A simulation-based approach to assess the economic viability of smallholding irrigation schemes in South Africa: Conceptualisation and first implementation

Sylvain Perret & Emilie Touchain

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Department of Agricultural Economics,
Extension and Rural Development
University of Pretoria
Pretoria, 0002
South Africa

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Sylvain PERRET
Emilie TOUCHAIN

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Executive summary

Government smallholder irrigation schemes (SIS) were developed in former homeland areas of South Africa during the apartheid era, mostly for community food supply purposes. The parastal entities that used to support them have gradually collapsed from the early 1990's. These schemes are now facing serious problems and an uncertain future, owing to low yields, deteriorating infrastructures, limited access to services, weak and unclear institutions regarding water and land, and lack of support.

Although representing a small percentage of irrigated land at country level, their location in deep poor rural areas represents a potential for poverty alleviation and food security in such areas.

The central and provincial governments aim to both revitalise SIS and curtail the financial burden of their maintenance and operation costs. Most schemes are earmarked for rehabilitation and transfer to users' associations in the Northern Province and the Eastern Cape Province.

In recent years, many countries have embarked on a similar process to transfer the management of irrigation systems from government agencies to water users associations (or other private sector entities). However, most professionals involved are still unsure about whether to adopt reforms and how to design and implement them.

In South Africa, it is very difficult for decision-makers and operators to evaluate the potential for long-term sustainability, then to organise rehabilitation and transfer accordingly, owing to a context of low participation, weak local institutions, and lack of information regarding farmers' strategies, land tenure arrangements, cropping systems, household socio-economics, and so on, which eventually determine the potential for cost recovery and economic viability.

A research team from CIRAD[1] and the University of Pretoria proposes an action-research approach of SIS, in three steps:

- Collecting information on the socio-economic and technical circumstances at household and scheme level
- Capturing data into a model that calculates both the costs incurred by scheme management, and the possible contributions by farmers to cover these costs in a context of management by a water users' association
- Running the model on a scenario-testing basis, evaluating the impact of certain measures or decisions, or certain farmers' strategies.

The following principles form the background of the approach:

- Establishing and sustaining multi-disciplinarity and partnership, meaning that engineers, agronomists, extension agents, economists, development operators, farmers, decision and policy makers are involved in the process
- Considering local and specific circumstances, meaning that, although generic, the approach takes account of peculiarities and adapts to local circumstances
- Developing and using a typology of farmers, i.e. groups with similar strategies and characteristics

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[1] CIRAD is a French research organisation, specialised in co-operation on agriculture, animal sciences, forestry, food processing and development support for the developing countries. CIRAD stands for "Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement".

- Acquiring a managerial vision of the scheme, i.e. the management entity provides irrigation water and related services to farmers, who, in turn, pay back for such services (client-supplier relationship, although farmers partake to the management)
- Modelling then running simulations as ways to demonstrate and show the likely results of certain decisions or measures, to fuel discussion and make people interact, to challenge hasty judgements and support sound decisions, to raise new questions, and to foresee issues and problems.

The approach itself has been developed for 15 months in two neighbouring schemes of the Northern Province. In-depth field surveys first allowed an accurate understanding of the schemes. A typology was developed. This first step revealed the huge inner diversity of the schemes, in terms of farmers' strategies and performances. A model (Smile[2]) was developed on a spreadsheet programme (MS Excel ™). It considers

- the costs incurred by irrigation water supply and related services (capital/refurbishment, maintenance, operation of the scheme, management and staff-related costs);
- land allocation, cropping systems and the farmers' strategies, which all define the farmers' capacity and willingness to pay back water services costs;
- the irrigation-water charging system (costs considered, choice of pricing, of base).

Scenarios were then tested. The simulations show that:

- the current situation is not viable, as costs are hardly covered;
- total costs can hardly be reduced, since the bulk lays on capital and maintenance costs (however, a partial rehabilitation may prove more costly in the long run than a total one);
- the current biggest problem is the majority of non-farming plot occupiers, with low capacity and willingness to pay water fees;
- low land productivity also strongly limits farmers' income and capacity to pay back water services;
- even slight changes can significantly improve the situation (i.e. reduction of the proportion of non-farming occupiers, shift from mere subsistence towards more commercial farming, increased cropping and improved cropping systems, etc.)

A number of recommendations measures and decisions may be drawn from the simulations. Operators and decision makers should especially address inner land tenure arrangements, farmers' training, access to markets and services. An inescapable prerequisite to sustainable management is the establishment of a sound local managing organisation, which cost is included in the model.

Although requiring accurate and reliable background data, the methodology shows huge potential for decision-making support and for investigation on sound management pathways. The conceptual framework that is proposed here form the basis for the development of simplified and well-targeted questionnaires, to address further schemes.

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[2] *Smile stands for "Sustainable Management of Irrigated Lands and their Environment"*

The present report is a working document. Readers are most welcome to react and comment on it. Please sent your reactions and comments to: sperret@nsnper1.up.ac.za *(Sylvain Perret)*

Introduction

Over the past three decades, the world's net irrigated area has increased by 73 percent, from 150 million ha in 1965 to 260 million ha in 1995 (FAO, 1998, quoted by Gonzalez, 2001). However, during the same period, the irrigation sector has been increasingly exposed to new challenges and changing driving forces, i.e. competing demands for water, emerging environmental issues, persistent and even pervasive food insecurity and poverty.

At the same time, many countries have also increasingly embarked on a process to transfer the management of irrigation systems from government agencies to water users associations (or other private sector entities). Professionals in many countries are in the process of considering or adopting such reforms. Some are still unsure about whether to adopt reforms and how to design and implement them. This process, the so-called Irrigation Management Transfer (IMT), includes state withdrawal, promotion of the participation of water users, development of local management institutions, transfer of ownership and management, and so on. A number of successes as well as failures have been already reported and analysed (FAO, 2001). South Africa has just cautiously initiated IMT in government smallholding irrigation schemes located in former homeland areas.

CIRAD and the University of Pretoria have launched a research programme which aims to assist decision-making on rehabilitation and management transfer of smallholding irrigation schemes to local management structures, then to pave the way for a sustainable management of these schemes on the longer run.

The present document aims to report back preliminary outcomes of the programme, which developed a modelling approach for assessing the economic viability of specific schemes of the Northern Province, earmarked for rehabilitation and transfer. The report first quickly describes the situation of smallholder irrigation schemes in SA, the current process of rehabilitation and transfer, and the numerous questions regarding sustainability and prospects of such schemes. The simulation approach to sustainability is then presented (principles and conceptualisation). Finally, scenarios are tested on a case study scheme where a first simulation tool has been developed.

The plight of smallholding irrigation schemes in SA

At present, South Africa has an estimated 1.3 million ha of land under irrigation for both commercial and subsistence agriculture. As described in table 1, due to history and past policies, different types of irrigation schemes have evolved in South Africa. These schemes consume about half the currently available water resources of the country and contribute to almost 30 % of the total agricultural production (Backeberg & Groenewald, 1995). The agricultural sector contributes to about 3% of the country's GDP.

Smallholding irrigation schemes – SIS- cover approximately 46000 to 47500 ha (Bembridge, 2000; NP-DAE, 2000) as former Bantustan schemes, and about 50000 ha as garden schemes and food plots. As a whole, such schemes account for about 4% of irrigated areas in SA. It is estimated that half of them are located in the Northern Province (about 175 schemes represent 20000 to 22000 ha). It is also estimated that two thirds of South Africa's SIS are dedicated to food plots, the purpose of which is subsistence, and that 200000 to 230000 rural black people are dependant at least partially for a livelihood on such schemes.

In spite of such a relatively small contribution, it is believed that those schemes could play an important role in rural development, since they can potentially provide food security, income and employment opportunities.
In the Northern Province, it is acknowledged that most SIS are moribund and have been inactive for many years (NP-DAE, 2000). Several causes have been mentioned, i.e. infrastructure deficiencies emanating from inappropriate planning and design, and/or poor operational and management structures, both beneficiaries and government assigned extension officers lacking technical know-how and ability, absence of people involvement and participation, inadequate institutional structures, inappropriate land tenure arrangements. In the Eastern Cape and Kwazulu-Natal, most schemes are also facing major infrastructural and institutional problems, along with local political power games that have characterized these schemes from the outset, and that hinder effective problem solving.
Following the dismantlement of apartheid, management agencies were liquidated and government gradually withdrew from its past functions in SIS (services, technical advise and extension, training, marketing and financial support).

