SUSTAINABILITY OF IRRIGATION SCHEMES FOR SMALL SCALE FARMERS: A CASE STUDY OF FURROW IRRIGATION SCHEME AT BULEYA MALIMA, GWEMBE VALLEY - ZAMBIA.

BY

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ABSTRACT

This study was carried out to determine factors that influence sustainability of smallholder irrigation schemes in Zambia. This was against the background that many schemes have been opened by the government to resettle people and have operated smoothly under its management. But upon government withdrawal, farmers have failed to manage these schemes.

The study was carried out at Buleya Malima smallholder irrigation scheme. The objectives of study were; (a) to evaluate the schemes using technical and socio-economic parameters inherent in the scheme, (b) to assess the current practices and, (c) to make recommendations for improving the performance of the scheme and management practices.

The average results for technical study were: 26.4%, 64.5% and 9.2% for application efficiency, tailwater ratio and deep percolation ratio respectively. The results revealed that there was a waste of water by farmers through tailwater runoff. Thus, the system was performing poorly, and could not be sustained at these levels of water loss.

The study on socio-economic revealed that irrigated farming could be sustainable if properly designed and planned with

the involvement of the farmers. The big problem was lack of managerial ability and innovativeness by the scheme management to provide farmers with enabling environment to form their own viable organisations which could see the continuity of the scheme even after the government had withdrawn.

Farmer participation in planning, decision-making and implementation of these decisions is advisable in order to sustain the scheme operations. Management should create enabling environment for farmers to form viable associations through which farmers and management would co-ordinate their operations. Formal and informal training in technical operations of irrigation infrastructure and new agricultural practices should be provided, so that farmers are able to operate the irrigation system with minimum dependence on management. Therefore, provision of well trained management personnel to impart appropriate knowledge on the operations and maintenance of irrigation system is advisable.

DECLARATION

I RUSMUS MASINJA, do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my original work, and has not been submitted for a degree in any other university.

Signature ------------------ Date ------------------

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ABBREVIATIONS AND SYMBOLS

Abbreviations

ADB	=	Asian Development Bank
a.s.l.	=	above sea level (m)
AV.TEMP.	=	Average Temperature (^{0}c)
CV	=	Coefficient of Variation
DPR	=	Deep percolation ratio
EC	=	Electrical conductivity
ET.	=	Evapotranspiration (mm)
LS	=	Loamy sand
LUS	=	Land use services
MA.TEMP.	=	Maximum Temperature (^{0}c)
Meq	=	Milliequivalent
MIN.TEMP.	=	Minimum Temperature (^{0}c)
ppt.	=	Precipitation (mm)
SAR	=	Sodium adsorption ratio
SCL	=	Sandy clay loam
SS.	=	Sunshine (%)
s.d	=	Standard deviation
TWR	=	Tailwater ratio
TR/F	=	Total runoff per furrow (m^3)
USDA	=	United States Department of Agriculture
US(SCS)	=	United States Soil Conservation Services
WS.	=	Windspeed (knots)

Symbols

a	=	empirical constant
A_o	=	cross-sectional area of flow at furrow inlet (m^2)
Ca	=	calcium
D_{rz}	=	rooting zone depth (cm)
E_a	=	application efficiency (%)
f_o	=	basic infiltration rate (m^3/min/m)
fc	=	field capacity
ha	=	hectare
K	=	constant coefficient (m^3/min/m)
L	=	length of furrow (m)
Mg	=	magnesium
mmhos	=	millimhos
n	=	manning roughness coefficient
Na	=	sodium
°C	=	degrees celsius
P	=	empirical parameter
pwp	=	permanent wilting point
q_o	=	furrow inflow (m^3/min)
Q_{in}	=	inflow at head of furrow (m^3/sec)
Q_{out}	=	the steady state runoff (m^3/sec)
r	=	exponent in the advance function
S_o	=	the slope of furrow
S_x	=	subsurface shape factor of furrow

T_a = time to advance the full length of the furrow (min)

$T_{o.5a}$ = time to advance half length of the furrow (min)

t_{co} = cutoff time

v = velocity (l/s)

X_1 = distance water had advanced across the furrow (m)

X_2 = distance water had advanced half the furrow (m)

Z = accumulated intake in volume per unit length (m^3/m)

$Z_{req.}$ = required depth of application to the furrows (m^3/m)

τ = intake opportunity time (min)

1 INTRODUCTION

1.1 Background information

Rainfall is erratic and low in many parts of Zambia. However, the Zambian government's policy on agriculture is to reduce food imports by developing irrigation schemes. This policy is based on 'smallholder irrigation schemes'. The government in conjunction with donor agencies established a number of small scale irrigation schemes throughout the country, with the hope that these communities would adopt the practice in the long run. These schemes were to use simple methods and required small capital investment (Mutelo, 1985).

Irrigated agriculture in Zambia has not recorded success. However, the government has continued to commission new irrigation schemes.

The advent of Kariba dam in 1958 for hydro-electric power generation called for creation of more irrigation schemes to resettle displaced people. This dam was built across Zambezi river between 1955-58 for hydro-electric power generation. It raised water level upstream thus flooding 536 400 ha of the Gwembe valley (Fig.1), where 34 000 people lived (LUS, 1970; Bolon, 1978). Consequently, the Zambian government with the help of donor agencies created irrigation schemes to settle people from the flooded area. These people were inexperienced in intensive systems of irrigation as they practised recession cultivation on the drawdown of the Zambezi river (Mutelo,1985). This made the adoption of irrigated agriculture difficult. Also the established schemes were not efficient due to the inequity in distributing water within the schemes (Poor water management). Farmers have never felt at home in their new settlements because these schemes were imposed on them.

Three schemes were established on the shores of the lake : Chiyabi, Siatwinda and Buleya. Buleya Malima is thus selected for the present study.

These schemes have continued to run smoothly as long as there was government funding. The trend has been such that, once the government funds are removed on certain services (e.g free water services, subsidised agricultural inputs etc.), the operations of these schemes were affected. This had been shown by the poor performance of these schemes after the government funding was removed (Chirwa, 1987).

There has been no rigorous investigation on the part of the government to determine why smallholder schemes were not sustainable. A correct procedure of establishing new schemes, (considering both technical and social aspects), has to be sort. There is also need to take measures towards improving the performance of the existing schemes.

Vermillion (1990) noted that it was easier to design and construct irrigation schemes than to operate and manage them. He observed that most small scale irrigation schemes have not been successful due to poor farmer participation from planning stage, through design, construction, operation and maintenance. Even a well designed irrigation scheme would fail if farmer input was overlooked in the early stages.

Poor water management has also been observed to be the main problem in managing smallholder irrigation schemes. Farmers have failed to manage water in these schemes due to lack of technical know-how. As a result the systems have been inefficient (Chambers, 1988).

Evaluations of irrigation systems are therefore, useful in helping farmers attain greater efficiency in irrigation. These evaluations would lead to better design criteria to suit the farmers' ability.

Inefficiencies in irrigation systems are common particularly in developing countries. In Pakistan, the irrigation application efficiency on farmers' fields ranged from 0 to 100% with a mean efficiency of 20% for 64 farmers. Cheong and Lim (1971) found that farmers tended to apply more water per unit area than was needed, especially, if an abundant water supply was available. This led to several problems including low efficiencies, reduced crop yields, increased costs, waterlogging and salinity. In most cases these technical problems coupled with the socio-economic problems (i.e. lack of farmer participation, lack of farmer training, poor organisational structure and management, and non-availability of agricultural inputs and credits) made it impossible for a small scale farmer to achieve intended objectives. Hence undermining the chances of sustaining the scheme.

1.2 Objectives

The main and general objective of this study was to determine technical, social and economic factors influencing sustainability of small scale irrigation at Buleya Malima irrigation scheme in Zambia.

The specific objectives of the study were:

(a) To evaluate the scheme using technical and socio-economic parameters inherent in the scheme

(b) to assess the current practices

(c) to make recommendations for improving the performance of the scheme and management practices.

1.3 Structure of the thesis

Chapter two surveys the relevant literature. Sustainability is defined in the context of small-scale irrigation scheme and also reviews technical and socio-economic aspects that have influence on sustainability.

The materials and methods are presented in chapter three. The chapter also provides information on extent, location, land use and vegetation, soils, and agro-meteorology of the study area.

Chapter four presents the results and discussion of the research. The chapter is divided into two main sections (a) technical study, and (b) socio-economic study. Under technical study performance indicators (application efficiency, tailwater runoff, deep percolation ratio) of a furrow irrigation system are presented. Under socio-economic study factors (ie. farmer participation, education and extension, organisation structure and management, and agricultural inputs and credits) influencing sustainability of schemes are presented.

The findings of the study are summarised in chapter five. The chapter is subdivided into two parts: (a) conclusion, and (b) recommendations.

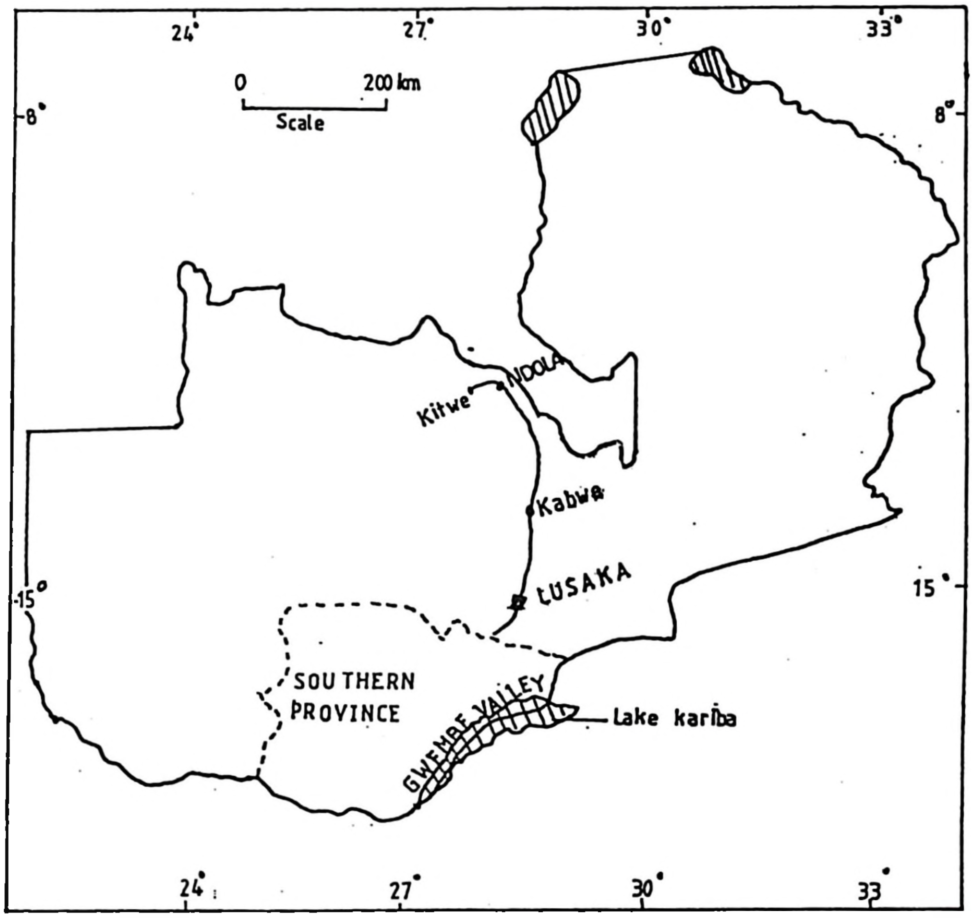


Fig.1 Location of Gwembe valley in Zambia

2 LITERATURE REVIEW

2.1 Introduction

This chapter defines and reviews the factors that influence the sustainability of small scale irrigation schemes. These factors can be grouped into two: Socio-economic and technical factors. These factors are closely interrelated, which one is given priority depends on national and local conditions (Fukuda, 1978). If farmers are suffering from social evils such as improper relations between management and farmers, intermediary exploitation, or heavy taxes, technical measures can hardly be applied. This could lead to the collapse of the scheme.

After the farmers have been educated to some extent (e.g in operation, maintenance, and water management), have been provided with proper agricultural administration, proper health facilities and have increased their farm production, then farmers would participate fully in running of the scheme, their health would improve and their income increased. This would enable farmers to support their families adequately, hence creating stable families (Fukuda, 1978).

2.2 Sustainable irrigation schemes

Sustainable agriculture has been defined as one that requires farm technologies and management practices that indefinitely meets rising demands for food and fibre at economic, environmental and other social costs consistent with rising per capita welfare of people (Crosson and Anderson, 1993). Sustainability of irrigation scheme concerns with ensuring that in the long term the production is maintained without environmental depletion or loss of productivity. Upoff (1986) stated that sustainable irrigation development means to have local institutions and responsible leaders in rural communities who can direct the course of local initiatives as they see fit. Thus, monitoring, evaluation, and scheme improvement could take place with little external direction or major investment of resources because local people have the capacity to follow up issues. These activities would ensure producing adequate output over time without irreparably damaging the natural resource base (Upoff, 1992).

The factors that govern the sustainability of small scale irrigation schemes are subjective, for they are dependent on which factors an individual feels are more important and to what degree they affect the scheme's operational efficiency in the long run (Uphoff, 1992). To achieve sustainability of small scale irrigation schemes, the following factors should be considered:

(a) technical factors;

- performance indicators
  - application efficiency
  - tailwater runoff
  - deep percolation ratio
  - equity
  - design of canal system
- factors affecting furrow irrigation

(b) socio-economic factors;

- farmer participation
- education and extension
- organisational structure and management
- agricultural inputs and credits

2.3 Technical factors

The knowledge as to how well an irrigation system is being used (actual application efficiency) or the confirmation of a design efficiency is important to the farmers. This information can only be obtained by field performance measurements (Jensen, 1983).

The evaluation of an irrigation scheme is necessary on regular basis to determine its performance. There is not a single parameter that is sufficient to define irrigation performance. Nonetheless, many researchers have come up with different views on what seems to be desirable characteristic of sustainable irrigation system. Desirable characteristics are referred to as performance indicators (Walker and Skogerboe, 1987; James, 1988; Maregesi, 1993).

