trainers (ToT) course and are fully familiar with the technical and communication aspects of the programme.

Although the methodology was originally developed to teach farmers how to sustainably manage pests and diseases, the IPM/

6 See also the brief on Farmer Field Schools within this toolkit

FFS concept has evolved to address improved crop production, soil fertility and soil conservation practices, as well as to improve farm water management and irrigation technologies.

Participatory training and extension programme in farm water management

Based on the FFS approach, the Participatory Training and Extension programme in Farm Water Management (PT&E/FWM[7]) was developed by FAO under the Special Programme for Food Security in order to introduce in a holistic manner irrigation technologies, water control and improved cultural practices under irrigation. The programme specifically focuses on capacity building of technical staff and field extension workers and aims to promote farmer cooperation in water management through the establishment and training of water users associations (WUAs).

Through consultation and diagnostic analysis with farmers, an assessment of the agricultural system and available water resources is made. Based on this assessment, the opportunities for new irrigation technologies are agreed upon. Once the technologies are identified, an action plan is established and implemented with full participation from the farmers and with technical support from the involved technical agencies. Through a series of training sessions lasting at least two seasons, the installation and operation of the irrigation technologies are demonstrated. Besides the implementation of the new technologies, attention is also given to the agricultural practices and inputs required for irrigated crops in order to ensure optimal production and yield.

Training of the technical staff is crucial to the whole process. Prior to the farmer training, support staff – both technical irrigation staff as well as field extension workers – receive intensive technical training as well as detailed instructions on the procedures for the farmer training. Training of technical staff is carried out for each season with in-service training and an intensive reporting system during the implementation of the farmer training allows for close monitoring and evaluation of the results.

Figure 27: Extension staff in farmer field school

7 The PT&E/FWM approach is described in detail in the manual and guidelines prepared and published by the FAO Water Service (NRLW) in the Land and Water CD-Rom series No 14: *Participatory training and extension in farmers' water management.*

Technical support services

Success and failures of new irrigation technologies can be attributed largely to the capacity of the national institutes and agencies entrusted with the implementation of the DRR/M programme. Good results can be directly ascribed to a good institutional system with effective support services.

Technical support services are indispensable in:

- The selection, conception, design and implementation of the irrigation technologies;
- The introduction of appropriate agricultural practices to optimize irrigated crop production;
- The demonstrations and farmer training and extension programmes; and
- The formation and strengthening of farmers groups.

Depending on a country's institutional structure, several national agencies and organizations (NGOs, private sector) can be engaged in an irrigation programme. The governmental organizations may include:

- The irrigation agency, responsible for irrigation and water resource policies, selection, conception and implementation of the water control technologies and the technical designs, construction, operation and maintenance of the irrigation infrastructure;
- The agricultural agency, responsible for technical advice and services related to appropriate agricultural practices and inputs for irrigated crops, which is linked to agricultural research and extension; and
- The extension departments or units directly responsible for maintaining direct contacts with the farmers for the transfer of knowledge.

To address potential gaps in technical assistance provided to farmers, collaboration among government, technical agencies and NGOs can be beneficial, and build on complementary expertise. Training supporting government staff is essential in order to establish the necessary capacity to successfully carry out the farmers training and demonstration programmes.

In several countries, NGOs have played an important role in the introduction and development of innovative technologies as well as in the training and capacity building of farmers' groups. Several international NGOs have specialized in the development of innovative water control technologies adapted to conditions in developing countries and have provided valuable assistance in the introduction of new irrigation technologies.

Figure 28: Manufacturing a metal treadle pump

The private sector can play an important role in ensuring sustainable support services, and in the sales and after-sales service of irrigation equipment – particularly for irrigation pumps, sprinkler and drip irrigation systems and solar systems. There is a need, however, to provide training and guidance to companies in the design, installation and operation of equipment. Most southern African countries have an active private sector for the sales of agricultural inputs and equipment. They may further profit from providing technical advisory services, selling/hiring irrigation or agricultural equipment, and/or selling the inputs required for irrigated agriculture, making this an attractive market and activity for the private sector.

Rural credit organisations may be further familiarized with the potential of irrigated agriculture and be advised on providing credit to farmers for the purchase and operation of irrigation equipment.

Finally, international aid programmes (e.g. FAO SPFS), often in close cooperation with specialized NGOs, have been successful in establishing and promoting the capacity of small private companies to manufacture irrigation equipment (treadle pumps, Figure 28); to design and install irrigation equipment; as well to train local teams for well development. They also link the government stakeholders and private sector to such initiatives to ensure sustainability and long-term gain for the participating farmers.

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