Table 1. A typology of the existing irrigation schemes in SA

Type of scheme	Private schemes	Irrigation board schemes	White settlement schemes	Bantustan schemes	Food plots, community garden schemes…
Period of development	1650 onwards	1912 onwards	1930s-1940s	1950s-1980s	-
Number	-	300		250	-
Total area	450 000 ha	400 000 ha	350 000 ha	40 to 50 000 ha	50 000 ha (est.)
Scheme size (range)	2 to 10000 ha	20 to 60000 ha	40 to 120 000 ha	30 to 2000 ha	1 to 30 ha
Average farm size per beneficiary	-	-	40ha	Initially 1.3-1.7ha, sometimes more	From several m3 to less than 1 ha
Scheme ownership	Private	Private	Government	Government	Communities, CBOs…
Land tenure	Private	Private	Private	Mostly Communal	Communal
Scheme development and maintenance	Private investment and running costs	Capital = 2/3 private + 1/3 Government	Government	Government	NGOs, CBOs, various donors, Departments, communities

Compiled by Perret (2001)

Since the late 1990s', provincial governments have set up rehabilitation and management transfer programs throughout the country (ECRA, 2001; NP-DAE, 2000); however, the processes are implemented very cautiously and slowly. For provincial departments, the underlying idea is undoubtedly to curtail the heavy financial burden of SIS, as most of them are not contributing to the commercial agriculture stream. On the other hand, departments would like to promote the emergence of small-scale commercial farmers, as well as the community subsistence function of the schemes (food security).
Like in European transition economies (former eastern block countries), these schemes were constructed with no consideration for operating costs or production economics (Svendsen, 2001). Like in such situations, national and provincial governments might be tempted to transfer "uneconomical" schemes to users.
Still, all rehabilitation and reactivation efforts face the same dilemma, i.e. how can the social and economic aspects of SIS be reconciled?

A new water management policy

Since 1994, the South African Government has undertaken massive reforms aiming to address rural poverty and inequalities inherited from the past apartheid regime. Amongst other programs, it has adopted an ambitious new water legislation, which culminated in the acceptance of a new National Water Act (NWA, Act 36 of 1998). The Act provides an opportunity to re-think the paradigm underlying water management in South Africa and to develop new institutions. It breaks drastically with the previous water laws in the sense that past key concepts are discarded (e.g. the riparian right to use water). Water is now considered a common asset. The right to use water is granted to users, most of whom have to be registered and licensed, and should pay for this right. Also, other core concepts of water management under the new dispensation are decentralization, and water service cost recovery. The Act promotes equity, sustainability, representativity and efficiency. Its key objectives are: social development, economic growth, ecological integrity and equal access to water. The Act distinguishes national areas of water management from regional and local ones. New management entities (Catchment Management Agencies and Water Users' Associations) will be established in order to achieve the aims of the Act. These institutions are to be established at regional and local level respectively, emphasizing a largely decentralized and participatory approach to water resource management. Direct consequences of the Act are: State withdrawal from most former commitments, controls and financial support, decentralization and the transfer of power to local management and decision-making structures (CMAs and WUAs), water users' registration and licensing.

WUAs as local irrigation management structures

Water Users Associations (WUAs) potentially form the third tier of water management and will operate at local level. These WUAs are in effect co-operative associations of individual water users who wish to undertake water-related activities for their mutual benefit. The role of the WUA is to enable a community to pool financial and human resources in order to carry out more effectively water related activities. Irrigation management forms one of the key activities to be performed by WUAs (DWAF, 1999 & 2000).

It is envisaged that a WUA would take over most irrigation management functions, i.e. water distribution rules, organising maintenance, collection of water supply charges and financial management, and possibly later, the management of investment, credit to farmers, marketing contracts, input supply, and so on.

These tasks are responses to institutional and political requirements as well as to operational needs with regard to a difficult situation. They imply:

(i) the emergence and sustainability of WUAs as local institutions,

(ii) their ability to carry out technical and financial management functions.

Issues and stakes

All the above raises a series of questions and demands investigation at different levels:

At Government level (policy making)

Which policies and measures should accompany the IMT process? (designing training programmes, level of rehabilitation, new waterworks and resource development,

resource and waterworks-related pricing policy, land tenure reform, service and input supply, etc.)
What is the current situation of the schemes earmarked for rehabilitation and transfer? Do these schemes have any prospects, any sustainable development potential? To which conditions? Is it possible to prioritise, i.e. to drive funds towards selected promising schemes? How to choose them?
Is it realistic to transfer all costs incurred to the local management entities? In other terms, can capital costs be covered by the farmers' contribution?

At WUA level (collective management of irrigation)

How can one help an emerging local institution to become a collective, representative and sustainable structure for negotiation, decision and management, in a changing and uncertain environment?
Or in other terms: How can one implement the building up of a local organisation, managing water distribution, maintenance and financial aspects?
More specifically, how can the tariff structure take into account farmers' capacity and willingness to pay, as well as cost recovery requirements? How can the water pricing strategy and the water charging system take account of the different issues at stake, i.e. equity, poverty alleviation, resource conservation, economic viability?

At farmers' level (farming and cropping systems management)

What is the current situation in terms of cropping systems and, more generally, income-generating systems in the schemes? Are they compatible with a cost-recovery approach of the scheme's management? In other terms, are farmers capable to pay, are they willing to pay?
What are the prospects and potential for changes and/or improvement in cropping systems?

The Smile approach

Overall objective

As described in previous sections, smallholding irrigation schemes of SA are currently facing major changes (Government withdrawal, rehabilitation and transfer of ownership and management; in one word, that is privatisation, although some form of public-sector support may remain).
Owing to current policies, and depending on the stakeholders ability to adapt and react, the process is likely to eventually end up with two scenarios (although it may take some time, either way):

- continuous degradation (which is the current trend) then collapse; this means that a large majority of the remaining cultivated plots would be eventually rain-fed,
- or some form of sustainable self-management, which means that a large majority of plots would be cultivated and irrigated, and that the neighbouring communities would benefit from it.

This second scenario is being promoted by central and provincial governments which aim to revitalise SIS through rehabilitation, and to curtail the financial burden of their maintenance and operation costs through a transfer of ownership and management. Most schemes are earmarked for rehabilitation and transfer to users' associations in the Northern Province and the Eastern Cape Province.
Although both provinces have drawn plans (NP-DAE, 2000; ECRA, 2001), it remains difficult for decision-makers and operators to evaluate the potential for long-term sustainability, then to organise rehabilitation and transfer accordingly, owing to a context of weak participation and local institutions, and lack of information regarding farmers' strategies, land tenure arrangements, cropping systems, household socio-economics, and so on, which eventually determine the potential for cost recovery and long term sustainability.
The questions listed in chapter 2 remain pending and require investigation in most schemes.
The overall objective of the approach is to accompany and support decisions and actions undertaken by development operators, in a process of rehabilitation and transfer of management to local entities.
A series of specific objectives consist of answering the questions listed in chapter 2.
The Smile approach strives to go beyond mere observation, qualitative participatory methods (Gosselink & Thompson, 1997) or general organisational principles (Ostrom, 1992), and to avoid complex systemic representations, although benefiting from those seminal works. Its objective is to facilitate decision-making and strategy development.
Before presenting the approach and the tool itself, it is necessary to describe briefly the principles and the conceptual framework, then some key practical features that are specific to the approach.

Principles, theoretical background

A managerial perspective of irrigation schemes

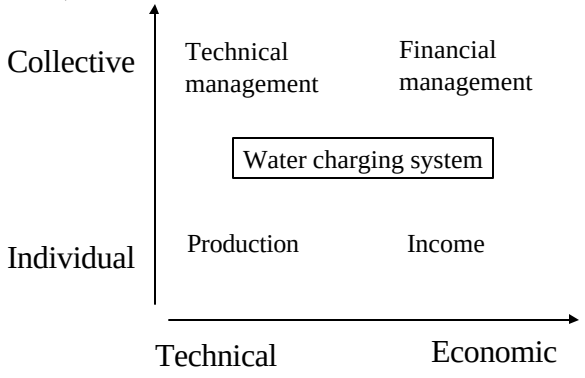
A major prerequisite to a **self-management scenario** is the establishment of a sound local management entity (e.g. a Water Users' Association). Such process is not directly addressed through the Smile approach. However, the model includes

management options and takes account of the management costs incurred, which may help making certain decisions at the outset (staff, management assets, etc.).
Having a self-management perspective on SIS means acknowledging the following mode of operation:

- The **management entity** (WUA) provides irrigation water and related services to **farmers**.
- Such services **generate costs**: capital costs (provision for further refurbishment), maintenance and operation costs, and personnel-related costs.
- Partial or total **cost recovery** supposes that the management entity charges the farmers according to a system to be established (which involves defining a cost recovery strategy, choice of a water pricing method, choice of a base, determining fees, etc.).
- The farmers tap into their **monetary resources** (generated by irrigated or rain-fed cropping systems, by off-farm income-earning systems) to pay these water service fees.
- It is a **client-supplier relationship**, although farmers indeed partake to the management entity.

In other words, a scheme can be seen as a firm with two interacting productive units, performing various functions in a given natural, institutional and economic environment (Rey, 1996; Le Gal, 2001). A number of flows take place between the different sub-systems: flows of water, money, labour, products, and information.
On one hand, the collective management entity (supplier) "produces" water with certain characteristics (quantity, quality, costs, etc.). It has to perform two types of functions: a hydraulic function (water supply, operation and maintenance) and a financial function (cost recovery, water pricing and fees fixing, financial management).
On the other hand, individual farmers (clients) "transform" this water in products through their productive systems (irrigated cropping systems), then possibly in money if they market these products. Thus, farmers perform two types of functions: agricultural production (cropping system, irrigation systems at plot level) and commercialisation.