These indicators show how well or badly the system operates so as to have a negative or positive influence on sustainability of a scheme. They include (a) application efficiency, (b) tailwater runoff, (c) deep percolation.

2.3.1 Application efficiency

Application efficiency gives information regarding water losses; usually deep percolation and tailwater runoff, for complete irrigation and overirrigation. This efficiency has been fairly standardised as (FAO, 1989):

$$E_a = \frac{100 \times Z_{req} \times L}{Q_o \times 60 \times t_{co}} \tag{1a}$$

and for underirrigation, Ea is expressed as;

$$E_a = \frac{Z_{req} \times X_d + V_{zi}}{Q_o \times t_{co}} \tag{1b}$$

where,

E_a = application efficiency (%)

Z_{req} = required depth of application (m^3/m)

L = length of field (m)

Q_o = discharge (m^3/sec)

t_{co} = cut-off time (min)

X_d = distance of inadequately irrigated area (m)

V_{zi} = infiltrated volume of water (m^3) over the inadequately irrigated area

Both equations were used in this study to evaluate the sustainability of smallholder irrigation schemes depending on the level of irrigation found in the field.

High tailwater losses would encourage waterlogging and soil erosion, while high deep percolation would encourage leaching of nutrients and salinity. All these factors acting on the land for a long time may lead to physical degradation of the land to levels where it would no longer be able to support crops. These factors would undermine the sustainability of the scheme.

Therefore, in situations where application efficiency is low, this implies that the system is not promoting sustainable productivity and profitability. The farmers may not be willing to stay in a place where they are not making any improvements on their lives.

The application efficiency should be maximised subject to limitations on erosion, the availability and total discharge of the water supply. Application efficiencies ranging from 0% to 100% have been reported in many parts of the world, with a large number of irrigation projects in developing countries performing below 50% (Walker and Skogerboe,1987). Generally, application efficiencies of 50% to 100% for furrow irrigation are considered satisfactory, although the average is taken as 75% (Bos and Nugteren, 1974).

Maheshwari and Macmahon (1992) found application efficiency of 33% for one irrigation scheme in Australia. This meant that about 67% of the water applied was lost through tailwater runoff and/or deep percolation. He found that the scheme had a problem of waterlogging and salinity. This affected the productivity of the land. Farmers were frustrated, because a lot of money was needed to reclaim the land. Thus the sustainability of the scheme was affected.

2.3.2 Tailwater runoff

Irrigation water that has passed beyond the lower end of the furrow is called tailwater runoff. This is taken as a loss. The impacts of tailwater runoff are: (a) erosion of top soil, (b) nutrients are transported away from the field by downstream water bodies.

Erosion of the top soil in the furrow is generally the major problem associated with tailwater runoff.
The sediments from eroded top soil can then obstruct conveyance and control structures downstream. Tailwater runoff may also bring about the problems of waterlogging and salinity downstream. Waterlogged areas may further become breeding grounds for vector insects like mosquitoes, which in turn would imply the prevalence of malaria in the community. The occurrence of topsoil erosion, salinity and waterlogging would entail the following to the farmer (FAO,1989): (a) poor soil fertility, hence poor crop yields, (b) physical degradation of the land, and (c) poor health of farmer community, hence poor performance in their agricultural activities. With all the problems mentioned above the scheme may not be sustainable.

The tailwater ratio, TWR, is defined as the ratio of the volume of runoff, to the volume of water applied to the field. It can be calculated as follows (FAO, 1989):

$$TWR = 100 - E_a - DPR \qquad (2)$$

Where DPR is the deep percolation ratio
In a good irrigation system, tailwater runoff should not exceed 20% (Walker and Skogerboe, 1987).

2.3.3 Deep percolation

Deep percolation refers to the irrigation water that soaks into the soil and drains into depths below the crop root zone. High deep percolation losses aggravate waterlogging and salinity problems and leach valuable crop nutrients from root zone. Deep percolation losses should not exceed 20-25 percent of the design application depth (Jensen,1983).

Poor aeration caused by waterlogging bring about accumulation of carbon dioxide and production of toxic substances. Hagan (1952) found that carbon dioxide reduced penetration of the roots to water. In growing tomato plants Krammer (1956), observed a reduction of 34 to 32% in yield.

Deep percolation losses if prolonged in fields would raise the water table, and the result would be the salinity problem. There are very few crops which are tolerant to salinity. This would mean that the farmer would be restricted in terms of choice of crops to grow on these soils (Jensen, 1983). Farmers usually would want to grow a lot of other crops apart from cash crops, and if they are restricted because of salinity, they may not view it correctly. In general salinity would affect the growth of crops and poor yields would be the result. Since profit making is one of the incentives that would make a farmer be making is one of the incentives that would make a farmer be willing to work in the scheme, then there would be no need for him to stay on if no profit is forthcoming from his sale of irrigated crops.

Deep percolation losses can be expressed as a deep percolation ratio, DPR, which is defined as the ratio of the volume of water stored in the root zone to the soil moisture deficit (Walker and Skogerboe, 1987). For complete irrigation and overirrigation, it is expressed as:

$$DPR = [(V_z - Z_{req}) \times X_d + Q_o \times t_{co}] \times 100 \qquad (3a)$$

and for under irrigation, DPR is calculated as follows:

$$DPR = [(V_{za} - Z_{req}) \times X_d \div Q_o \times t_{co}] \times 100 \qquad (3b)$$

Both equations were used to evaluate sustainability of smallholder irrigation schemes in this study depending on the level of irrigation encountered in the field. The infiltrated volume is estimated by intergrating the subsurfarce moisture distribution by using the trapezoidal rule (Walker and Gichuki, 1985):

$$V_{zi} = (Li/2na) * (Zoi + 2 * Z_1 + 2 * Z_2 + .. + Zni) \qquad (4a)$$

$$V_{za} = (La/2na) * (Zoa + 2 * Z_1 + 2 * Z_2 + ... + Zna) \qquad (4b)$$

$$V_z = (L/2n) * (Zo + 2 * Z_1 + 2 * Z2 + .. + Zn) \qquad (4c)$$

where:

Vzi, Vza, Vz = infiltrated volume over the inadequately irrigated area, adequately irrigated area and whole area, respectively

Li, La, L = furrow lengths over the lengths over the inadequately irrigated area, adequately irrigated area, and whole area, respectively.

ni, na, n = number of increaments used to subdivide the furrow over the inadequately irrigated area, adequately irrigated area, and whole furrow, respectively.

Zoi, Zoa, Zi = cummulative intake at the ith point in the inadequately irrigated area, adequately irrigated area and whole furrow, respectively.

2.3.4 Equity

Equity is a measure of spatial uniformity of water distributed to each farmer in an irrigation system that supplies multiple users. On the other hand, inequity, often referred to as tail end problem, is well known to exist in many systems (Abernethy, 1986). Inequity implies poor distribution of water and therefore, reduced productivity of the available water. Two studies in Sudan and Zimbabwe showed that production and ability to meet costs were drastically reduced in inequitable water supplies (Tiffen,1990). Most small scale farmers are poor. If they are subjected to an irrigation system which reduces their income, they may get frustrated and leave the scheme. The irrigation system should be able to provide sustainable water supply equitably to all farmers. This way farmers would be encouraged to carryout their agricultural activities diligently. Thus the scheme would be sustained.

Variation of water distribution occurs at various levels in an irrigation system. Inequity may be between users of a common field channel and inequity can be between the flows issued from the main system to distributaries or to field channels. The variation over the geographic area of scheme, include the well known "top-tail syndrome", with more water available to farmers at the top end and less to farmers at the tail end (Maregesi,1993). When supply is variable over time, the farmers at the tail end are the ones who frequently suffer most in years of shortage. These shortages may lead to illegal withdrawal of irrigation water by some upstream farmers. Some farmers may influence the water-men so that they can divert some of the water to their fields at times when it was not their turn.

This habit tends to affect very much the farmers who are at downstream. These farmers would get frustrated and may leave the scheme, if the event repeats itself several times.

The perfomance of many irrigation schemes in Bangladesh were found to be generally unsatisfactory due to engineering problems, e.g. poor canal structures which were resposible for poor water distribution (Biswas, 1988). Experience had shown that only a few farmers upstream were benefiting. Farmers upstream had the tendency to use more water than they needed.

Insufficient supply of water in Lower Moshi and Majengo, Tanzania, generated conflict between upstream and tail farmers. This situation adversely affected cropping pattern and agricultural production (Masija and Kagubila, 1994).

When a farmer is faced with a situation where there is inequitable water distribution, he may resort to giving out bribes to the people in charge of distributing water. Then the whole system would become corrupt in the long run. Those farmers who are poor, may not be able to find money to bribe the water distributors. The end result would be frustrations. Some farmers may decide to run away from such unfair system. The scheme would not be sustained under such conditions. The formation of farmers organisations, e.g. Water Users' Association - WUA is seen as the only viable solution to resolve water conflicts between farmers. WUA should participate in formulation of plans for scheduling water supplies to members, this would also help to reduce irrigation tailwater ponding and waterlogging by some selfish farmers upstream (Masija and Kagubila, 1994).

The causes of variability in water supply are many. Those that lie within the direct responsibility of irrigation management include the following: (a) design faults; such as inadequate control and measurement structures resulting in water being inequitably distributed and inadequate canal capacity for the area they are supposed to command, (b) failure to carry out essential maintenance and, (c) management faults such as inadequate scheduling plan or failure to have an alternative crisis management plan when it is known that shortages occur every few years (Maregesi, 1993). Each factor mentioned above may lead to collapse of the scheme. The situation may only be corrected by involving farmers in the operation and maintenance of the structures. Farmer involvement should start from planning, design, and construction to operation and maintenance of the scheme. This would allow smooth transfer of management to the farmer. Thus ensuring the sustainability of the scheme.

The study in Sri Lanka showed that lack of adequate and regular supplies of water was a mojor constraint to increased agricultural production in dry zones of Sri Lanka. The following action was proposed to be taken; the operation and maintenance of the system should be on the hands of farmers through their water user associations who would be able to distribute water equitably in sustainable quantities (Farrington, 1984).

2.3.5 Canal design

The purpose of a canal system is to provide adequate water at the right time for a given command, to all plots within the area serviced (Israelson and Hansen, 1962). The system should be convenient to operate and should blend with the pattern of farming. Poor canal design will overlook all results of human activity in the area which are of technical, legal, or economic snags and benefits (Thorn,1959). Such a canal design may not be sustainable because some points where canals pass could be footpaths or animal tracks and people may continue to use these paths, that will destroy the canals.

If canals are designed discretely i.e, without the farmers' consent, structure tend to get damaged or deteriorate quickly because of poor management by farmers, and farmers are less inclined to pay fees for irrigation service when they perceive structures as being unmanageable, irrelevant or extravagant (Uphoff,1986). The damage to the irrigation structure would mean no water to farmers' fields, then the scheme would have to close down.

The design engineers should involve farmers before designing so that some urgent need by the farmers may be included in the design. A canal system which is solely designed by an engineer may become too complicated for the farmer to operate and maintain when he is running the scheme himself. Thus, the system would not be sustainainable (IIMI,1990).

In Butiama and Pawaga irrigation schemes, Tanzania, incomplete canal system resulted into poor water management. This situation had adversely affected cropping pattern and agricultural production. Farmers saw no need to be in the scheme in which they were not making profit (Masija and Kagubila, 1994).

Poor canal system design can frequently increase existing mosquito problems. Favorable conditions include standing water for a duration of several days in tailwater ditches, and seepage areas along canals. There is an obvious implication of mosquito on the farming community. Because of malaria, the welfare of the community would be affected. If no control measures are taken, some farmers may decide to move away from the scheme. If many farmers decide to move, then the sustainability of the scheme would be jeopardized.

Soil erosion in unlined canals may be a problem if water control structures are not installed. Accumulation of silt and clay sediment load along the canal would clog the canal and water flow to the fields would be slowed down. Furthermore, if weeds are allowed to grow in unlined canals, they will slowdown the flow of water, and increase the loss of water through evapotranspiration and seepage. If the problem is not solved quickly, farmers may not manage to clean the clogged canals. Therefore, it becomes important that farmers participate in construction of canals so that even when it comes to operation and maintenance, they would do so willingly (Hansen, 1979). This would ensure long term operation of the canals.

Canals and laterals located in permeable soil with excessive leakage would cause waterlogged areas or ponds. This would give rise to salinity problems. If the situation is not corrected early enough, it would affect the productivity of the land. Crop yields would be lowered. Farmers are in the scheme to sustain their livelihood through good crop yields. But if the land can no longer provide them with enough food, they may see no need of being in the scheme (Chambers, 1988).

2.4 Factors affecting furrow irrigation

2.4.1 Infiltration rate

It is the infiltration capacity of the soil that determines the rate at which water can be applied to the soil surface without runoff. The ideal situation is to have the infiltrated depth equal over all portions of the field (Walker and Skogerboe, 1987). But this is not the case because of variations in intake opportunity time and soil intake properties which generally result in overirrigation over a significant fraction of the field.

The lack of knowledge about the infiltration capacity of soil has most times undermined the efficiency of many systems (James, 1988). The end result for this has been either underirrigation and/or overirrigation. Both ways is not good for the smallhoder farmer. If the field is underirrigated, then the crops would receive less water than they needed. This would have a direct effect on the yields. If the situation is that of overirrigation, the results are those of either deep percolation and/or tailwater runoff. The consequencies of high deep percolation and tailwater runoff usually result in erosion of top soil, leaching down of crop nutrients, high water table, hence salinity and waterlogging problems. If all these problems are to bear on the farmer, it may be very difficult for him to obtain high productivity and good income. This state of affairs would frustrate the farmer if it prolongs.

Several expressions have been proposed for infiltration rate in most earlier studies and in this work the simplest equation used is the Kostiakov-Lewis equation expressed as:

$$Z = K \times \tau^{a} + f_{o} \times \tau \qquad (5)$$

Where;

Z = accumulated intake in volume per unit length (m^3/m)

τ = intake opportunity time (min)

a = constant exponent

K = constant coefficient ($m^3/min^a/m$)

f_o = basic infiltration rate (l/s)

When calculating the infiltration function, there are other parameters which need to be considered, and these include; (a) flow geometry, (b) cross section, (c) values of a and k, and (d) the basic infiltration rate, f_o.

Flow geometry is difficult to describe under furrow irrigation, because the furrow shape changes continually due to erosion and deposition of soil as water moves it along it. The shape of furrows ranges from triangular to parabolic. Trapezoidal and parabolic furrows can handle large flows without erosion than the triangular shape. Also, they can easily be made different widths, therefore they are more desirable shapes (Merriam and Keller,1978).

Simple power functions can be used to relate the cross sectional area and wetted perimeter with depth, as follows:

$$A_o = [\frac{q_o \times n}{60 \times S_o^{.5} \times P_1}]^{\frac{1}{P_2}} \qquad (6)$$

where:

A_o = cross-sectional area of flow at furrow inlet (m^2);

q_o = furrow inflow (m^3/min);

n = Manning roughness coefficient

S_o = the slope of furrow

P_1, P_2 = fitting parameter

The values for a and k in the infiltration function are estimated as follows (Walker and Skogerboe, 1987).

$$a = \log(V_a/V_{0.5a}) \div \log(T_a/T_{0.5a}) \qquad (7a)$$

$$K = \frac{V_a}{S_x \times T_a^a} \qquad (7b)$$

where:

$$V_a = \frac{Q_o \times T_a}{L} - 0.77 \times A_o - \frac{F_o \times T_a}{(1+r)} \qquad (8a)$$

and

$$V_{0.5a} = \frac{2 \times Q_o \times T_{0.5a}}{L} - 0.77 \times A_o - \frac{F_o \times T_{0.5a}}{(1+r)} \qquad (8b)$$

Where:

Q_o = discharge (L/s or m^3/s);

T_a = time to advance the full length of the field (min);

L = length of the furrow (m);

A_o = cross-section area of flow at furrow inlet (m^2);

f_o = final infiltration rate (L/min);

$T_{0.5a}$ = time to advance half the length of the field (min);

a = empirical constant.

The largest potential error in estimating an infiltration function for a field lies in the a and k term of Eq. 7a and 7b.

There are several approaches used for estimating basic infiltration, f_o. For this study f_o was found by using the following equation (Walker and Skogerboe, 1987):

$$f_o = (Q_{in} - Q_{out})/L \tag{9}$$

Where:

f_o = final infiltration rate (m^3/min/m)

Q_{in} = Inflow at head of furrow (m^3/sec)

Q_{out} = the steady state runoff(m^3/sec)

L = Length of furrow (m)

The application required to replace the root zone, Z_{req}, was calculated in this study as follows (James, 1988):

$$Z_{req} = D_{rz} \times (fc - pwp) \times p \tag{10}$$

where:

D_{rz} = depth of root zone (cm)

f_c = field capacity by volume (%)

pwp = permanent wilting point by volume (%)

p = maximum allowable deficit

In order to attempt to find the cause of poor furrow irrigation performance, one should bear in mind that infiltration changes a great deal from irrigation to irrigation, from soil to soil, and is neither predictable nor effectively manageable. The infiltration rates are an unknown variable in irrigation practice (Jensen, 1983). Trout (1990) found that furrow - to - furrow infiltration variability causes non - uniform water adsorption rates along the furrow. He concluded that infiltration variability results in excess water application and reduced irrigation water use efficiency.

Walker and Skogerboe, (1987) defined the infiltration opportunity time as the time difference at each measuring station between the clock time or cummulative time of advance and recession for infiltration to occur. Excess opportunity time results in deep percolation.

2.4.2 Furrow discharge or stream size

Furrow discharge refers to the amount of flow into a furrow per unit time. It depends on the soil type, slope, length of run and the availability of water supply. In most studies to date the inflow rate has been assumed constant with time (Jensen, 1983).

Furrow discharge has a direct influence on the infiltration rate and velocity of water in the furrow. If the furrow discharge is great, this would mean increased head and water velocity and usually when velocity is high, infiltration rate tends to be reduced. This would increase the amount of tailwater runoff. High velocity would also cause soil erosion. Due to low infiltration rate the water deficit in the crop root zone may not be fully replaced, although this is dependent on the length of time of irrigating. Prolonged high furrow discharge would result into extensive soil erosion, loss of nutrients from the rich top soil, waterlogging downstream, and hence physical degradation of farm land and/or poor crop yields. With such problems the scheme may not be sustainable.

To enable enough wetting to the end of the furrow as early as possible, maximum non - erosive flow capacity is suggested as (USDA - SCS, 1956):

$$Q_o = \frac{45}{S} \tag{11a}$$

where:

Q_o = maximum non - erosive stream size (l/min)

S_o = longitudinal slope of furrow (%)

Non-erosive discharges commonly vary from 2 to 8m/hr (Withers and Vipond, 1974). Maximum flows are limited to non-erosive velocities below 0.15m/s (Jensen, 1983). As slopes increase, a large number of cutback should be made to the initial flow so that at any given time water just reaches the end of the furrow with no runoff occuring. In practice, one or two cutbacks are carried out. The final cutback stream should be of the soil intake rate, i.e. just above the basic rate of infiltration f_o.

$$Q_{cutback} = 1.1 \times f_o \qquad (11b)$$

where:

$Q_{cutback}$ = final cutback stream size

f_o = basic infiltration rate (l/s)

2.4.3 Land surface slope

To avoid costly land grading and subsequent restriction of rooting depths, longitudinal and cross slopes should be adapted to natural topography. For cross slopes there is a wide tolerance, the only constraints being the reduced capacity of furrow and the command of the water surface in the supply ditch.

Erosion problems during periods of rainfall can occur, and the furrows channelling the runoff should have a limited slope. To prevent deep percolation losses during irrigation, slopes in sandy soils should be greater than for clay soils, therefore, some compromise is required.

For furrow irrigated fields, the slope, or grade, of the field may not be uniform and have a significant effect on time of advance (Walker and Skogerboe, 1987). For farmer managed irrigation scheme it may be more desirable to break the field into portions to avoid the expense of land grading. High grade of land would encourage high water velocities along furrows. The result would be, high tailwater runoff, hence loss of top soil and finally physical degradation of the land in the long run. The soil erosion process of such a nature may be very insignificant, but the impact may be felt in the long run. Proper soil conservation measures should be used to prolong the utility of the land. If measures are not used the scheme may not be sustainable, because of physical degradation of the land (Jensen, 1983).

Generally, furrow slopes vary from 0.2 percent (sandy soils) to 1 -2 percent (clay soils). In furrow irrigation, when slopes exceed 0.05 percent, recession time is relatively short and can be ignored, but on low gradient (<0.05 %) or level furrows, it is a very significant portion of opportunity time (Walker and Skogerboe, 1987).

2.4.4 Advance time and time of cut-off

The advance time needs to be known by the farmers, so that they know when to cut-off the supply of water to the into either high tailwater runoff and/or deep percolation or worse still underirrigation if advance time is too small. In both cases the crop yield decreases. To reduce frustration of the farmer, he should be provided with the correct advance time for a given length of run, land surface slope, and type of soil so as to know the exact time of cut-off. If these parameters are not considered, the system would be inefficient and the scheme may not be sustainable.

A simple power function is generally used to describe the advance trajectory and is expressed as (FAO,1989):

$$X = P \times t_x^r \tag{13a}$$

where x is the advance distance (in meters) from the field inlet that is achieved in t_x minutes of inflow, and p and r are fitting parameters.

The empirical parameters, p and r, can be defined by a two point fitting of the equation. The time to advance to a point near one half of the field length, $t_{0.5a}$, and the advance to the end, t_a, can be solved simultaneously as follows:

$$r = \log\frac{X_1}{X_2} \div \log\frac{T_a}{T_{0.5a}} \tag{13b}$$

and

$$p = \frac{L}{t^r} \tag{13c}$$

The power advance exponent r typically has a value of 0.3 to 0.9 (Walker and Skogerboe, 1987). The ideal advance time may be achieved when the following conditions are met: (a) the stream reaches the lower end of the furrow but does not cause erosion or overtopping, (b) losses to deep percolation are minimal, and (c) variation in intake opportunity time is greatly reduced.

Advance time increases when (a) stream size is decreased, (b) length of run is increased, (c) hydraulic roughness is increased, (d) field slope is decreased, and/or (e) infiltration capacity of the soil is increased.

The time of cut-off and discharge are interdependent parameters which must be known in order to operate the system properly. The following equation may be used to find the time of cut-off (Walker and Skogerboe, 1987):

$$t_{co} = \frac{Z_{req} \times L}{Q_o \times E_a} \qquad (14)$$

In this study only application efficiency, tailwater runoff and deep percolation ratio were considered due to lack of time and insufficient funds.

2.5 Socio-economic factors

Farmer management in irrigation schemes is recognised as a vital factor because it determines their long-term operations. Fukuda (1976) stated that there is an obvious relationship between sustainability of schemes and the human environment, but this aspect has often been overlooked. Studying human factor in irrigated agriculture he found that farmers usually planned their economic strategy in the light of their total resources, which may include rainfed crop production, livestock, opportunity for off farm labour etc. Therefore irrigation development if it is to be sustainable should study thoroughly the existing economic enterprises and advise on the improvements gradually.

There was a need for a new approach involving the farmer, their tradition and their social environment. For instance traditionally some tribes preferred to go on break after every harvest, hence cropping intensity would not be maximised even with irrigation facilities. Under such situations, to avoid conflicts between management and farmers, farm operating calender could be made with full participation of farmers (ADB, 1982). Consequently, the socio-economic factors include; (a) farmer participation, (b) education and extension, (c) organisational structure, and management, and (d) agricultural inputs and credits.

2.5.1 Farmer participation

To encourage farmer participation, there must be clear policies from relevant government agencies. These policies must be seen to be supportive of farmer participation in irrigation system development. Farmers' capability, self reliance and sense of ownership should be promoted to encourage farmer participation (IIMI, 1990). Once farmers come to realise the scheme is their property, they would make sure the scheme succeeds. Hence, ensuring sustainability.

Farmer participation is seen as the key to attaining sustained performance improvement. Therefore, farmers should participate actively at all stages of scheme planning, design, construction and finally operation and maintenance (FAO, 1987). The farmers should be effectively involved in the excution of construction work by either providing some labour, finance, or material contribution.

This way farmers would see the scheme as their property necessary to increase their food security and income (Coward, 1984). After all, the government by itself may not manage to handle all the tasks of irrigation development.

Participation of farmers in design of an irrigation system is seen as an important prerequisite for the sustainability of the system structures. Design is usually conceived and implemented as a discrete task, rather than a gradual incremental process, and yet it sets long term management parameters (Vermillion, 1990). Lack of farmer participation at design stage results into poor operation and maintenance of these structures.

Lack of appropriate methods and policies for motivating and training farmers in effective participation in irrigation development and management undermined the idea of sustainable irrigation development. To this end, effective farmers' associations are recommended. The formation of these organisations take different forms depending on the environment in which they are working. The functions of these organisation would include (Maregesi, 1993):

(a) Distribution of water between users;
(b) Maintenance of the canal system and related structures;
(c) Fee and fine collections;

related structures;

(c) Fee and fine collections;

(d) Resolving disputes between farmers and management;

(e) Involving the farmers in decision making process;

(f) Presentation of the farmers' views to government agencies ;

(g) Provision of an organised means for extension and farmer training;

(h) Mobilisation of local resources to construct, improve or maintain facilities; and

(i) organise agricultural inputs and credit facilities for farmers.

The farmers should play a significant role in managing the irrigation scheme. Therefore, the government should retain the farmers' responsibility for irrigation management. For example, if the government has assisted in the rehabilitation of the weir and other large structures, the operation and maintenance of the system should be on the hands of the farmers through their water user associations. The government should assist in providing training in all aspects concerning the management of the scheme. It is only by way of such an approach that the schemes would be sustained (FAO,1985; Oad and King, 1991).

The concept of participation have been misused. Other people have used it to obtain information in order to diagnose problems for the farmers. This is opposed to the approach of trying to help the farmers to consider their ability to analyse their situation and decide what further actions to take. Farmers should be encouraged to participate in decision making process, especially if the decisions made involve the running of the scheme. If the farmer realised that he was being used as a guinea-pig and yet nothing was improving in his living standard, he might decide to leave the scheme (Illo et al., 1984).

2.5.2 Education and extension

Although the profitability of certain techniques has been demonstrated, the farmer still needed to be motivated towards change in order to make him stable in his new environment. This motivation is presently based mainly on increase in monetary income and production surplus. But literacy has remained a crucial problem in modernising irrrigation schemes (Johl, 1979). Assistance to the farmer should be provided by training him in all areas concerned with operation and maintenance of the scheme, e.g. water management.

The absence of training the farmers in how to use and maintain the irrigation structures has frequently led to their destruction or damage. It is proper that the training should be offered to both government staff as well as farmers. The training should be multidisplinary in nature with aim of increasing crop production sustainably (Corsiga, 1989). This would ensure smooth hand-over of the scheme to the farmers. In schemes where no such training took place, the sustainability of these schemes was at stake.

In India, studies have shown that in areas where small-scale irrigation schemes were failing or weakening, regardless of local level training in water allocaton and irrigation scheduling. The causes were traced to human factor of not being able to grasp the irrigation techniques (Patil, 1989). Training of farmers on the operation and maintenance of the irrigation system should start at design stage of a scheme. This way farmers would be able to operate the system independently with minimum assistance from the government personnel. If farmers are not trained properly, at the time when the government withdraws its personnel there would be no one to run the scheme or the farmers would be forced to employ some one to operate the system on their behalf. This would mean extra expenses on the part of the farmer. Some farmers may not favour the idea. This might bring conflicts among farmers. The conflicts if prolonged may result into the breakdown of a scheme.

Farmers should also be educated on the likely irrigation hazards which would occur under poor water management. Pathogenic agents are easily bred and respectively transported through irrigation water. In this way a large number of diseases are transmitted e.g. Malaria schistosomiasis, yellow fever etc. These diseases may cause deaths, which would naturally affect the stability of these communities. If farmers are not educated of these diseases they may be over-whelmed when deaths start occurring and may start running away from the sheme (Worthington, 1977).