Figure 1. A conceptual framework for the management of irrigation schemes (adapted from Le Gal, 2001)



Smallholder families seldom rely solely on the production of an irrigated plot. It is common for irrigated plot holders to have rain-fed cropped areas, livestock, non-farm sources of income and so on (Chancellor, 1999; Merle et al. 2000). One should

consider the whole income-earning system of smallholder irrigation farmers while reckoning their capacity and willingness to pay water fees.
Water pricing and the water charging system form the key interface between farmers and the management entity. Defining crop production strategies, organising commercialisation, striking a balance between water supply and demand, developing a management information system, and the like, are also key subjects for both farmers and the WUA (Le Gal, 2001).

Action research

It is now acknowledged that mere technology generation and transfer, or market forces are not enough to bring about the necessary changes that have to occur in agricultural and resource-management systems faced with a quickly changing economic, legal and social environment. For such changes to occur, renewed approaches require facilitation of collective learning and negotiated agreement (Jiggins & Roling, 1997). **Action-research** strives to play this facilitation role. As defined by Liu (1994), it combines:

- the convergence of a will for change and a research intention, which entails a two-fold objective, i.e. problem solving and knowledge generation (with local and generic scope),
- an ongoing long-term joint project between researchers, development operators and users,
- a common ethical framework negotiated and accepted by all stakeholders.

Several previous experiences show that projects inspired by action-research can efficiently support local development (Valleyrand, 1994; Albaladejo & Casabianca, 1997; Perret & Legal, 1999). The tricky and essential point is to implement properly the participation of stakeholders, not only while collecting data but also during recurrent, interactive workshops (information sharing, discussions about scenarios, solutions seeking, etc. See Section 3.3).
A recent trend in management-oriented researches is to proceed through direct intervention within the targeted organisations (Moisdon, 1997). **Intervention-research** means that the researcher is no longer an external observer, analysing managerial processes, then prescribing possible improvements in line with optimal solutions (such an approach refers to operational research). He/she is actually embarked in a common work with the individual and collective stakeholders. The prescription dimension takes part of an inner process in which control, strategy, piloting, ongoing learning are central.

Supporting decision making with models and scenario-testing tools

Human organisations (such as irrigation schemes) are complex systems, meaning that no simple representation can encompass or exhaust their scope, interactions, implications, issues, and dynamics (Le Moigne, 1990). Furthermore, they evolve in uncertain environments (e.g. climate, markets, resource, etc.).
Complexity and uncertainty call for strategy. Rather than striving to stick to a long pre-established trajectory, developing a strategy in complex and uncertain environment means developing a step-by-step approach, striving to foresee, adapt to, and benefit from any new issue, emerging situation or unexpected event, according to a broad guideline and several main objectives (Avenier, 1997).
Besides, human organisations are not only constituted by individuals and assets, but also by **knowledge, rules and information**, enabling monitoring and assessment of

the activities performed, and orienting behaviours and choices. Very often, this information is combined to stand as a workable synopsis, in various forms such as indicators, worksheets, management boards, schedules, and production forecasts among others. These formalised representations of the organised activity are called **management tools** (Moisdon, 1997).

Owing to the increasing complexity and dynamics of organisations, and to the increasing uncertainty of their economic environment, management tools no longer seek optimal solutions and one-way prescriptions or recipes, but rather favour **information, learning processes, adaptability, discussion, collective awareness**, and so on.

Such an instrumental approach aims to support and accompany the knowledge and exploration of reality. Its main objective is to help a group of stakeholders sharing a common representation, making decision and developing an adaptative strategy on the process they are involved in, and anticipate the possible evolution.

As such, developing a management tool represents an intervention into the organisation, as the structure of the model is based on dynamic links with the conceptual representation of the organisation and the rules structuring intervention. Developing management tools goes along with developing the organisation itself, and its strategy (Moisdon, 1997), which may prove crucial in the context of the establishment of WUAs as local management entities.

Modelling then running simulations may fuel discussion and make people interact, challenge hasty judgements and support sound decisions, raise new questions, and foresee issues and problems.

Practical features

A three stages approach

The approach implies three phases:

- Data collection, which includes field visits, farmers' and operators' interviews, literature review on infrastructures (e.g. pre-rehabilitation reports), crops, farming systems, markets, local institutions, and so on. Information is required on the socio-economic and technical circumstances at household level
- Data processing and model development; future developments will benefit from the existing model (Smile) which may be adapted to other situations rather than actually be redeveloped. The model evaluates both the costs incurred by scheme management, and the possible components of cost recovery in a context of management by a water users' association. Prior to model development, it is necessary to develop a typology of farmers' strategies and practices (see below)
- Running the model on a scenario-testing basis, evaluating the impact of certain measures or decisions, or certain farmers' strategies on agricultural and production features, land allocation, costs and cost recovery, economic indicators, equity- and sustainability-related indicators. This supposes interactions with experts and local stakeholders

The need for accurate data

The more accurate and reliable the data, the better the modelling and simulation development. In spite of the numerous reports that have been written on most schemes earmarked for rehabilitation and transfer, it proved very difficult to gather the

necessary information for modelling then simulation purposes. This called for multiple contributions and partnerships with knowledgeable experts (see below), and proved crucial in choosing the case study schemes: Dingleydale - New Forest (DD-NF) (see chapter 3.5).
Concerning infrastructure, most data are usually lacking since the schemes were managed by former independent homeland authorities and have only been recently re-transferred to the South African authorities. In DD-NF, recent studies have been undertaken prior to rehabilitation and offer very accurate and reliable data (AWARD, 1999; ARC-LNR, 1999b).
Concerning the communities and their farming practices, studies have been undertaken on some case studies, but often focusing on certain issues such as gender or productivity for example. For this study, economic data were of major importance. In DD-NF, most economic data were made available via two complementary surveys both undertaken in 2000 on the farming households: a quick pre-feasibility survey based on a large sample (200 households) undertaken by Loxton Venn & Associate (Mitchell, 2000) and a more comprehensive survey done by CIRAD, based on a similar sample size (Merle & Oudot, 2001). Data on the whole communities would have been very helpful, but were not available.
Concerning management entities and their strategies, DD-NF offered, once again, a good compromise. It doesn't have a WUA yet, but as a pilot project, a transitional development steering committee has been established.

Multi-disciplinarity and partnership

The approach requires interest and commitment by a number of individuals and institutions. Partnership and multi-disciplinarity have been established and sustained during the course of the project. Engineers, agronomists, extension officers, economists, development operators, farmers, decision and policy makers were first involved mostly on an individual and informal basis during the two first phases as listed above. Then some key experts and stakeholders have been involved in an informal and flexible, yet very efficient, steering committee for the last phases. Members of the Agricultural Research Council, Department of Water Affairs and Forestry, International Water Management Institute, Water Research Commission, Provincial Departments of Agriculture, consulting agencies (Loxton Venn & Associates) have been involved at different stages.

Diversity of strategies: the need for a typology of farmers

A strategy may be defined as the combination of processes (plans, decisions and acts) that an individual or a group of individuals (a firm, a family, etc.) develop purposively, and which aim at changing/transforming their social, economic and/or physical environment. Such processes combine resources and/or techniques and/or knowledge and know-how (Olivier de Sardan, 1995).
Farmers develop strategies as responses to a changing and uncertain environment, in order for them to duplicate/reach/transform a given life style that corresponds to an objective, as groups and/or as individuals. The crops, crop management sequences, cropping systems, animals and animal production systems, farming systems, off-farm activities, and so on, that the farmers combine and mobilise reflect such strategies (Yung, 1998).
Within an irrigation scheme, diverse strategies may develop, depending on each household's history, composition, objectives, and so on.

On the one hand, it is impossible to take account of each and every household's characteristics; on the other, it is irrelevant to consider the scheme homogeneous; hence a typology that groups households with similar strategies and characteristics, with regard to a given objective. For example, Lamacq (1997) built up farm typologies according to action models, aiming at modelling water demand. Merle et al. (2000) developed a typology of households in Dingleydale -New Forest scheme in South Africa, mostly according to their social and micro-economic traits, and to their production and marketing styles. Such a typology has been simplified and re-focussed on production/marketing styles (because of their importance in a self management perspective), then used for modelling purposes in the case study (see chapter 3.5).

Developing the model: conceptual framework

The approach as a whole takes root in the above principles and practical traits. The conceptual framework on which the model is developed is presented hereafter, then a first version of a simulation tool is briefly described.
Four input modules form the basis of the model, as interfaces for data capture by the user:

- The **"cost" module** is independent. Each cost-generating item is listed, with its capital, maintenance & operational costs, personnel costs. This module generates a series of output variables that reckon the costs incurred by the scheme and its management (i.e. capital costs, maintenance costs, operation costs, personnel costs) (see figure 2).
- A **"crop" module** is also independent. Each potentially income-generating and/or irrigated crop is listed with its technical and economic features (e.g. management style, cropping calendar, water demand, yield, production & marketing costs). This module generates a series of micro-economic output variables (i.e. gross and net margin par ha, and per m^3) (see figure 3).

These two first modules generate output variables that are used by other modules (The reader may refer to appendices where calculations are presented).

- A **"farmer" module**, in which the different farmers' types are documented, along with their cropping systems (combination of crops), average farm size, percentage of scheme's size, willingness to pay for irrigation water services; this module generates a series of type-related output variables (e.g. aggregated income per type, crop calendar) and scheme-related output variables (e.g. number of farmers, aggregated water demand, income) when combined with the "scheme" module (see figure 4).
- A **"scheme" module**, in which some characteristics of the scheme are listed (e.g. size, rainfall patterns, tariff structure); this module is combined with the "farmer" and "cost" modules, and generates output variables on water pricing, tariff, cost recovery rate, contribution per type, and so on (see figure 4).