Due to absence of training of farmers in water management, studies in Sudan showed an increase in malaria and schistosomiasis incidences which resulted into many deaths. This reduced the labour force, and affected the agricultural productivity. This led to some farmers abandoning the schemes (Alam, 1991).

Irrigation is a new technology. It has been observed that, if this technology is to be sustained it should be supported by new agricultural practices such as proper fertilizer application, proper pesticide use and above all correct application of water, thus, applying right amount of water at the right time. Therefore, the extension workers should try to bring these agricultural practices to the attention of the farmers. This could be done in several ways; by conducting frequent visits to individual farmers' fields and teaching them right in the fields, and by extension workers organising demonstration plots within the scheme where all farmers would be invited once in a while to learn the applicability of these new practices. Such would keep farmers up to date with their agricultural operations. This would go along way to improving the farmers' productivity and hence increasing their incomes. The sustainability of the scheme would also be ensured (Farrington, 1984).

2.5.3 Organisational structure and management

The appropriateness of a structure will vary in accordance with a number of factors which are specific to each organisation's objectives, function and local context. The followng factors have been observed to be important determinants of appropriate structure in the context of irrigated agriculture (Kart and Rosenzweig, 1974): (a) size of scheme, (b) human capabilities (i.e, level of training), (c) stability of decision-making environment, and (d) social structure and objectives.

Within the hierarchy of scheme structure there should exist farmers' body to represent their interests. It is through these bodies that farmers would participate in decision making, manage resources, resolve conflicts and maintain communication with the management. The absence of such bodies like Water users' Association - WUA hinder farmers from participating in decision making process in the schemes. Farmers should participate in formulating plans for operation and management of the schemes to ensure sustainable development of irrigated agricuture. A good structure should be able to facilitate good working relationships between management on one hand and the farmers on the other. This would ensure sustainability of the scheme (Simon, 1976).

Poor performance of schemes have often been blamed on poor management skills by government staff given the responsibility to run these schemes. Studies in Sri Lanka showed that in most irrigation schemes the scheme management, which happened to be government employees, had a big influence on the way decisions were implemented in the schemes. Whatever decisions were passed during meetings between farmers and management, they were still subject to verification by the scheme management. As a result farmers were no longer interested in attending meetings (Asian Development Bank, ADB, 1982). Such influencies by the management tended to underscore the objective of transfering the running of the scheme to farmers to ensure long term operations.

Farmers as individuals know exactly what they would want to achieve and know the capabilities of their neighbours for leadership and decision making. In this respect, the scheme management should give guidance to farmers in selecting leaders among farmers so that management responsibilities of a scheme are gradually transferred to farmers who by design are expected to remain in the scheme for years to come. This would ensure sustainability of these schemes (Kagubila and Mnzava, 1993).

The attitude of management towards the scheme sometimes creates an impression that the scheme is government property and that it was the government's responsibility to run the scheme for the farmers. This creates insecurity among farmers, as a result farmers' attitude towards the scheme is that of skepticism. Management should create conducive environment whereby farmers would be able to assume leadership responsibilities. In any case these schemes are supposed to be farmers' property, and have to use them sparingly for their children in future (Hossain , 1986).

2.5.4 Agricultural inputs and credits

Farmers are essential in the production enterprise, and if they are to participate fully in the operations of the scheme, they need some motivation. Majority of the small scale farmers are poor. They lack financial support to purchase inputs but have only limited labour force which may not be adequate to complete all farm operation at a specified time. Farmers may get frustrated when they discover that they are helpless in terms of agricultural input. An integrated approach in providing subsidised agricultural inputs would result in greater agricultural production and an increased farmers' income. This in turn would enable the farmer to be self reliant (Winnie, 1958). A good number of self reliant farmers in a scheme would increase chances of a scheme being sustainable.
Farmers practising irrigated agriculture if motivated adequately and appropriately would be able to take off and hence repay back on what the government incurred (Kagubila and Mnzava, 1993). The farmers would no longer rely on government handouts, hence ensuring sustainable operations of agricultural activities in the scheme.

Farmers should have access to commercial lending institutions. This would allow them to carryout their agricultural activities with minimum reliance on government handouts. The reliance on government by farmers made it impossible for farmers to be on their own after government services are withdrawn. Many small scale irrigation schemes have had this aftermath effect and have always resulted into abandonment of the schemes (Chirwa, 1987).

Agricultural inputs (i.e, seeds, fertilizers etc) and loans should be made available to farmers at the right time and in the right amount, so that farmers have ample time to plan for their following cropping season. The delay or non availablity of these facilities tend to frustrate farmers. Thus the scheme's sustainability would be threatened.

2.6 Summary

In this chapter, some commonly used indicators of successful irrigation schemes are discussed with emphasis on performance indicators at field level (i.e, application efficiency, tailwater runoff, deep percolation ratio, equity, and canal design). Other factors reviewed are factors affecting furrow irrigation and their design limitations. These include (a) infiltration rate, (b) furrow discharge, (c) land surface slope, (d) advance and recession time, and (e) time of cut-off.

The socio-economic factors include (a) farmer participation, (b) education and extension, (c) organisational structure and management, and (d) agricultural inputs and credits. These factors require involving the farmers right from the inception of the scheme, the need to train the farmer, and the importance of creating a scheme structure that will accomodate farmers' contributions to the running of the scheme, and further, the promotion of subsidised agricultural inputs and provision of loans as incentives to the farmer.

3 MATERIALS AND METHODS

3.1 Introduction

Field studies are necessary to define quantitatively the irrigation system performance and not only in relation to the physical features of the system but also its design and management. Thus, site specific tests of advance and recession, streamsize, and runoff were carried out in 5 sites. Further, a socio-economic study was carried out to evaluate factors which influence sustainability of smallholder irrigation schemes. The evaluations were done between September and December. Therefore, this chapter presents:(a) extent of the study area,(b) location, (c) climate, (d) soils, (e) land use and vegetation, (d) agro-ecological regions, and (f) procedure of research.

3.2 Description of study area

3.2.1 Extent

Buleya Malima irrigation scheme occupies an area of 71.5 ha which has been divided into four phases (Fig.2), for easy management. There are 156 farmers in three operational phases (Hossain, 1990). Each farmer irrigates 0.25 ha. The distribution of hectares by phase is as follows;

Phase 1. 17.5 ha with 49 farmers,including 3 ha of Citrus orchard. Water is received directly from pipe line,

Phase 2. 15 ha with 51 farmers. Water is received from night storage reservoir by an open canal through gravity,

Phase 3. 14 ha with 56 farmers. Irrigation water is received from the night storage reservoir and

Phase 4. 18 ha. is not yet rehabilitated.

The scheme is conventional with large number of farmers. A single water source (night reservoir), is used by 107 farmers. Fig.3 shows the organizational structure of the scheme.

This scheme uses furrow irrigation which receives water from a pumping plant located at the mouth of Nangombe river into lake Kariba. Water is pumped from a 10 * 10 * 2 m sump connected with an open canal to the river flow. It is also connected with underground perforated 120m pipeline which is recharging the sump. In the present situation, 1000 m^3 water per day can be easily available. Water is by gravity from a night reservour, via concrete lined canals. Each tertiary canal serves the optimum of 18 ha. The design furrow length is 100 m at a gradient 0.0075 (Hossain, 1986).

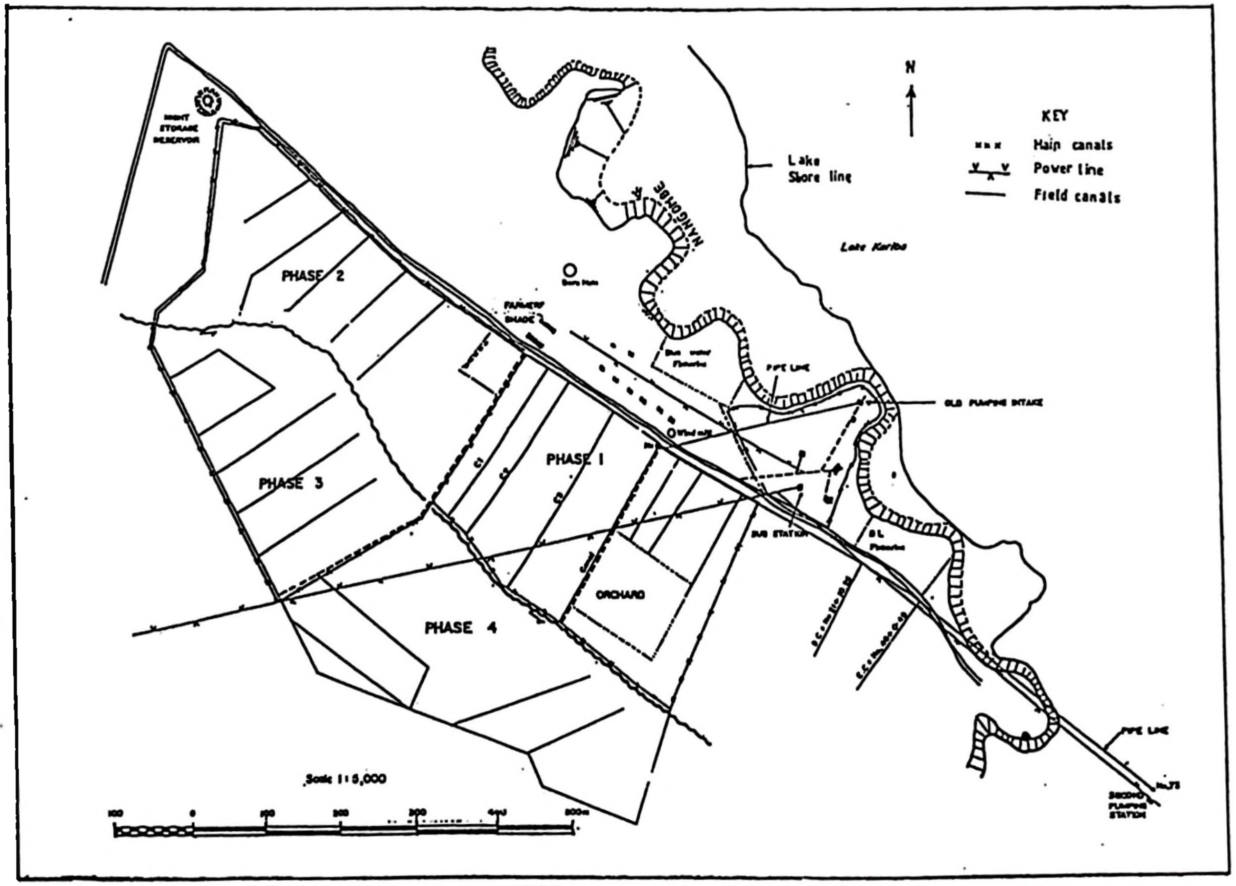


Fig.2 Buleya malima irrigation scheme (Design)

Source: Kazuhiro shibayama (1985) (See Hossain, 1986)

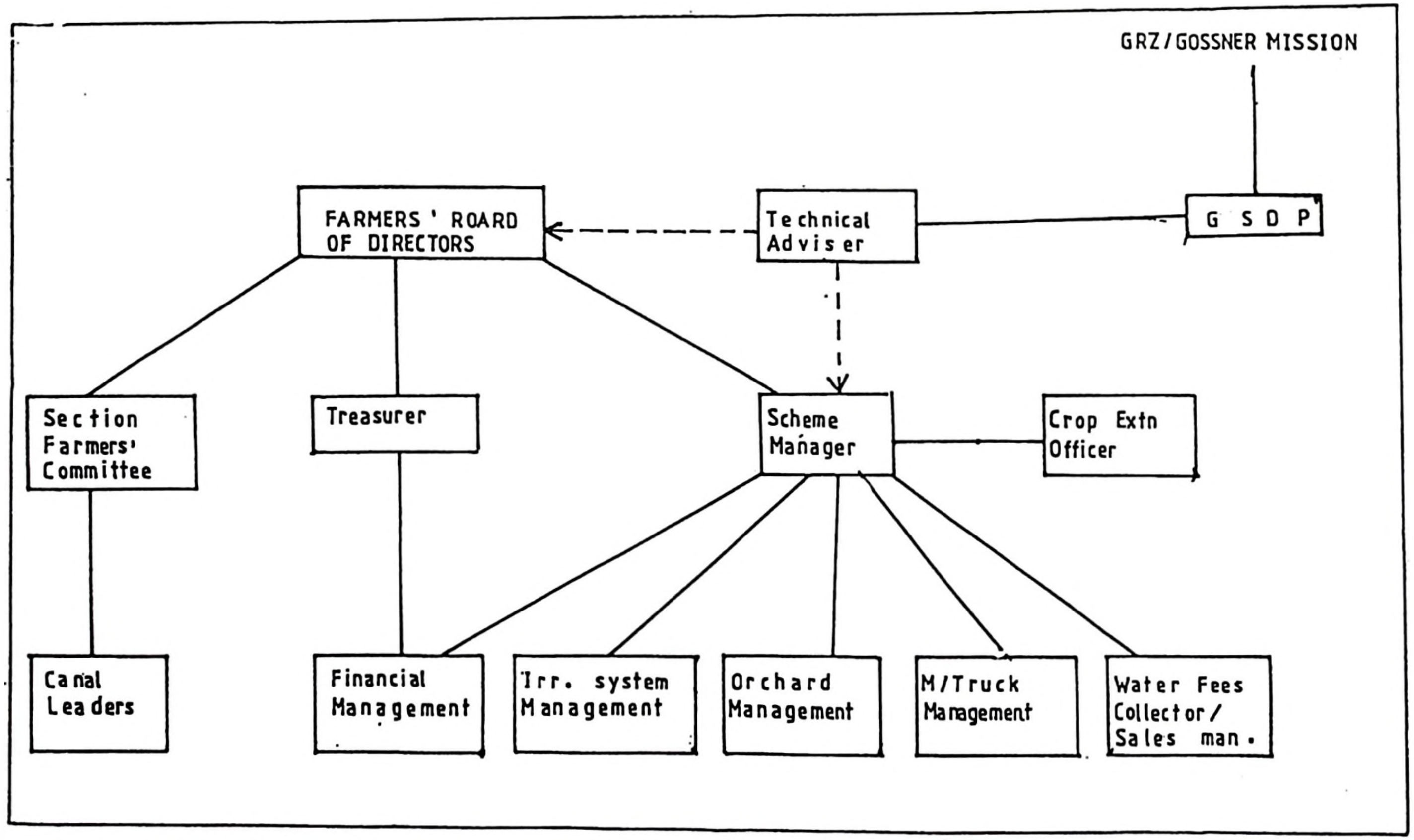


Fig.3 Organisational chart - Buleya malima irrigation scheme

Source: Hossain (1990)

3.2.2 Location

The scheme lies between latitude 16^0 51′ and 17^0 S and longitude 27^0 42′ and 27^0 48′E (Fig.4), in the southern province of Zambia. It is situated in the mid-Gwembe valley, approximately 110 km up-stream the Kariba Dam (LUS, 1969). The area is 102.5 km^2 in extent, bounded at its lower end by the shore line of lake Kariba and by the steeply rising hills of the Zambezi escarpment (Fig.5).