All four modules may be documented independently and feed a database. The initial inputs (real data) form the base scenario. Additional scenarios may be tested through the capture of non-real / prospective data (e.g. alternative crops and cropping systems, immerging types, changes in management patterns, new infrastructures, and so on).
These four modules generate a number of output variables that stand as interesting indicators:

- The economic variables from the "cost" module form the unavoidable base to the scheme's cost recovery strategy, they answer the question as to **how much does it cost to operate the scheme in a sustainable manner** (regardless of who is going to pay for it).
- The micro-economic and hydraulic data from the "crop" module make **crop comparative evaluation** possible in terms of profitability, land productivity, water productivity, improvement potential, and overall water consumption.
- The "farmer" and "scheme" modules generates together a number of micro-economic, socio-economic, and technical variables which make it possible to address **social and equity concerns** (total number of farmers, area per type, number of farmers per type), **economic performance issues** that give some information on the farmers' capacity to pay back water services (type net income, scheme total net income), **hydraulic performance and water scarcity issues** (total water consumption, overall weekly water balance).

Figure 2. The "cost" module: input classes and output variables

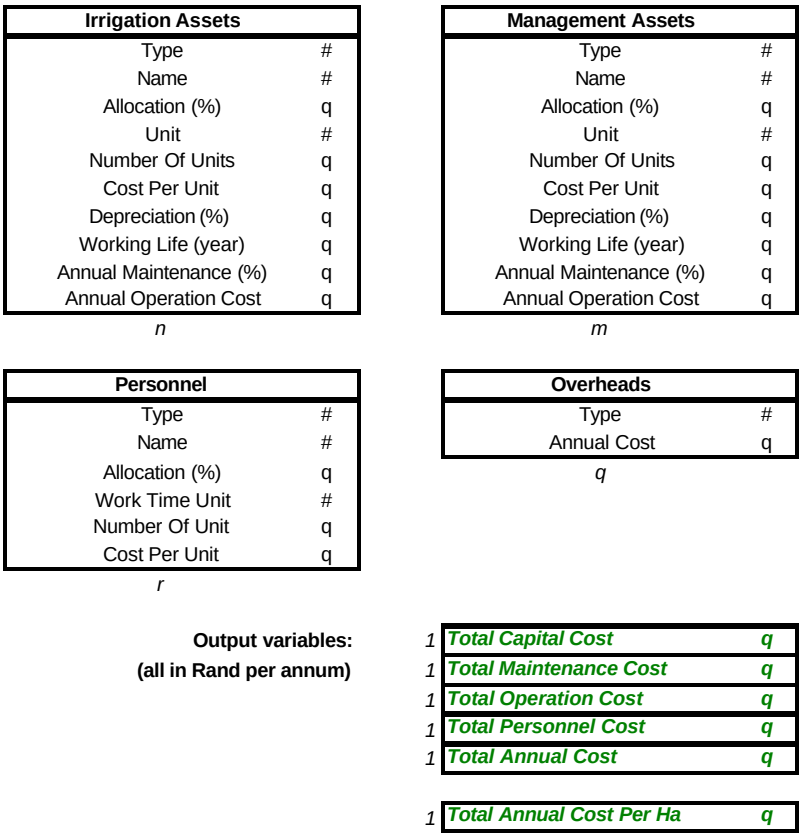
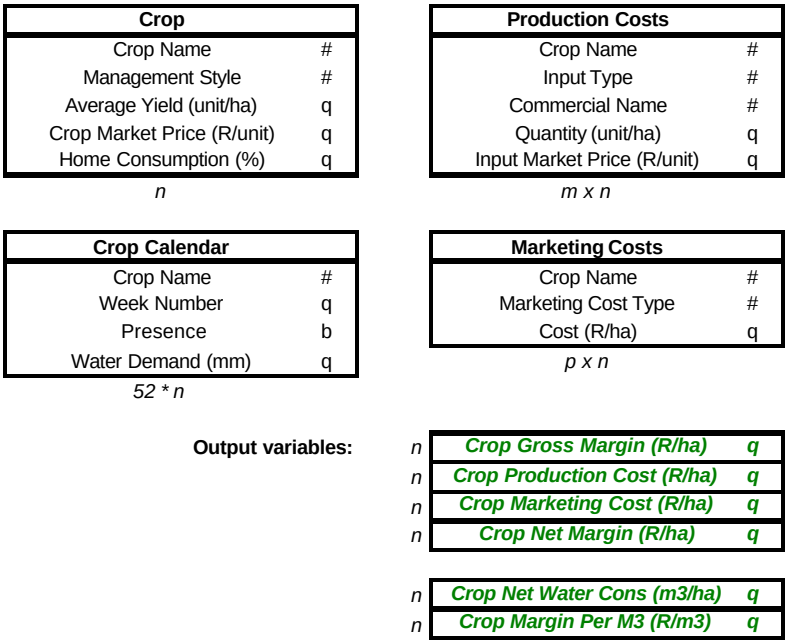


Figure 3. The "crop" module: input classes and output variables



However, such indicators do not answer the questions as to

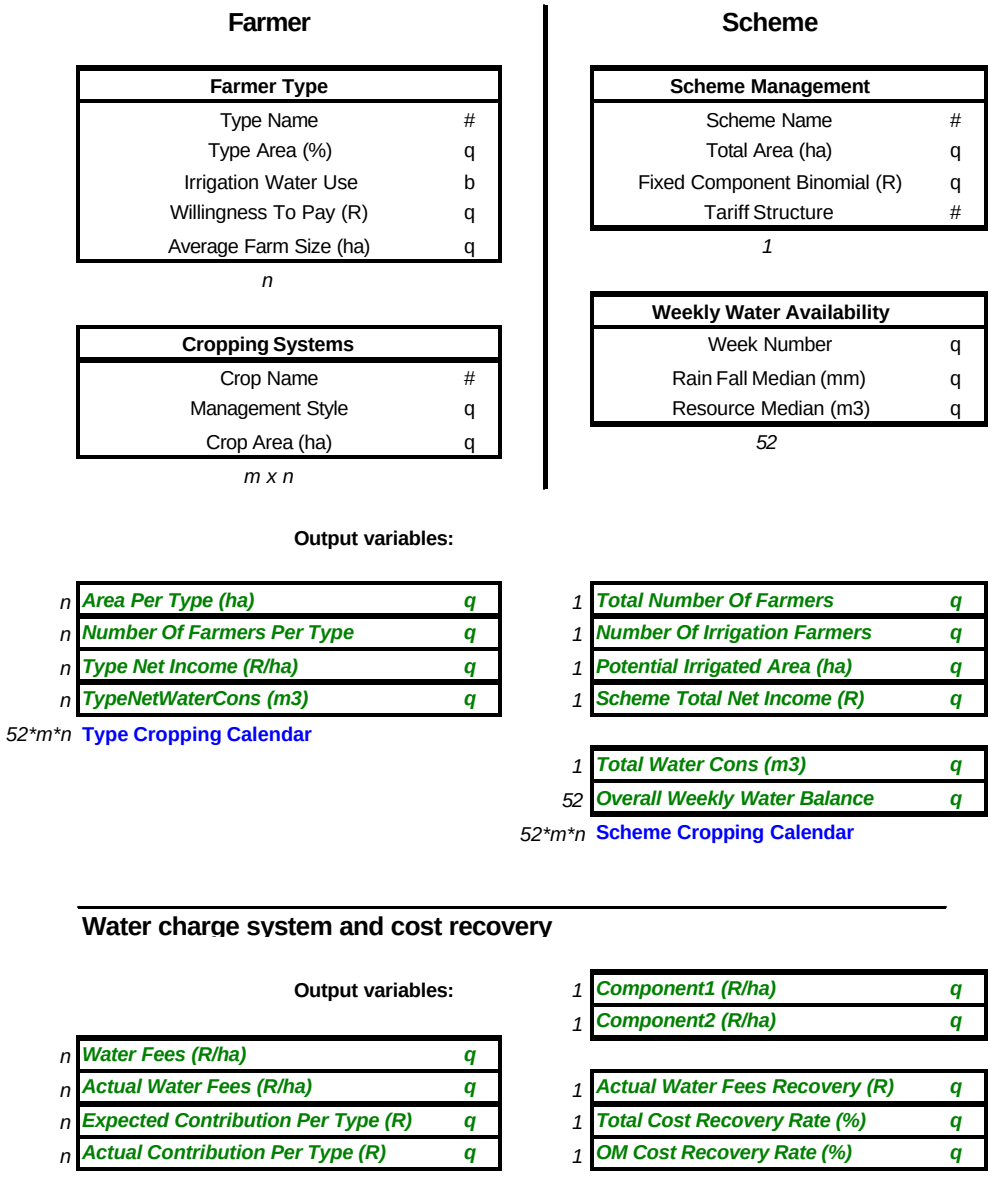
- who is capable and willing to pay for irrigation water services;
- what should be the charging system to meet objectives such as affordability, increased production, intensification (on farmers' side), or sustainability, equity, cost recovery, water savings (at scheme level).