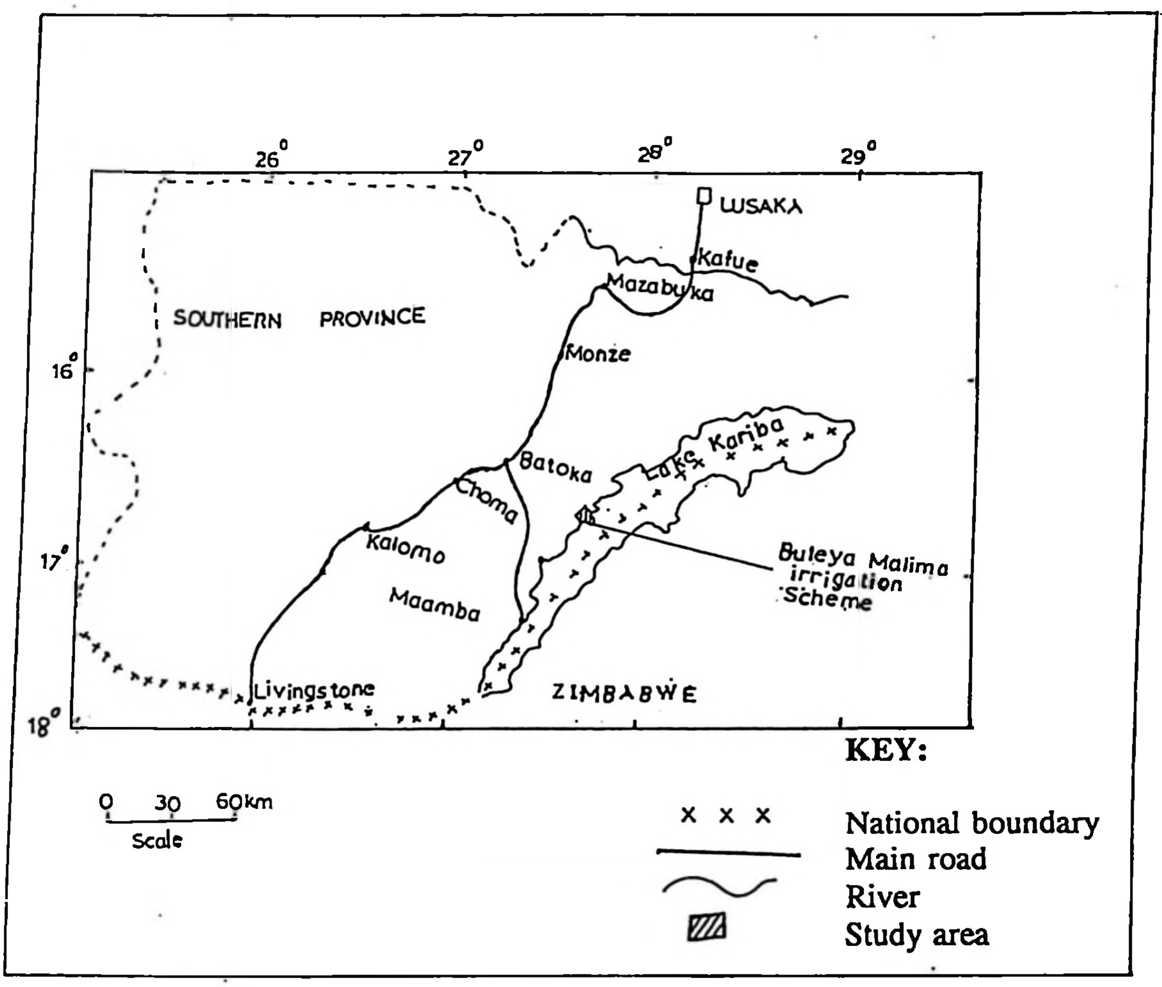


Fig.4 Location of Buleya malima irrigation scheme

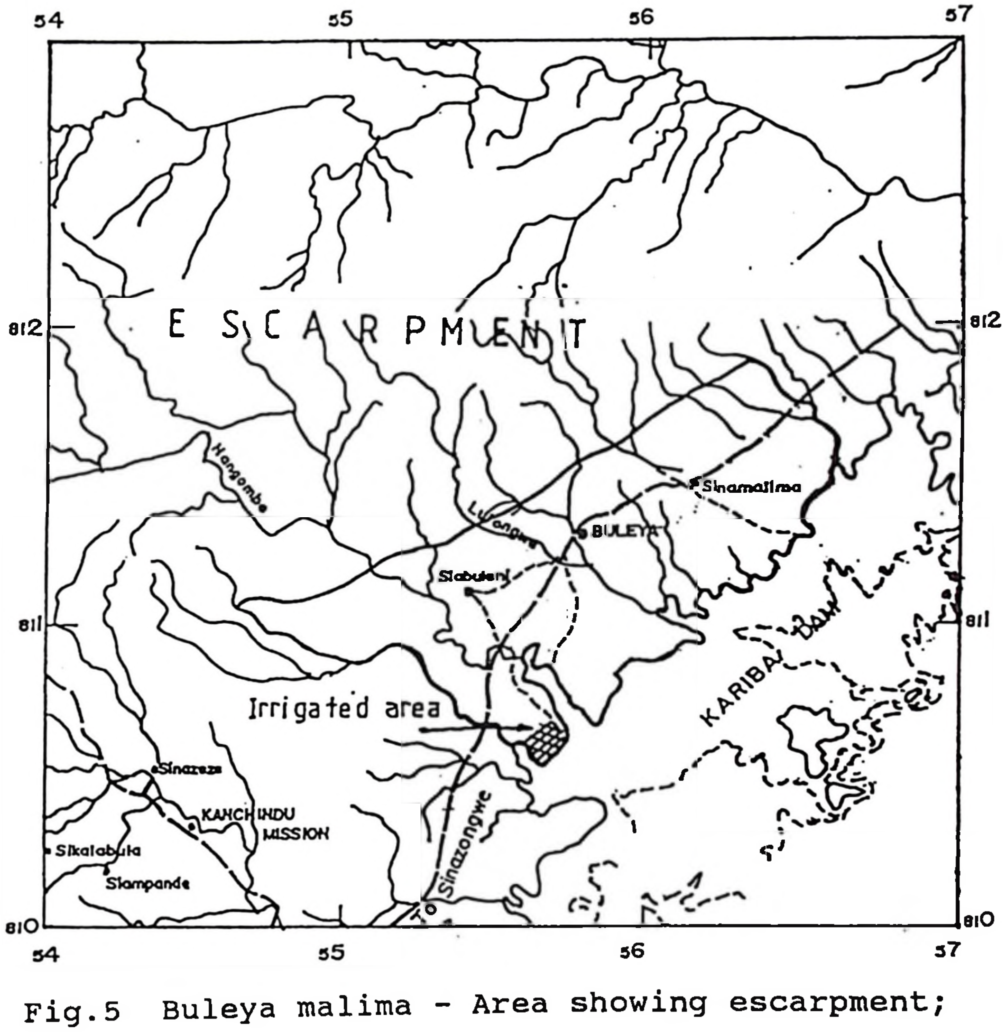


Fig.5 Buleya malima - Area showing escarpment;
Source of colluvium soil

Scale 1 : 250,000

5000 0 5000 10000 15000 20000 25000 30000 m

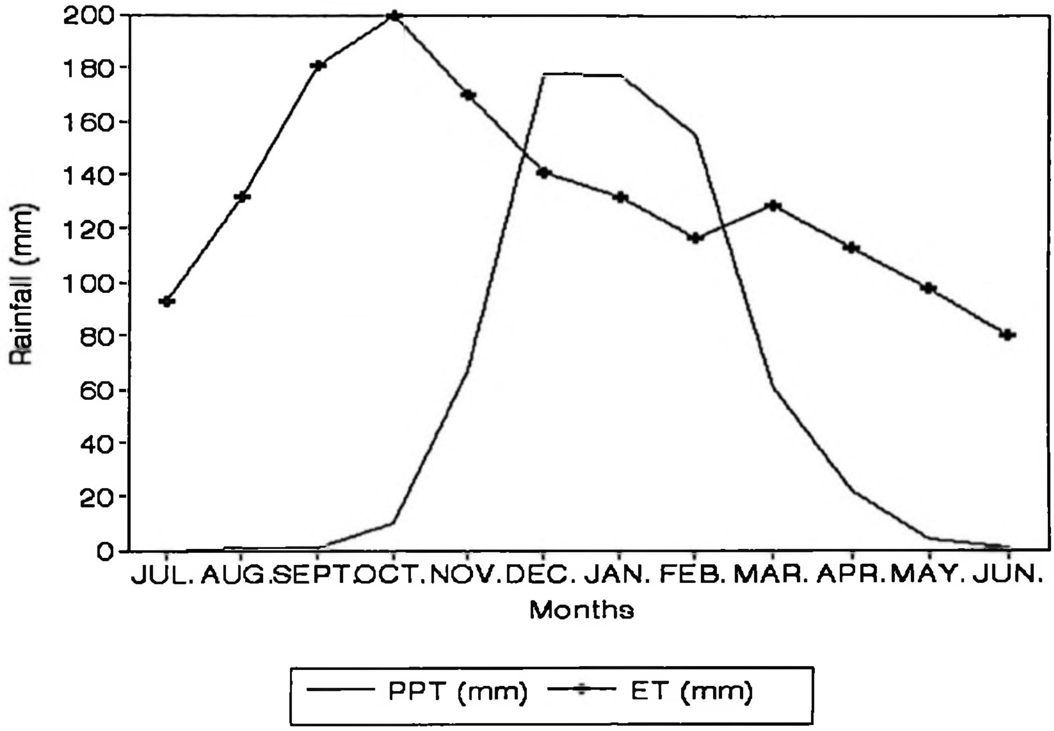
3.2.3 Climate

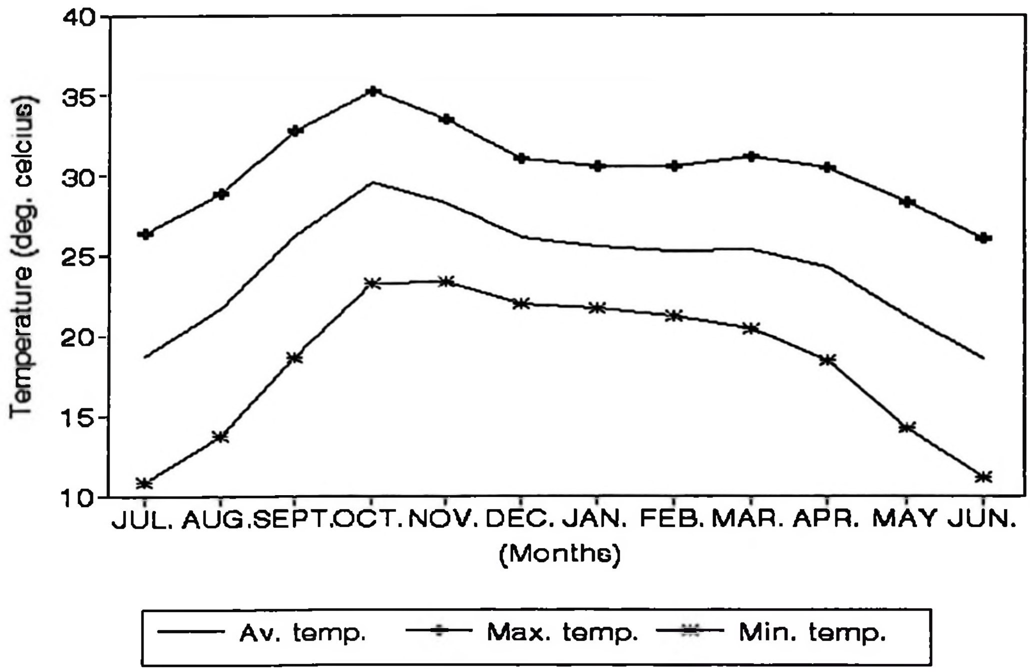
Zambia experiences long dry season and short wet season. The length of rainy season and amount of rainfall decreases from North to South. Rainfall variability decreases from South to North. Dry spells are longer in the South than in the North (Griffiths, 1972).

The climatic data is presented in appendix I. The rain season starts in mid November and ends in mid March (Hutchinson,1974). Data indicate total annual rainfall of 677 mm and the annual rainfall deviation is about 200 mm with 86 wet days. The period between December and February has surplus moisture (Fig.6). For the rest of the year the moisture deficit due to evaporation losses exceeds precipitation.

July is the coldest month with temperatures falling to 10.8^{0}c, while October has the highest temperature reaching 35.20^{0c} (Fig.7).

August - November corresponds to the period with the highest windspeed of 3 - 5 km/h. November - February is the period with the lowest Sunshine hours falling to 43% of day light (Appendix I).





Figures 6 and 7, showing Water balance between 1960-72 and Monthly mean Min, mean Max.and Average temperature respectively (Kariba airport)

3.2.4 Soils

The water courses from the escarpment (Fig.5), have deposited an extensive fan of colluvium. As a result the soils that occur are developed from old alluvium deposited by the streams flowing out from the Zambezi escarpment. A variety of parent rocks contributed to this old alluvium. The general elevation of the area is slightly above 487 m a.s.l. High water of the Kariba lake is only about 3.5 to 4.5 m below the general elevation in the area (LUS, 1970). The slope of the land ranges around 1 percent.