A fifth module, a **"charging system" module**, is subsequently created and fed with data from the "cost", "farmer" and "scheme" modules (see figure 4). It forms a real interface between these four modules and aims at answering the above questions. Also, this module deals with hypotheses regarding the possible water pricing and charging systems to be set up. As most smallholding irrigation schemes have not reach such points, there are no existing data. The user must imagine scenarios to feed this module, whereas the four first modules may use actual data.

Depending on choices made at scheme level (tariff structure, fixed component of a possible binomial charging system, actual water fees) and to farmers' willingness and capacity to pay, a number of output variables highlight the economic viability of the scheme (total cost recovery rate, operation and maintenance costs recovery rate) but also equity issues (actual contribution per type).

The conceptual framework corresponds to the need for a generic formalisation. It has been actually developed in parallel with the development of a first version of a simulation tool, which corresponds to the local circumstances of the case study scheme. It ultimately proved extremely useful (1) to structure the questionnaires when investigating further schemes, and (2) to develop an improved simulation tool on other software platforms.

Figure 4. The "farmer" and "scheme" modules: input classes and output variables



A first simulation tool

Dingleydale - New Forest as a case study

A simulation tool has been developed (Touchain, 2001), based on such a conceptual framework, and from data collected in the Dingleydale - New Forest irrigation scheme. This scheme was chosen as a case study. It is one of the pilot projects in the Northern Province through the Water care Program (i.e. a scheme earmarked for rehabilitation then transfer by the Provincial Department of Agriculture). With 1600 ha under flood irrigation, it is the largest scheme of the Northern Province. It is actually composed of two schemes sharing parts of their infrastructure and used by

different communities. Merle & Oudot (2000) showed that the scheme is typical, and displays a number of traits that are common to other SIS:

- a large majority of non-farming plot occupiers,
- a diversity of practices and performance among irrigation farmers, yet generally little productive and subsistence-oriented,
- a simple conception of infrastructures (dam and canals, operating under gravity), yet deteriorating,
- a lack of support services, a weak agri-business environment, and missing markets,
- water allocation and water availability problems, especially in winter.

Although in a virtual state of collapse, this scheme appears to be in a better shape than other schemes in the country, with a 30% land use ratio and a diversity of crops being grown apart from grain maize. This seems to be linked with an early autonomous development and the closeness for many years of a tomato factory as a market outlet. Besides, the scheme is one of the best-documented schemes (see chapter 3.3).

Principles

Moisdon (1997) listed a number of characteristics that are deemed indispensable to enable a management and decision-making support tool to reach its goals; it should be:

- Simple: the tools must be user-friendly, easy to use and to understand, yet with a sound compromise between accuracy and simplicity,
- Flexible and fragile: the tool should not be fixed but should be revised and adapted overtime, according to the users' requirements; the tool may evolve, or even be discarded, according to new circumstances or rising questions; such a short life cycle is important to sustain interest, focus and participation around a common problem-solving purpose,
- Interactive and discussible: in the context of intervention research, it is important that the process of development itself create a multilateral dynamic of retroaction and revision of choices; scenarios will neither be ranked or rated; the tool is not prescribing, but rather facilitating discussion, investigating possibilities, then supporting decision; the outputs form a range of indicators,
- Decentralised: the tool should be made available and used at different levels of decision.

Following these principles and the conceptual model, it was decided to develop a prototype of a tool on a spreadsheet software: Microsoft Excel™.

Main features

The prototype follows the principles of the conceptual model, although with some alterations: it does not consider weekly crop calendars but just cropping seasons (winter vs. summer crops), neither it considers water balance at crop, type or scheme levels.

Owing to the spreadsheet platform's characteristics and limitations, the tool is made of 3 types of spreadsheets, all belonging to a single MS Excel file:

- 3 input/output boards, namely "farmer", "cost" and "charging system" boards, whereby data are captured, then output variables, indicators and graphs are reported;
- 3 calculation sheets, whereby calculations are made for each of these boards;
- 2 data-storage sheets, whereby background information on infrastructures and crops are captured and stored.

An additional sheet displays the summarised output of a simulation for printing or demo purposes. The user may keep record of any scenario and its outcome, just through file saving.
Such a first attempt proved easy to develop, to use and to adapt, although with several limitations:

- The user must be familiar with Excel.
- The different input areas are open and unprotected, allowing mistakes. If running simulations is easy, capturing background data remains awkward.
- There is a lack of an actual database attached to the model.
- If certain modules become bigger, some calculations will be limited or impossible.
- Finally, the model has a limited genericity and cannot be applied to every situation without major updating and adaptation.

Running simulations

Principles

A scenario-testing approach basically refers to a comparative approach whereby the user attempts to see how changes in certain inputs affect outputs and indicators. Thus, the approach lies much on two important principles:

- A base scenario should be defined, reflecting a management and water charging system being applied to the current situation. The most realistic and likely features of a water charging system and of a local management entity are chosen according to information collected.
- A number of realistic alternative scenarios should be defined. They include changes that are very likely to occur and/or that are likely to affect much output indicators.

The definition of scenarios must be done in close partnership with a number of stakeholders and experts (see chapter 3.3).
It is also advisable not to test a scenario that includes too many changes at once, since it may become impossible to identify their individual weigh and impact. Changes may be combined afterwards, when each individual impact is well known.

Examples in the case study scheme

A base scenario

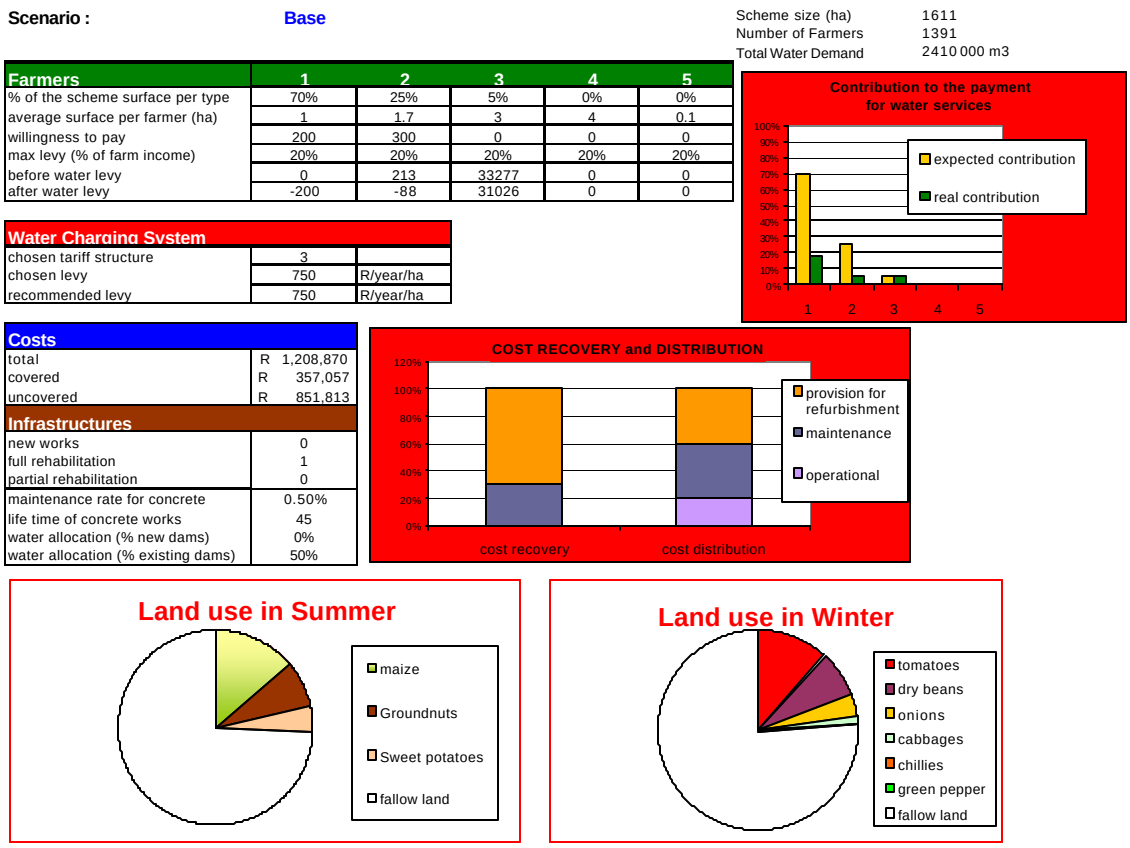
The base scenario data feeds a first simulation that provides a number of output variables, graphs and indicators, as shown displayed in figure 5. The base scenario may be summed up as shown in table 2.

Table 2. Base scenario

Modules	Current situation	Hypotheses on non-existing components
Cost	Existing infrastructures once rehabilitated	Full rehabilitation option but no new waterworks. Basic management assets and personnel that are deemed necessary
Crop	Existing crops with their current features (gross and net margins, yields,	

	etc.)	
Farmer	Existing types (non farming land occupiers, subsistence farmers, transition farmers), with their existing features (farm size, crop combinations, net income, willingness to pay, etc.)	
Scheme	Current size	Basic tariff structure (per ha)

Figure 5. Synoptic board with the results from a base-scenario simulation



The outcome highlights that the current farmers' strategies and cropping systems do not make it possible to cover the costs. Less than 25% of the total cost is recovered (R 357 000 over R 1 208 000).