Soils are nearly uniform being derived from the colluvium deposits. Two soil types occur in the area. The variations which occur between them is as a result of existence of a calcareous layer at 150 cm over a limited area. The two soils have been described as; "Malima Sandy Loam" and "Malima Sandy Loam with calcareous substratum phase" (Yager,1969). Malima Sandy Loam consists of deep, medium textured well drained, moderately permeable soil. The undisturbed profile has a 15 cm humic layer of sandy loam. The texture improves as depth increases below the soil surface. Soils vary in colour from a dark reddish brown to reddish brown, becoming lighter with increased depth (Maclean, 1969).

3.2.5 Land use and vegetation

Before the re-settlement the Buleya Malima area was sparsely populated. The available landuse was based largely on ox-cultivation and considerable hecterages of land have been opened in the recent years (LUS, 1969).

Sorghum was the most popular crop. Occasional crops of finger millet, bulrush millet, maize and cotton were grown. However, maize was not so popular owing to unreliable rainfall.

The area is free from tsetse fly and as such keeping Cattle, goats and sheep was and is still a common practice. These animals are grazed communally by herding and kraaled overnight for protection against wild animals (LUS, 1970).

The colluvial soils of Buleya Malima scheme support vegetation dominated by well - grown *Combretum Imberbe* and *Sclerocary Caffra* with occasional *Cassia abbrevita*. On the banks of the Nangombe River various acacias are found, notably *Acacia albidia*, the winter thorn. On the irrigated land there used to be many young Acacia woodii (LUS, 1970)

3.2.6 Agro-ecological zones

In Fig.8 the country is divided into three agro-ecological regions (viz. I, II, III), based on the amout of rainfall during the rainy season. The agro-ecological regions are subdivided into 36 zones, each with its own characteristics of length of growing period, occurrence of drought, minimum night and maximum temperatures during December to February, occurrence of frost in the dry season (June-August) and amount of sunshine during the rainy season.

The study area is situated in the agro-ecological region 1 and zone 1-cv (central valley). It is characterised by growing period of less than 90 days in an average year and drought during the growing season is in the margin of 40 days or more (Veldkamp, 1987). These variables were determined at 70% probability.

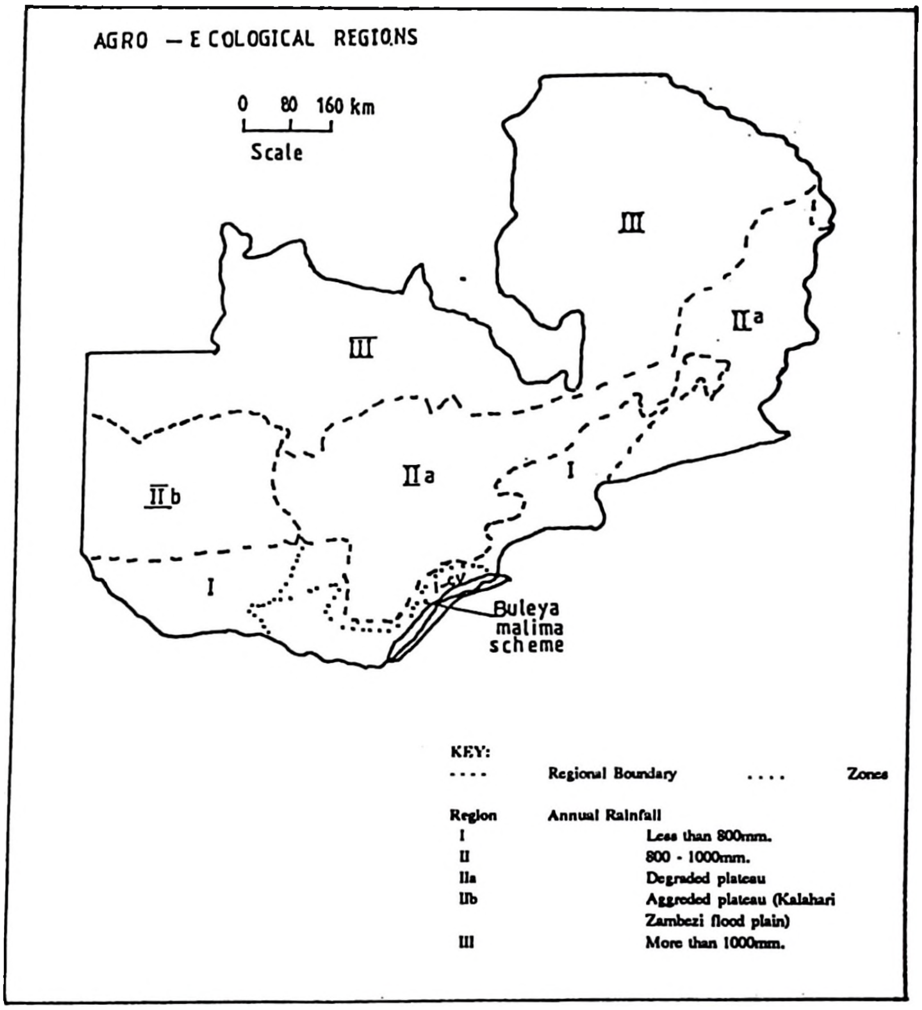


Fig.8 Agro-ecological Regions in Zambia

Source: Veldkamp (1987)

3.3 Procedure

Data required for assessing the sustainability of small-scale irrigation were measured and/or collected. Two studies were conducted: technical and socio-economic study, respectively.

3.3.1 Technical study

Measurements of water applied by surface irrigation require techniques for farmers to know whether or not they are over or under-irrigating (Jensen, 1983). Therefore, water management problems which affect efficient use of water in the furrows were assessed by carrying out an evaluation of the system at field level. This was done to determine its performance using application efficiency, tailwater ratio and deep percolation ratio.

Plots were randomly selected during the reconnaissance of the plot and furrows. Three representative furrow lines were chosen; the middle one taken as test furrow while the outer two acted as buffers. Then the following measurements were carried out: (a) advance and recession, (b) soil moisture content, (c) furrow discharge and runoff, and (d) furrow cross-section.

Measurement of advance and recession

Observation points were located at 30m interval along the furrows. Wooden stakes were then fixed from the beginning of the maize line to the end of the field. Water was introduced into the furrow through a siphon. Using a stop watch, the time water arrived at each station along the furrow, starting with zero time at station zero, was recorded on advance and recession evaluation forms. The time of cut-off of siphon from the tertiary canal was noted down. As soon as all the water disappeared at the first peg, the time was noted down. The recession was then followed to the second and subsequent pegs (appendix II).

The data were used to obtain the intake opportunity time and time of cut-off, t_{co}, which are important parameters in calculating the infiltration function and application efficiency, respectively.

Measurement of soil moisture content

Soil samples were taken at 10cm, 30cm, 60cm and 80cm depths in each sampling point. These depths were chosen since they represent depths where roots of maize extract the maximum moisture. A metal rod with a cylindrical core sample holder was used to take the soil samples. Moisture content and bulk density were determined by the gravimentric method and converted to volumetric moisture content (Appendix III).

Measurements of furrow discharge and runoff

Farmers used 60 mm siphon tubes to tap water from the field canals. First volume of water that the siphon tube discharged per second was measured by using a stop watch and a calibrated 20 L water bucket. Time taken to fill a 20 L water bucket was recorded. Discharges for six siphon tubes were measured. The average discharge from the six siphon tubes was calculated.

The following operations were done to measure runoff: where the furrow drains into a drainage ditch, a hole was excavated big enough for a 20 L water bucket to fit. A furrow tube (50cm long), was placed in the ditch to direct water into the bucket. Measurement of runoff was recorded at various time intervals (Appendix IVa - IVe).

Measurements of furrow cross-section

Measurements of cross-sections for furrows were made. These data were needed to develop geometric relationships required by the infiltration function (Eq.5). Using a tape measure,the following parameters were measured:

(a) size of furrow;

(b) shape of the furrow;

(c) spacing of the furrows; and

(d) length of the furrows.

3.3.2 Socio - economic Study

A structured questionnaire (Appendix V) was adopted to get farmers' opinions on the management of the scheme. Indeed, the use of questionnaire as the main instrument in data collection has been blamed of some weaknesses associated with it. One such weakness was pointed out by Blablock and Blablock jr. (1982).

> "We do not know whether the respondents will tell us how they really feel and think. They may decide to tell us what they think we want to hear or what they consider to be a socially approved answer".

To minimise the magnitude of this limitation, the researcher employed a non-participant as observer technique, unstructured interviews, and formal discussions with different key informants in the scheme. The information was then noted in the researcher's diary.

Following Boydy et al.(1981) a sample (n) was chosen such that the sampling fraction (n/N) was at least equal or greater than five percent.

Therefore, 20 farmers in the scheme were interviewed. These represented about 1/10 of the farmers who had plots planted with maize in that season. The selection of farmers was by random sampling.

This study adopted a cross sectional design which according to Babbie (1985), is appropriate for descriptive study. Data collection took place between september and december 1993.

3.4 Data processing and analysis

Summarised and condensed data on technical and socio-economic studies are presented in the next chapter. Averages, standard deviations (s.d), coefficient of variation (CV), summations and percentages were obtained to facilitate interpretation and analysis of the factors that influence the sustainability of small scale irrigation schemes.

4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results of different evaluations from 5 sites at Buleya Malima Irrigation Scheme. The three standard performance indicators investigated in the study include (a) application efficiency, (b) tailwater runoff, and (c) deep percolation ratio. These indicators were used for this study.

Lastly, results of the questionnaire, interviews and personal observations during the study on farmers' participation, education and extention, organisational structure and management, and agricultural input and credit are discussed. The analysis helped to pinpoint the factors which could influence sustainability of irrigation schemes for small scale farmers.

4.2 Application efficiency

The application efficiency, Ea, at each site was estimated using Eq.1a. The average Ea of 26.4% (Table 1) was obtained. This is less than the design Ea most commonly quoted value of 75% for furrow irrigation (section 2.4.1). The Ea of 26.4% implied that nearly 70% of all water applied was wasted from the field as tailwater runoff and/or deep percolation.

The evaluation showed that the loss of water at the scheme was largely due to high tailwater runoff (64.4%), as compared to deep percolation (9.2%) (Table 1).

It was observed that in many plots, furrow banks were not maintained, leading to movement of water across furrows and contributed to further runoff. The measured steady stream size of 0.12 m^3/min seems to have been too large for the basic intake rate (0.00081 m^3/min/m) of the soils, which was calculated using Eg.9. This led to large quantities of water being lost as runoff, especially towards the end of each irrigation.

The water loss of 64.4% through tailwater runoff would mean that in the long run the fertile top soil will be eroded. Farmers might not manage to buy fertilizers to replenish the lost fertility, as a result yields would be poor. Some farmers may not be willing to tolerate such a situation.

4.3 Tailwater runoff

The overall mean TWR (tailwater ratio) was 64.4% (Table 1) and was the main way of losing water in the plots. It was estimated using Eq.2. The TWR ranged from 61 - 68% in 5 sites (Appendix VI). The coefficient of variation (0.043) was low (Table 1). This shows that the losses of water through tailwater runoff was uniform throughout the scheme.

The TWR of 64.4% was higher than the most commonly quoted maximum allowable limit of 20% for furrow irrigation (section 2.4.3).

Although furrows run down the slope that is not steep, it appeared that the slope in furrows had been steepened, by erosion formed by irrigation water moving along furrows. This was shown through relatively clear water introduced at the furrow inlet exiting the furrow as muddy runoff.

However, Fig.9 shows that the advance was slow in the furrows. This could have been contributed by the flat gradient (0.0075). Under such situations one would have expected high deep percolation ratio, but this was not the case. The factor which seemed to have contributed to high tailwater runoff would be time of cutoff which was usually delayed. It was observed that the design cutoff time was 240 minutes. To reduce heavy losses through tailwater runoff out several cutbacks during the irrigation process were needed. This would reduce the amount of water lost and would improve the application efficiency.

High tailwater runoff implies loss of rich top soil. At Buleya Malima Irrigation Scheme, some farmers were already complaining of maize crop not doing well if no fertilizer was applied. In some fields signs of land degradation were visible in form of rills. These rills could develop into gulleys if the situation is not controlled.

Table 1. Representative performance evaluation on five sites (Buleya Malima irrigation scheme)

Parameters	Mean	s.d	CV
E_a (%)	26.4	± 0.082	0.003
TWR (%)	64.4	± 2.8	0.043
DPR (%)	9.2	± 2.8	0.031

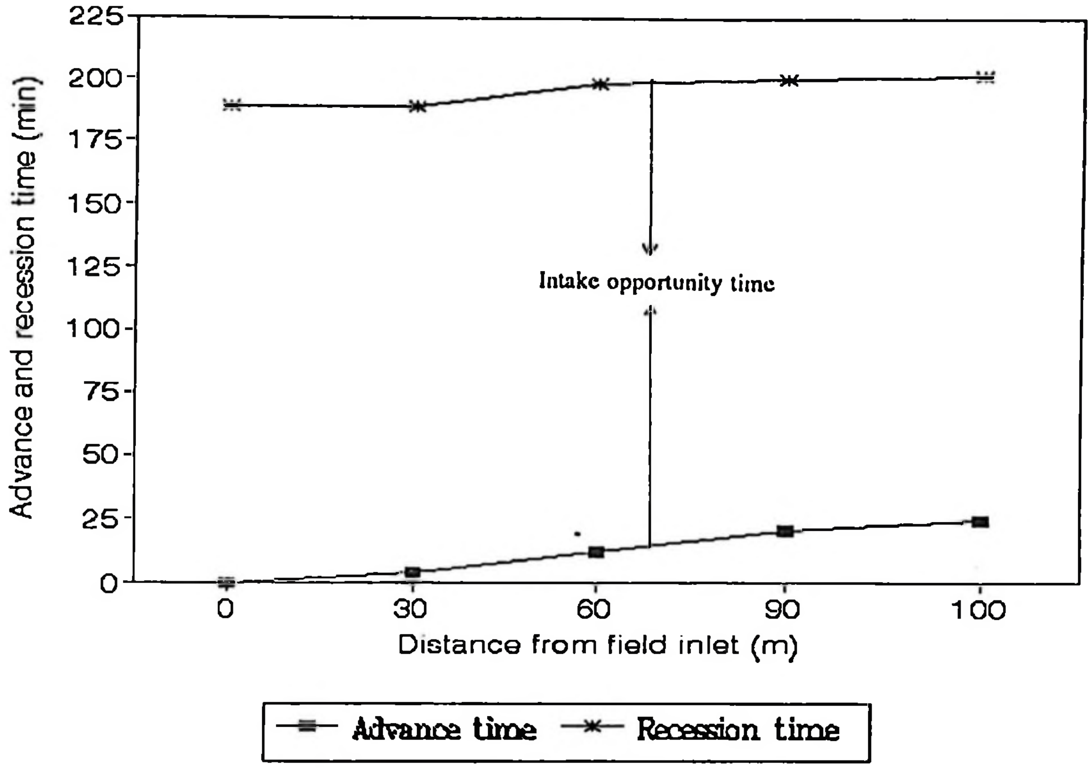


Fig. 9 Average advance and recession curves and the intake opportunity time

4.4 Deep percolation ratio

In calculating the deep percolation ratio, DPR, for each of the 5 sites, the applied distribution was integrated first, using Eqs. 4a to 4c. Then DPR was estimated from Eq.3a and 3b. The mean basic intake rate was estimated from Eq.9 and equalled 0.00081 m^3/min/m (Table 2). The value of a and k in the infiltration function (Eq.5) were estimated by Eq.7a and 7b, respectively. a was found to be 0.43 and k was 0.045. The overall mean DPR of 9.2% (Table 1) was within the acceptable range 0 - 25% (Jensen,1983).