A "partial rehabilitation" scenario

At the time of the study, the rehabilitation strategy and means were still discussed. It appeared interesting to test a "partial rehabilitation" scenario, whereby concrete furrows for secondary conveyance are refurbished instead of being replaced by pipes in the "full rehabilitation" scenario.
The total cost then raises to over R 1 600 000, mostly because of the much heavier maintenance costs incurred.

A "land use and maize productivity" scenario

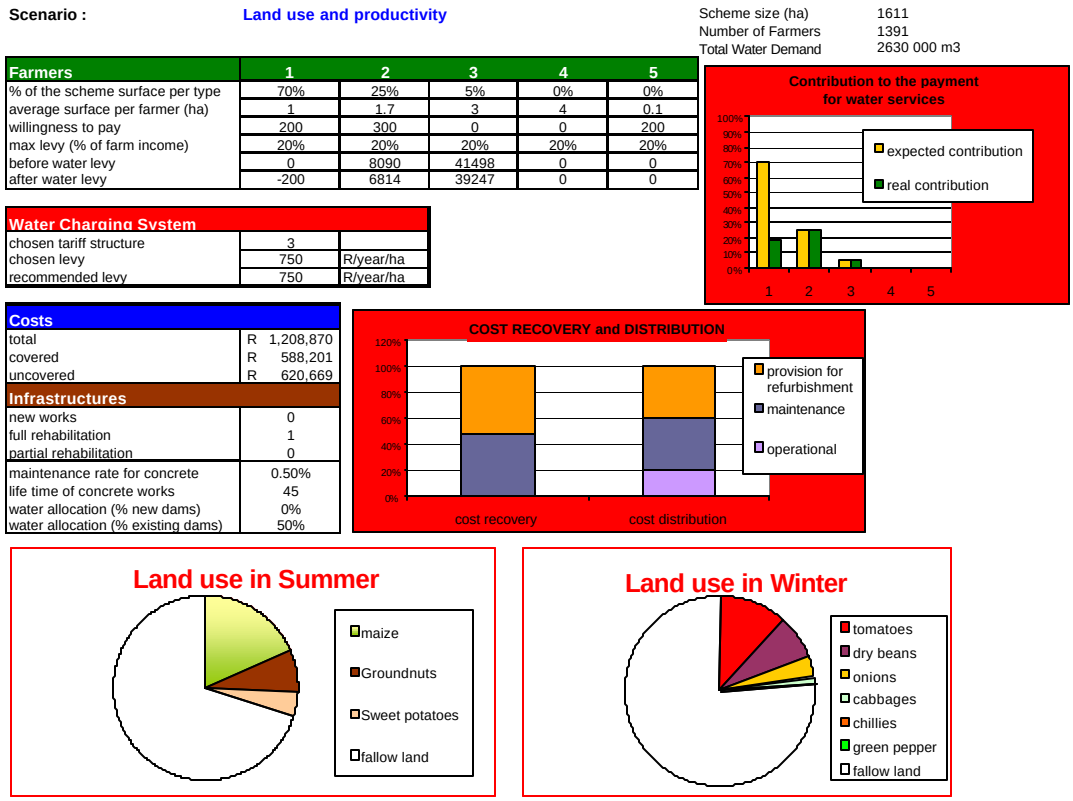
Low yields and partial land use cause low productivity at scheme and community level, and also generate low income at farmers' level, which in turn make impossible for them to pay back water services.
A "land use and productivity" scenario may be tested. It considers the same types of farmers, but assumes that after training sessions on maize production techniques, on-farm experimentations and demonstration plots, and the like, the two farming types (subsistence farmers and transition farmers) have intensified maize production, thus increased their yields, and their land use in winter (see table 3). Such scenario supposes also better access and support to farmers in terms of input / output markets, and possibly credit.

The results show a slight increase in land use in winter. However, the major outcome is the improved cost recovery ratio, since subsistence farmers start making some money out of maize production and can pay back water services (see figure 6).
Such a scenario presupposes the necessary integration/combination of interventions (training + input/output markets + credit, etc.).

Table 3. Changes between the base scenario and a "land use and maize productivity" scenario
(percentages indicate the proportion of the type area covered with maize with a given management style in winter)

Scenario	Subsistence farmers	Transition farmers
Base (current situation)	Low yield (1t/ha): 50%	Average yield, partly harvested in green (3t/ha): 30%
Land use and maize productivity	Low yield (1t/ha): 10% Average yield (3t/ha): 20% Average yield, partly harvested in green (3t/ha): 20% High yield, partly harvested in green (7t/ha): 15%	Average yield, partly harvested in green (3t/ha): 20% High yield, partly harvested in green (7t/ha): 20%

Figure 6. Synoptic board with the results from a "land use and maize productivity" scenario



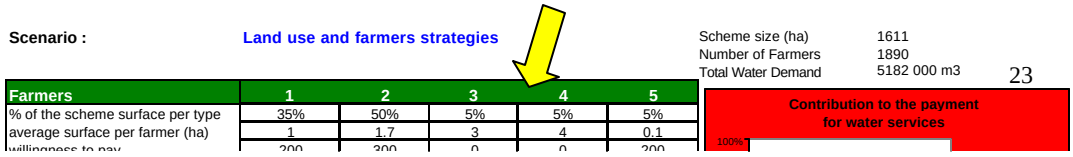
A "land arrangements" scenario

It is clear that the overwhelming proportion of non-farming plot occupiers is a major cause for poor economic viability of the scheme (see figure 4). It has been observed that unclear land rights and poor information prevent farmers from developing innovative inner arrangements (sale, renting, lending, leasing, or swapping arrangements, permanently or temporarily, etc.) (Merle & Oudot, 2000; Lahiff, 1999). Alternative scenarios may be developed on such bases.

As an example, a "land use arrangements" scenario may be imagined. It processes the same data than the base scenario except for farmers' types. Non-farming plot occupiers cover only 35% instead of 70%. The land has been redeployed towards subsistence farmers. There is a shift towards commercialisation strategies (type 4) and also the creation of a number of food plots (see figure 6).

Figure 6 shows the outcome of the simulation, which highlights a significant improvement in land use and production, yet with much higher water consumption. Cost recovery is slightly improved. Above all, land use rearrangements and the creation of small food plots have an impact on social issues (more women involved in food plots), equity (more families benefiting from the scheme) and food security (increased production). The number of farmers, thus families, involved in the scheme is about 1400 in the base scenario (current situation). It reaches more than 1800 in that example.

Figure 6. Synoptic board with the results from a "land rights arrangements" scenario (the arrow spots the changes from the base scenario)



Conclusion

The approach that is described in this document takes root in the circumstances of smallholding irrigation schemes, and in the new institutional and water policy framework of South Africa (see chapter 2).
Such situation generates a number of development-related questions (see chapter 2.4). The Smile approach consists of trying and answer some of those questions.

Conceptual framework and principles

It relies on a number of background principles, orientations and concepts that have been chosen (see chapters 3.1 to 3.3), among which it seems important to highlight the following:

- Establishing and sustaining multi-disciplinarity and partnership, meaning that engineers, agronomists, extension agents, economists, development operators, farmers, decision and policy makers are involved in the process. More specifically, data collection, model development, scenario development and the outcome of simulation should be discussed or imple mented collectively.
- Acquiring and sharing a vision of self-management, and of long-term autonomous viability of the scheme, i.e. including economic perspectives into the analysis, along with social and technical ones.

A conceptual model has been developed, as a framework (see chapter 3.4). Beyond the case study and the pilot tool that has been developed, the model makes it possible:

- to share a common representation on the subject,
- to gather information in an homogenous and exhaustive manner,
- to develop further simulation tools, and reach genericity.

Several frameworks and guidelines have been proposed for SIS assessment (Field et al., 1998; ARC, 1999; De Lange et al., 2000; Bembridge, 2000), although not having generated a common platform for data collection, processing, and then decision support.

A pilot tool on a case study

A first pilot tools has been developed, based on case study data (see chapter 3.5). Scenarios have been tested (see chapter 3.6). The simulations show that:

- the current situation cannot lead to sustainability, since costs are hardly covered;
- total costs can hardly be reduced, since the bulk lays on capital and maintenance costs (however, a partial rehabilitation may prove more costly in the long run than a total one);
- the current biggest problem is the majority of non-farming plot occupiers, with low capacity and willingness to pay water fees;
- low land productivity also strongly limits farmers' income and capacity to pay back water services;
- even slight changes can significantly improve the situation (i.e. reduction of the proportion of non-farming occupiers, shift from mere subsistence towards more commercial farming, increased cropping and improved cropping systems, etc.)

A number of recommendations measures and decisions may be drawn from the simulations. Operators and decision makers should especially address inner land

tenure/access arrangements, farmers' training, access to markets and services. An inescapable prerequisite to sustainable management is the establishment of a sound local managing organisation, which cost is included in the model.
Although requiring accurate and reliable background data, the methodology shows huge potential for decision-making support and for investigation on sound management pathways.

The way forward

Even though Smile has been ultimately specifically designed to try and match the current questions, issues and stakes of SA's smallholding irrigation schemes, previous and still on-going works paved the way for such an approach, in Senegal, Brazil, Reunion Island, Tchad, Mali, where CIRAD and its partners are operating (synoptic review by Le Gal, 2001).
In turn, some interesting aspects rise from the Smile experience in South Africa:

- A strong and sustained interest from a number of various stakeholders,
- The unique opportunity to work collectively, in a multi-disciplinary manner,
- The situation in SA shows a huge diversity and definitely demands further investigations, as the IMT process is just unfolding now.

That generates a unique opportunity to develop further an action-research programme.

The approach is not completed yet. Further developments are currently taking place, with two major orientations:

- Addressing other situations (other schemes of the Northern, Eastern Cape and Kwazulu-Natal Provinces), within which the team is willing to apply the Smile approach, trying and answer strategic questions on the sustainability of schemes earmarked for rehabilitation and transfer. Such situations are also likely to feed back the conceptual framework.
- Developing the tool as such (a software), aiming to ultimately provide an investigation and decision-making tool to scheme managers, consultants and stakeholders.

Those two orientations are indeed very interactive. It is expected that the first one feed the second, providing some generic character to the software. In turn, it should be easier to collect relevant data in line with the existing framework.

Our wish is that the partnership that has been established, and proved efficient and successful so far goes on, for us to assist a successful transfer, then a sustainable management of smallholding irrigation schemes in SA.

Bibliography

Albaladejo, C. & Casabianca, F (editors) (1997) *La recherche-action: ambitions, pratiques, debats*. Document Etudes et Recherches sur les Systemes Agraires et le Developpement, num. 30. INRA, Versailles, France

ARC-LNR (1999) *Checklist for the rehabilitation of Small-Scale farmer irrigation schemes*, draft report, Pretoria, SA

ARC-LNR (1999b) Final report to AWARD, *New Forest and Dingleydale Irrigation Scheme overview and development potential*, Pretoria, SA

Avenier, M.J. (co-ordinator) (1997) *La strategie chemin-faisant*. Economica (publisher), Series "Strategies et organisations", Paris, France

AWARD (1999) *Save the sand Phase I, Feasibility Study: the development of a proposal for a catchment plan for the sand river catchment*, AWARD report, Bushbuckridge, SA.

Backeberg, G.R. & Groenewald, J.A. (1995) Lessons from the economic history of irrigation development for smallholder settlement in South Africa. *Agrekon*, 34 (4): 167-171.

Bembridge, T.J. (2000) *Guidelines for rehabilitation of small-scale farmer irrigation schemes in South Africa*, WRC report Num. 891/1/00, Pretoria, SA

Chancellor, F. (1999) Smallholder irrigators : economic challenges and tools. Agrekon, 38 (Special issue): 259-268

De Lange, M., Adendorf, J. & Crosby C.T. (2000) *Developing sustainable small-scale farmer irrigation in poor rural communities: guidelines and checklists for trainers and developers*. WRC Report Num. 774/1/00, Pretoria, SA

Department of Water Affairs and Forestry (1999 & 2000) *National Water Act News* (various information pamphlets on the principles and implementation of the new Water Act.
Web site: http://www-dwaf.pwv.gov.za

Eastern Cape Restructuring Authority (2001) *Transformation of the Eastern Cape agricultural corporations and irrigation schemes*. ECRA Report, march 2001, Bisho, SA. 16p.

FAO (2001) E.Conference on Irrigation Management Transfer, Sept/Oct. 2001, Conference website:
http://www.fao.org./landandwater/aglw/waterinstitutions/default.htm

Field, W.P., Collier, F.W. & Wallingford.R (1998) *Checklist to assist preparation of small-scale irrigation projects in Sub-Saharan Africa*. ICID-DFID report, New Delhi, India

Gonzalez, F.J. (2001) Summary for the FAO E.mail Conference on Irrigation Management Transfer, Sept/Oct. 2001, Conference website:
http://www.fao.org./landandwater/aglw/waterinstitutions/default.htm

Gosselink, P. & Thompson J. (1997*) Application of participatory rural appraisal methods for action research on water management*. IIMI, Colombo, Sri Lanka

Jiggins, J. & Roling, N. (1997) Action research in natural resource management. Marginal in the first paradigme, core in the second. *Etudes et Recherches sur les Systemes Agraires et le Developpement*, 1997, 30 : 151-167.

Lahiff, E.P. (1999) *Land Tenure on the Arabie-Olifants irrigation scheme*, IWMI Working Paper No. 2, Colombo, Sri Lanka.

Lamacq, S. (1997) *Coordination entre l'offre et la demande en eau sur un perimetre irrigue. Des scenarios, des systemes et des hommes…* Unpublished Doctorate Thesis, CEMAGREF-ENGREF, 134p.
Le Gal, P.Y. (2001) *Gestion des systemes de culture et organisation collective de la production: elaboration d'une demarche d'aide a la gestion des perimetres irrigues.* Rapport scientifique final de l'ATP 10/98, CIRAD, Momtpellier, France
Le Moigne, J.L. (1990) *La modelisation des systemes complexes*. Dunod (publisher), Paris, France.
Liu, M. (1994) Action-research and development dynamics. *In : Systems-Oriented Research in Agriculture and Rural Development.* International Symposium, Montpellier, France, 21-25 nov. 1994. pp. 111-116.
Merle S. & Oudot S. (2000) *Stratégies, systèmes techniques et situations économiques d'exploitations agricoles familiales dans un périmètre irrigué d'Afrique du Sud,* PCSI. INA P- G, Paris, France.
Merle, S., Oudot, S. & Perret, S. (2000). *Technical and socio-economic circumstances of family farming systems in small-scale irrigation schemes of South Africa (Northern Province).* PCSI report, CIRAD-Tera, num. 79/00, Pretoria, SA.
Mitchell C. (2000) *A report consolidating the early development information gathered at Dingleydale and New Forest schemes*, Loxton Venn & Associates report, Pretoria, SA
Moisdon, J.C. (co-ordinator) (1997) *Du mode d'existence des outils de gestion. Les instruments de gestion a l'epreuve de l'organisation*. Seli Arslan publ., Paris, 286p.
NP-DAE (2000) Different discussion documents on the principles and implementation for irrigation management transfer of schemes in the Northern Province. Northern Province Department of Agriculture and Environment, Directorate of Agricultural Engineering. Loxton Venn & Associates.
Ostrom, E. (1992) *Crafting institutions for self-governing irrigation systems*. ICS Press, NY, USA
Perret, S. & Le Gal, P.Y. (1999) Analyse des pratiques, modélisation et aide à la décision dans le domaine de l'irrigation : cas de la gestion d'une retenue collinaire collective à la Réunion. *Economie Rurale*, 254 (1999): 6-11.
Perret, S. (2001) *New water policy, IMT and smallholding irrigation schemes in South Africa : institutional challenges*. FAO International E.mail Conference on Irrigation Management Transfer, Rome, Italy. 14p.
http://www.fao.org./landandwater/aglw/waterinstitutions/default.htm
Rey, J. (1996) *Apports de la gestion industrielle au management des perimetres irrigues : comment mieux piloter la production* ? Unpublished Doctorate Thesis, ENSM Paris, 177p.
Svendsen, M. (2001) Synthesis note on theme 6: Financing irrigation. Contribution to the FAO e.conference on Irrigation Management Transfer, Sept/Oct. 2001, Conference website:
http://www.fao.org./landandwater/aglw/waterinstitutions/default.htm
Touchain, E. (2001) *Smile: un modele d'aide a la decision sur l'avenir et la promotion de l'agriculture irriguee dans les anciens Bantustans d'Afrique du Sud.* DAA dissertation, INAPG, CIRAD num. 58/01, Montpellier, France
Valleyrand, F. (1994) The contribution of action-research to the organization of agrarian systems : preliminary results of experiments under way in France. *In : Rural & Farming Systems Analysis. European Perspectives.* Dent, J.B. & McGregor, M.J. edit., CAB International, pp320-337.

Yung, J.M. (1998) Strategies des acteurs et amenagements hydro-agricoles. In: *Traite d'irrigation* (Tiercelin J.R. editor), Lavoisier, Paris, France, pp 725-737.

Appendices

Documentation on input classes and attributes

Cost module

Irrigation and management assets

Type: e.g. dam, canal, pipe, weir, vehicle, etc.
Name: if any, e.g. for a dam
Allocation (%): for the given asset, percentage of the use and/or resource allocated to the scheme (e.g. for a dam)
Unit: 1 for a punctual asset (e.g. a dam, a weir), meters (e.g. canal, pipe, fence) or else
Number Of Units: number of units for the given asset (e.g. n meters of pipe)
Cost Per Unit: cost per unit for the given asset (e.g. Rand per meter for fencing, Rand for a dam)
Depreciation (%): percentage of the initial value of the asset (capital) that is lost at the end of its working life
Working Life (year): time period during which the asset is operating, before being sold (e.g. vehicle) or refurbished (waterworks)
Annual Maintenance (%): percentage of the initial value of the asset (capital) that is allocated annually to its maintenance during its working life
Annual Operation Cost (Rand): amount that is spent annually for the operation of the asset (e.g. vehicle, pump)

Personnel

Type: e.g. water bailiff, pump station attendant, accountant, manager
Name: Name of the person
Allocation (%): percentage of time allocated to the scheme operation, maintenance, and/or management by the given person
Work Time Unit: work time unit, as used as a basis for salary/fees (e.g. hour, day, month, session)
Number Of Units: number of work time units
Cost Per Unit: cost per unit (e.g. Rand)

Overheads

Type: e.g. telephone bills, transport costs, etc.
Annual Cost (Rand): evaluating the amount that is spent annually for the given item

Crop module

Crop

Crop Name: e.g. maize, tomato, etc
Management Style: e.g. summer maize, low inputs, low yield (1t/ha)
Average Yield (unit/ha): e.g. 1 ton / ha
Crop Market Price (R/unit): e.g. R1500 / ton
Home Consumption (%): Percentage of harvested product that is not marketed (i.e. self consumed, given to relatives, etc.)