The low DPR (9.2%) could have been contributed by surface crusting which was observed in furrows. This encouraged water advance with less infiltration.

Figure 10 shows how the infiltrated values of water at specific points compare with the required depth of irrigation. It can be ascertained graphically that the farmers applied more water than enough. However, under this situation, it seems the deep percolation losses could not cause alarm, because the ratio (9.2%) was within the acceptable range (0 - 25%). Therefore, the scheme could still be sustained at these levels of water losses through deep percolation. The infiltration function, Z, was estimated using Eq.5 and the application depth required, Z_{req} was calculated using Eq.10. The mean depth to root zone for maize crop is 1.2m, field capacity for Buleya Malima soils (sandy loam) is 14% by volume and wilting point is 6% by volume. The maximum allowable deficit, MAD for maize crop is 0.65 (James, 1988).

The volume of water infiltrated at each point during irrigation tests ranged from 0.07 to 0.185 m^3/m (Appendix II).

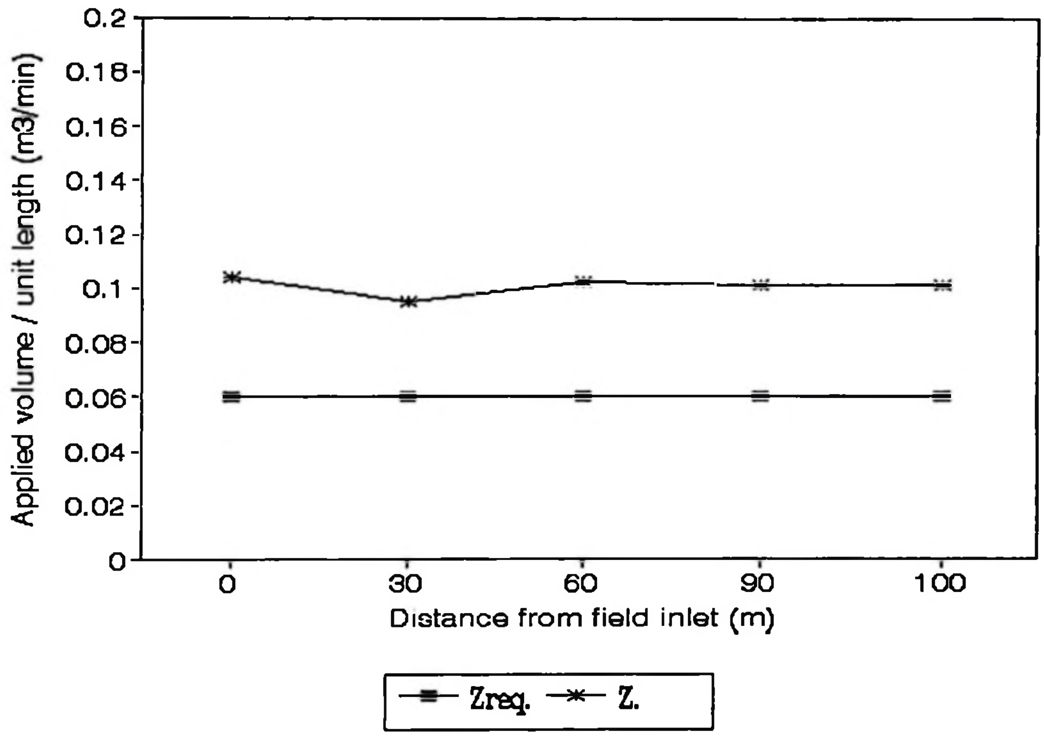


Fig.10 Distribution of applied water during the test irrigation

Table 2. Results of calculated parameters

Parameter	mean	s.d	CV
A_o (m2)	0.0051	± 0	0
Q_o (m^3/min)	0.12	± 0	0
f_o (m^3/min/m)	0.00081	± 0	0
Z (m)	0.101	± 0.01	0.1
t_{co} (m)	189.4	± 0.55	0.0029
X_l (min)	21.0	± 2.34	0.11

4.5 Participation of farmers in the planning stage

90% of the farmers interviewed indicated that the whole idea of establishing a scheme came from government, and only 10% of the farmers interviewed had the view that the idea was by both the farmers and the government (Table 3.1). But given the background of how Buleya Malima irrigation scheme came into being, one tends to believe what the majority (90%) of farmers said.

The idea of establishing Buleya Malima Irrigation Scheme came from the then colonial government, which needed enough electric power for the copper mines. The concern at that time was to tap energy for the mines. It was only upon realising later that a lot of people and animals were affected by the flooding that the government thought of constructing a few irrigation schemes to resettle a few people. Therefore, in a nutshell it can be said, the scheme was organised by government starting from feasibility study, securing of fund, design, construction and have been operating and maintaining the scheme. But it is no longer possible, because of lack of funds.

For the case of Buleya Malima irrigation scheme it has been clearly revealed that the farmers did not participate in the initial planning and design of the scheme. This is in contradiction with the notion that the participation of farmers in the initial stages of the project is a crucial issue in farmer managed irrigation schemes. It is believed that this approach would have positive impact, as farmers would see the scheme as their property necessary to increase their food security and income. Further, farmers need to be acquainted with the system's operation and maintenance if it is to run smoothly (Coward, 1984).

Design is usually conceived and implemented as a discrete task, rather than a gradual incremental process, and yet it sets long term management parameters. Design carried out without the participation of the farmer usually presents a problem to farmers when these structures are left under the farmer responsibilities. As a result they usually get damaged quickly. To ensure their long term utility there should be a dialogue between the engineers and the farmers so that alternative criteria and possibly operating norms, can be integrated into the design process (Vermillion, 1990).

Farmer participation in early stages of scheme development would assist in building their capabilities and promoting sense of self reliance and ownership. This would ensure sustainability of schemes (IIMI, 1990).

Table 3.1. Original idea to establish scheme

Source	Percetage
Farmers	0
Government	90
Both	10

4.6 Farmers' participation in decision making

The findings revealed that 65% of the farmers indicated that decisions were made by the scheme management. Thirty five percent of the farmers acknowledged their participation in decision making process, while 70% disagreed with any decision being made in meetings in which farmers participated (Table 4.2).

Usually where decisions are made by the majority, the chances that such decisions will be respected by the majority are high. In this regard real commitment to scheme activities by the majority of the farmers to meet the objectives they set is expected. If farmers were given chance to participate in decision making it would imply that realisation of the objectives to improve their lives was going to be fast.

It has been further observed that participation of farmers in decision making is essential if schemes are to be sustained. This could be done by formation of farmers' associations like water user's associations. It is through these associations farmers would participate in decision making. Further, these associations should be given most of the responsibilities regarding the affairs of the farmer. This would ensure the sustainability of the schemes even after the government has pulled out, since the change in management of the scheme would not be felt by the farmers (Maregesi,1993).

At Buleya Malima irrigation scheme, it was observed that farmer associations were just there in name. They were not given the mandate and recognition they deserved by the management. This created a situation whereby those farmers who got frustrated with the way the scheme was being run, just moved out of the scheme on their own; because these associations could not assist the farmers in any way. This undermined the sustainability of the scheme.

Table 3.2 Opinion of farmers on the participation in decision - making (n=20)

	Responses (%)		
Opinion	Agree	Don't know	Disagree
Farmers were actively Involved in decision making	35	55	10
Only Management and Farmers organization leaders made decision for farmers	65	10	25
Decisions made in meetings	10	20	70

4.7 Farmer education in water scheduling, distribution and operation and maintenance of irrigation system

In the interviews, it was found that 40% (Table 4.1) of the farmers interviewed had attended seminars organised by the scheme management. A good number of farmers had attended seminar on water scheduling and distribution (25%). The interviews revealed that 60% of the farmers never attended any of the seminars. There seemed to be some apathy among farmers on attending seminars. The relatively high percentage of farmers who attended seminar on water scheduling and distribution (25%) showed that this was one area of concern to most farmers.

The low turnout for seminar on operation and maintenance (10%) may be understandable in that, farmers were not consulted in the initial stages of planning of the scheme. Training of farmers in the operation and maintenance of the irrigation system should start at design stage of a scheme development. This way farmers would feel part of the scheme and would go any length to see it succeed, because they will view it as their property (section 2.5.2).

It was observed that at Buleya Malima irrigation scheme, the government was finding it difficult to hand-over the running of the scheme to the farmers because farmers in the first place were ill-prepared by the government for the eventual take-over. Chances are that if the government went ahead to hand-over the scheme management to the farmers the scheme might fail in its operations. This is in line with Kagubila and Mnzava (1993) in Tanzania who observed that the absence of training farmers in how to operate and maintain irrigation structures has frequently led to the destruction or damage. Hence the breakdown of schemes.

Table 4.1 Attendance to seminars organised by the scheme management

Type of seminar	% farmers attended
water scheduling and distribtion	25
operation and maintenance	10
all above	5
None	60

4.8 Extension service to farmers

The degree of adoption of a technology by farmers depends on the level of extension services rendered to them.

Table 4.2 shows the response of farmers whether they practise certain agricultural technologies from extension workers. In the interviews it was found that the majority of farmers (90%) at least practise some of the agricultural technologies recommended by the extension workers. However, of the farmers interviewed, it became clear that the most popular practice was weeding (50%). The three practices i.e, proper fertilizer application, use of pesticides and proper water application were not very popular among farmers as shown by 10%, 5% and 10%, respectively.

What the results revealed is that extension workers who served the farmers could not help the farmers much in planning of agricultural activities such as the application of water, fertilizer and pesticide respectively. Thus adoption of improved practices such as applying fertilizer and pesticide was poor partly due to inadequate extension services coupled with lack of practical demonstrations (Section 2.5.2). It was observed that farmers mostly adopted those practices which did not appear to be difficult technologically such as timely planting, and control of weeds.

This created a situation whereby farmers' agricultural activities remained outdated. But, irrigation is a modern technology and as such to sustain it, modern agricultural practices are needed (Farrington, 1984). Therefore, the failure to transfer modern agricultural practices by extension workers to the farmers undermined the sustainability of irrigation development.

Table 4.2. Implementation of new agricultural technologies by farmers

Technology	% farmers who adopted
Proper fertilizer application	10
Proper use of pesticides	5
Correct water application	10
Proper weeding	50
All the above	20
None	5

4.9 Working relationships between farmers, and management

The results as revealed by 80%, 35%, and 50% (Table 5) of the respondents, the working relationships between farmers and farmer's organization were good but not between the management and farmers. This showed that such poor relationship between management and farmers were unlikely to promote coordination of farmers' activities to achieve long-term smooth running of the scheme.

In very few cases, differences in behaviour and attitude existed between farmers themselves. These differences were associated with envy and rivalry. As an example, it was reported that if one farmer had means to simplify work by ox-ploughing, he could not readiy lend the ox-plough to other farmers even if it meant hiring. Complaints from individual farmers that the management favoured certain farmers were reported, however, evidence could not be found and those complaints appeared to be associated with envy to the successful farmers.

However, some individual farmers expressed concern over lack of efforts by management to strengthen relationships amongst farmers so that they could assist and learn from each other when necessary. This underscored the need to have the management that had broad understanding in dealing with such problems in order to ensure sustainability of the scheme.

Based on the findings and observations, the approach used to coordinate activities was not conclusive for participatory leadership. Simon (1976) observed that peasants needed organizational channels through which to make decisions, maintain communication, manage resources and resolve conflicts, without which sustainability of the scheme would be at stake. Some farmers would get frustrated and leave the scheme as experienced at Buleya Malima irrigation scheme.

Interviews carried out from farmers revealed that, although the organizational structure (Fig.3) of Buleya Malima irrigation scheme had provision for a farmers' committee in its hierarchy, this committee was not effective. Farmers felt that the management was still influential when choosing farmers to represent them on this committee.

Findings in Table 6 show that 65% of the farmers elected leaders that were proposed and supported by majority, while 30 and 40% of the farmers interviewed showed that election was by virtue of being an initiator and by self appointing, respectively. These systems of choosing did not seem to ensure democracy. Bias was likely to occur especially where someone had a great influence over many farmers. It was not easy to appoint to responsible positions people who were really dedicated to the long-term benefits of the scheme by using this electoral system. The morale of farmers would be affected under such leadership.

Farmers know what they want to achieve and know the capabilities of their neighbours for leadership and decision making. In this respect, the scheme management should give guidance to farmers in the selection of leaders among farmers so that management responsilities of the scheme are gradually transfered to farmers to ensure sustainability of the schemes (Section, 2.5.3).