Crop calendar

Crop Name
Week Number (1-52): sets up the 52 annual weeks in a table

Presence (Boolean): identification of the weeks when the crop is grown, from planting to harvest
Water demand (mm): weekly water demand by the given crop, from planting to harvest

Production costs

Crop Name
Input Type: e.g. fertiliser, herbicide, insecticide, labour
Commercial Name: if any
Quantity (unit/ha): e.g. kg / ha, bag / ha, hours of labour per ha, etc.
Input Market Price (R/unit): R200 / kg, R7 / hour, etc.

Marketing costs

Crop Name
Marketing Cost Type: e.g. packaging, transport, transaction costs, etc.
Cost (R/ha): evaluating the amount of the given marketing cost

Farmer module

Farmer Type

Type Name: e.g. non-farming land occupiers, subsistence farmers, large commercial farms, etc.
Type Area (%): percentage of the scheme's area that the given type occupies
Irrigation Water Use (Boolean): specifies whether the type is using irrigation water or not
Willingness to pay (Rand): amount that the type is willing to pay for water services, although they are not earning an income from their plots, e.g. R200 / year.
Average Farm Size (ha): Average farm size in the given type, i.e. cumulated area of the irrigable plots, e.g. 1,5 ha

Cropping Systems

Crop Name
Management Style
Crop Area (ha): area allocated within irrigable plots to the given crop on an annual basis (on average)

Scheme module

Scheme Management

Scheme Name: if any
Total Area (ha)
Fixed Component Binomial (Rand / ha): in case of a binomial water pricing system, this is the proposed figure for the first (fixed) component, e.g. R200 / ha (see appendix 6.2.4.1).
Tariff structure (a figure from 1 to 6) : defines the water pricing system to be set up (see appendix 6.2.4.1).

Weekly Water Availability

Week Number (1-52): sets up the 52 annual weeks in a table
Rainfall Median (mm): propose a weekly rainfall figure for each week (median figure)
Resource Median (m3): propose a weekly water resource figure that is available to the scheme (median figure) (from a dam, a river, a main primary canal, etc.)

Calculations

Cost module

Capital Costs

Input classes involved: Irrigation Assets, Management Assets
Capital Cost = [Allocation * Number Of Units * Cost Per Unit * Depreciation / Working Life]

Total Capital Cost = $\sum_{assets}$ Capital Cost

Maintenance Costs

Input classes involved: Irrigation Assets, Management Assets
Maintenance Cost = [Allocation * Number Of Units * Cost Per Unit * Annual Maintenance]
Total Maintenance Cost = $\sum_{assets}$ Maintenance Cost

Operation Costs

Input classes involved: Irrigation Assets, Management Assets, Overheads
Total Operation Cost = $\sum_{assets}$ [Annual Operation Cost + Annual Cost]

Personnel Costs

Input classes involved: Personnel
Personnel Cost = [Number Of Unit * Cost Per Unit * Allocation]
Total Personnel Cost = $\sum_{staff}$ [Personnel Cost]

Total Costs

Total Annual Cost = [**Total Operation Cost** + **Total Maintenance Cost** + **Total Capital Cost** + **Total Personnel Cost**]
Total Annual Cost Per Ha = Total Annual Cost / Total Area (from the scheme management module)

Crop module

Production Costs

Input classes involved: Production Costs
Production Costs = [Quantity * Input Market Price]
Crop Production Cost = ∑ Production Costs

Marketing Costs

Input classes involved: Marketing Costs
Crop Marketing Cost = ∑ Marketing Costs

Crop Gross Margin

Input classes involved: Crop
Crop Gross Margin = [Average Yield * Crop Market Price]

Crop Net Margin

Input classes involved: Crop, Production Costs, Marketing Costs
Crop Net Margin = [Crop Gross Margin – Crop Marketing Costs - Crop Production Costs]

Crop Net Water Demand

Input classes involved: Crop Calendar
Crop Net Water Cons = $\sum_{week}$ [Water Demand * 10]
{Crop Margin Per M3 = [Crop Net Margin / Crop Net Water Cons]

Farmers' strategies & the scheme

For each type

Input classes involved: Scheme Management, Farmer Type, Cropping Systems + outputs from module "crop"
{n} Area Per Type = [Type Area * Total Area]
{n} Number Of Farmers Per Type = [Type Area * Total Area / Average Farm Size]
{n} Type Net Income = $\sum_{crop}$ [Crop Net Margin * Crop Area]
{n} Type Net Water Cons = [$\sum_{crop}$ (Crop Net Water Cons * Crop Area]

{52 * n * m} Type Cropping Calendar = a graphic output of [Crop Calendar] in 52 weeks

At scheme level

Input classes involved: Scheme Management, Farmer Type + outputs from module "farmer"
{1} Total Number Of Farmers = $\sum_{type}$ Number Of Farmers Per Type
{1} Number Of Irrigation Farmers = $\sum_{type}$ Number Of Farmers Per Type (excluding non-farming types, i.e. Irrigation Water Use = n)
{1} Potential Irrigated Area = $\sum_{type}$ [Type Area% * Total Area] (excluding non-farming types, i.e. Irrigation Water Use = n)
{1} Scheme Total Net Income = [($\sum_{type}$ Type Net Income) * Total Area]
{1} Total Water Cons = $\sum_{type}$ [Type Net Water Cons]

Resource available at plot = Resource Median – (Resource Median * Conveyance loss%)
Resource actually available = Resource available at plot – (Resource available at plot * Irrigation loss%)
{52} Overall Weekly Water Balance = [$\sum_{type}$ {$\sum_{crop}$ (**Resource actually available** + (Rainfall Median * 10 * Area) – (Water Demand * 10 * Area)}]
{1} Scheme Total Net Income = [($\sum_{type}$ Type Net Income)]

{52 * n * m} Scheme Cropping Calendar = a graphic output of $\sum_{type}$ [Crop Calendar] in 52 weeks

Water pricing & cost recovery

Input classes involved: Scheme Management, Farmer Type + output variables from the "cost" module

Determining water rates

IF Tariff Structure = 1 (payment per ha, total cost recovery, everybody pays according to the area owned)

THEN **Componant1** = [Total Cost / Total Area]
Componant2 = 0

IF Tariff Structure = 2 (payment per ha, O&M costs recovery, everybody pays according to the area owned)
THEN **Componant1** = [(Total Operation Cost + Total Maintenance Cost) / Total Area]
Componant2 = 0

IF Tariff Structure = 3 (payment per irrigated ha, total cost recovery, those who irrigate pays according to the area owned)
THEN **Componant1** = [Total Cost / Potential Irrigated Area]
Componant2 = 0

IF TariffStructure = 4 (payment per irrigated ha, O&M costs recovery, those who irrigate pays according to the area owned)
THEN **Componant1** = [(Total Operation Cost + Total Maintenance Cost) / Potential Irrigated Area]
Componant2 = 0

IF Tariff Structure = 5 (bimodal tariff, per ha & irrigated ha, total cost recovery, everybody pays according to the area owned but depending on irrigation)
IF Irrigation Water Use = n
THEN **Componant1** = [Fixed Component Binomial] or [(Total Capital Cost + Total Maintenance Cost) / Total Area]
Componant2 = 0
IF Irrigation Water Use = y
THEN **Componant1** = [Fixed Component Binomial] or [(Total Capital Cost + Total Maintenance Cost) / Total Area]
Componant2 = [Total Operation Cost / Potential Irrigated Area]

IF Tariff Structure = 6 (bimodal tariff, per ha & irrigated ha, O&M cost recovery, everybody pays according to the area owned but depending on irrigation)
IF Irrigation Water Use = n
THEN **Componant1** = [Fixed Component Binomial] or [Total Maintenance Cost / Total Area]
Componant2 = 0
IF Irrigation Water Use = y
THEN **Componant1** = [Fixed Component Binomial] or [Total Maintenance Cost / Total Area]
Componant2 = [Total Operation Cost / Potential Irrigated Area)

For each type :
{n} Water Fees = [Component1 + Componant2]

Determining actual water fees

IF Water Fees > Willingness To Pay
THEN **Actual Water Fees** = Willingness To Pay

IF Water Rate =< Willingness To Pay
THEN **{n} Actual Water Fees** = Water Fees

Contribution per type

{n} Expected Contribution Per Type = Water Fees * Average Farm Size
{n} Actual Contribution Per Type = Actual Water Fee * Average Farm Size

Cost recovery rate

{1} Actual Water Fees Recovery = $\sum_{type}$ [Actual Contribution Per Type]
{1} Total Cost Recovery Rate = [Actual Water Fees Recovery / Total Cost * 100]
{1} OM Cost Recovery Rate = [Actual Water Fees Recovery / (Total Operation Cost + Total Maintenance Cost) * 100]