Table 5. Relationships between management as perceived by farmers (n=20)

Relationship	Extent of agreeing on relationship being good %		
	agree	don't know	disagree
Between farmers and farmer organization leaders	80	20	-
between farmers and management	35	65	-
between farmer organization leaders and management	50	50	-

Table 6. Election of leader in farmers' committee

Method used	Response % Yes	No	No response
Secret ballot	20	35	45
By virtue of being an initiator	30	15	55
Proposed and supported by majority	65	10	25
Self appointment	40	45	15
Arbitrary appointment	25	20	55

4.10 Agricultural inputs and credits

20% of the farmers interviewed had access to chemical fertilizers namely compound D and Urea while thirty five percent of the farmers had access to pesticides and 40% used improved crop seeds. Only 10% of the farmers interviewed had access to credit facilities (Table 7).

Farmers complained of high prices for fertilizers and pesticides. Others complained of the non-availability of most agricultural inputs at the time when they were needed. Agricultural inputs and loans should be made available to farmers at the right time, so that farmers have ample time to plan for their following irrigation season. The delay of these facilities tend to frustrate farmers, thus, undermining the sustainability of agricultural activities in the scheme (section, 2.5.4).

Through informal interview with farmers, it was revealed that individual farmers had no access to credit facilities from commercial lending institutions (i.e. commercial banks). Also the security requirements by these banks were not easy to meet. The banks required a title deed for the land owned. Apparently farmers never owned individual lands. The government should be blamed for this since it has no clear policies regarding credit facilities to farmers in irrigation schemes.

Most of the loans to farmers came from the management. However, the loans were too little to satisfy their needs. If farmers had access to lending institutions, they would be more self-reliant from government assistance. In this way the government would find it easy to hand-over the management of the scheme to the farmers. Farmers would be able to buy most of the agricultural inputs at the right time (Chirwa, 1987). But at Buleya Malima irrigation scheme it was observed that farmers had problems to secure loans. This frustrated farmers making some to decide to leave the scheme in preference to non-intensive rainfed agriculture.

Table 7. Farmers' opinion on agricultural inputs and loans

	opinion %	
Facility	Yes	No
Access to commercial fertilizer	20	80
Access to pesticides	35	65
Access to certified seed	40	60
Access to loan	10	90

5 CONCLUSION AND RECOMMENDATIONS

The conclusion and recommendation of the study on sustainability of smallholder irrigation schemes, based on technical and socio-economic factors are presented in this chapter.

5.1 Conclusion

Loss of water through runoff irrigation was significant. The sites tested showed an overall tailwater runoff loss of 64.4% (Table 1). The loss had a direct bearing on the application efficiency of the system, which was 26.4% on average (Table 1). Such a loss could not make the scheme sustainable. The deep percolation ratio of 9.2% was within the acceptable range (0-25%), and as such it posed no immediate danger to the sustainability of the scheme. However, the infiltration function range (0.07-0.185 m^3/m) was relatively high as compared to the required depth of irrigation (0.06 m^3/m). The timely water application need to be practised in this case.

Clearly shown was the non participation of farmers in the initial stage of scheme design. This made it impossible for the farmers to operate and maintain the irrigation structures.

It became clear that participation of farmers in decision-making, discussions, group activities, and encouraging them to use improved agricultural practices more competently on their own was lacking. This made the farmers in the scheme to rely more on the management for all their requirements. This created a situation whereby the farmers could not sustain the running of the scheme without the presence of government staff.

The irrigation process took place under conditions whereby; (a) the farmers' association leaders were appointed through undemocratic means and thus was unacceptable to majority of the farmers and such leadership endangered sustainability of the scheme, (b) relationships between farmers and management were not very good, and (c) channels for passing information from management to farmers were not well established. This undermined the sustainability of the scheme.

Availability of resources to support production, loans and other agro-support services were lacking. Fertilizers and other agro-chemicals were either not available or brought in late in the season. Individual farmers had no access to loans from lending institutions except for loans provided by management occassionally, which was not enough also.

The situation was such that farmers were entirely relying on government handouts.

5.2 Recommendations

As water is a scarce resource, measures to reduce water losses during irrigating should be given special attention. Farmers should be motivated to avoid these losses and economise on water use through for example, instituting water charges, formation of water associations etc. To minimise deep percolation and runoff losses, the flow through the field inlet onto the surface of the furrows should be measured to yield a hydrograph which, when integrated, determines the total volume of applied water. The inflows should be maintained at a steady rate. The most obvious way would be to cut the inflow off when the application at the lower end of the furrow was approaching the required depth. This can be done by utilising a cutback flow after the advance was completed.

Farmers should be given adequate training in all matters related to proper operation and maintenance of the irrigation system.

A policy framework which emphasises equity and farmers' participation in making and implementing decisions, through their own associations should be developed. The management should create enabling environment which encourages cooperative spirity development amongst farmers to work in communal activities as an inspiration to sustain irrigation scheme activities. The participation of farmers in decision making is essential from the project identification stage through operation and maintenance of the scheme to ensure sustainability.

Loans and other agro - support services should be made available to farrmers in good time. Exposure of farmers to methods of securing loans from relevant institutions is one of the merits of irrigated agriculture that could be introduced into the extension service to enable farmers to obtain resources for production. Provision of loans would assist farmers to sustain their agricultural activities.

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APPENDICES

Appendix I. KARIBA AIRPORT CLIMATIC DATA (1960-72)

MONTH	PPT (mm)	ET. (mm)	AV.TEMP. (^{0}C)	MA.TEMP (^{0}C)	MIN.TEMP (^{0}C)	SS (%)	WS (kn)
JUL.	0	93	18.7	26.3	10.8	88	1.7
AUG.	1	132	21.6	28.8	13.7	87	2.0
SEPT.	1	181	26.2	32.8	18.6	85	2.5
OCT.	10	200	29.5	35.2	23.2	79	-
NOV.	67	170	28.3	33.4	23.3	58	2.2
DEC.	178	141	26.1	31.0	22.0	47	1.6
JAN.	177	132	25.5	30.5	21.6	48	1.4
FEB.	155	117	25.2	30.5	21.1	52	1.4
MAR.	61	129	25.3	31.1	20.4	62	1.4
APR.	22	113	24.2	30.4	18.4	76	1.4
MAY	4	98	21.1	28.2	14.1	85	1.6
JUN.	1	80	18.5	26.0	11.1	86	1.7
TOT.	677	1586					

Wet Days = 86

Appendix II. **Advance and recession time, intake opportunity time and water infiltrated at each point for 5 sites**

(1) Advance Distance (m)	(2) Advance Time (min)	(3) Recession Time (min)	(4) τ (3-2) (min)	(5) Z (m^3/m)	(6) Z_{req} (m^3/m)
		Site 1			
0	0	190	190	0.099	0.06
30	4	194	190	0.099	0.06
60	10	198	188	0.098	0.06
90	16	200	184	0.095	0.06
100	20	202	182	0.094	0.06
		Site 2			
0	0	189	189	0.094	0.06
30	4	189	185	0.091	0.06
60	12	198	186	0.092	0.06
90	20	200	180	0.088	0.06
100	24	202	178	0.087	0.06
		Site 3			
0	0	189	189	0.107	0.06
30	4	195	191	0.112	0.06
60	11	201	190	0.111	0.06
90	17	204	187	0.109	0.06
100	19	207	188	0.111	0.06
		Site 4			
0	0	190	190	0.111	0.06
30	5	194	189	0.107	0.06
60	11	198	187	0.109	0.06
90	17	200	183	0.106	0.06
100	19	202	183	0.106	0.06
		Site 5			
0	0	189	189	0.111	0.06
30	6	196	190	0.071	0.06
60	14	203	189	0.112	0.06
90	20	206	186	0.109	0.06
100	23	209	186	0.109	0.06

Appendix III. Representative soil moisture properties at Buleya Malima irrigation scheme

Depth (cm)	Tot. available water (cm/m)	Available water before irr. (cm/m)	Soil moisture deficit (cm/m)
0 - 10	17.1 (15.8-18.3)	10.5 (9.99-10.99)	7.91 (5.83-9.98)
20-30	13.7 (11.7-15.8)	9.15 (8.32-9.99)	5.42 (3.33-7.5)
50-60	12.9 (12.5-13.3)	7.5 (6.66-8.32)	7.3 (4.17-6.66)
80-90	12.9 (12.5-13.3)	7.1 (5.83-8.32)	5.23 (4.17-7.49)
Mean	-	-	6.0
s.d	-	-	± 1.178
CV	-	-	0.159

Appendix IVa. Recorded runoff for site 1 during the irrigation test

Time since irr. started (min)	Runoff (l/s)	Runoff flow rate (m^3/min)
20	0	0
28	0.064	0.00384
37	0.260	0.0156
50	0.372	0.0223
68	0.480	0.0288
98	0.603	0.0362
158	0.639	0.0383
190	0.649	0.0389
194	0.524	0.0314
198	0.240	0.014
200	0.056	0.0034
202	0.035	0.0021
206	0	0

Appendix IVb. Recorded runoff for site 2 during the irrigation test

Time since irr. started (min)	Runoff (l/s)	Runoff flow rate (m^3/min)
24	0	0
28	0.06	0.0036
37	0.272	0.0163
50	0.365	0.0219
68	0.476	0.0286
98	0.605	0.0363
150	0.630	0.0378
189	0.649	0.0389
194	0.530	0.0318
198	0.236	0.0142
200	0.062	0.0037
202	0	0

Appendix IVc . Recorded runoff for site 3 during the irrigation

Time since irr. started (min)	Runoff (l/s)	Runoff flow rate (m^3/min)
19	0	0
28	0.064	0.0038
37	0.254	0.01524
50	0.379	0.02274
68	0.485	0.0291
98	0.580	0.0348
32	0.606	0.03636
189	0.647	0.03882
195	0.455	0.0273
201	0.252	0.01512
204	0.140	0.0084
207	0.069	0.00414
210	0	0

Appendix IVd. Recorded runoff for site 4 during the irrigation test

Time since irr. started (min)	Runoff (l/s)	Runoff flow rate (m^3/min)
19	0	0
29	0.067	0.00402
38	0.265	0.0159
55	0.360	0.0216
69	0.475	0.0285
98	0.566	0.03396
132	0.608	0.03648
190	0.645	0.0387
194	0.450	0.027
198	0.265	0.0159
200	0.135	0.0081
202	0.057	0.00342
206	0	0

Appendix IVe. Recorded runoff for site 5 during the irrigation test

Time since irr. started (min)	Runoff (l/s)	Runoff flow rate (m^3/min)
23	0	0
33	0.084	0.00504
45	0.270	0.0162
60	0.395	0.0237
78	0.488	0.02928
95	0.565	0.0339
130	0.624	0.0374
189	0.649	0.03894
196	0.485	0.0291
202	0.260	0.0156
204	0.135	0.0081
208	0.056	0.00336
210	0	0

Appendix V.

A SURVEY OF FACTORS AFFECTING THE FARMERS' ATTITUDE TARWARDS IRRIGATION

FARMERS' QUESTIONNAIRE

Farmer's name ....

Identification number ------------

Instructions; For each item, please put a check (V) or fill in the blanks to indicate an appropriate response.

A. DEMOGRAPHIC DATA;

1. Farmer's age ------------------(years)

2. Highest level of education reached
   (a) Adult education
   (b) Primary education
   (c) Form 111
   (d) No formal education at all
3. Gender;
   (a) Male ------- (b) Female -------
4. Marital Status;
   (a) Married -------- (b) Single---------
5. Size of the family; Number of children----------
   Number of dependants---------

B. GENERAL INFORMATION;

6. What attracted you to join the scheme?

   ----
7. When did you join the scheme?
   ----
8. Have you gone for any training concerning the operation of furrow irrigation system?
   (a) Yes (b) No
   If yes, where and for how long?

   If no, if such a course is started in the local Farmer's training centre (FTC), would you sacrifice some of your time to attend it?
   ----
9. Do you feel you own the area?
   (a) Yes (b) No
   If not, why is it so?
   ----
10. Do you work full time on this area or you are a part time farmer?
    (a) Full time (b) Part time
11. How often does the Agricultural Extension Agent visit you?
    (a) once/week (b) twice/week (c) as often
12. Does he offer you advise on the technical aspects of

furrow irrigation?
(a) Yes (b) No

----

13. Is the flow of water regular in your fields?
(a) Yes (b) No
If no, what could be the problem?

----
14. Is the water sweet or salty?
(a) Yes (b) No
If yes, does the water affect the growth of some crops?
(a) Yes (b) No
15. How many hours do you irrigate your field?
(a) 1-4 (b) 4-8 (c) 8-12
16. What is the size of your area?
----
17. How do you decide when to irrigate and how much to apply?

----
18. How much water is delivered to the irrigated area in general?
----
19. How much money do you pay each year for running and maintenance of water pump?
----
20. Do you have your own transport for transporting your produce to the market or you hire transport?
(a) My own (b) Hire
21. If there is a farm vehicle, is the vehicle used for other purposes apart from farm activities?
(a) Yes (b) No
Who pays for costs of running and maintenance?
(a) Management (b) Farmers
22. Do you use/have ever used farm credit?
(a) Yes (b) No
If yes, What is/was the source of credit?
(a) Bank (b) Management (c) Fellow farmers
23. Under what terms do/did you take the credit?
(a) Interest rate
(b) Grace period
(c) Repayment schedule
24. For what purpose do/did you take the credit?
(a) Farm investment
(b) Working capital
(c) Both
25. What proportion of the investment and working capital is your own?
(a) half
(b) Three-quarters

(c) a quarter

26. Where do you invest the farm income?
    (a) into industry
    (b) back into the farm
    (c) both
    (d) not enough to invest

27. In general what problems do you find in irrigation farming?

    Is seasonality of rainfall an advantage or disadvantage to irrigation?

    Whether other inputs like fertilizers, manures, seeds etc, are readily available?

    Whether a lot of technical know-how and experience is required?

    Whether crop pests are a menace?

    ----

28. Given more resources, i.e land, labour and capital would you increase the irrigated area or leave it as it is?

    ----

29. List the various crops that you grow.

    <u>Crop</u> <u>Ha.</u>

30. Do you grow the same crop every season?
    (a) Yes (b) No

    If no, which crops do you grow in what season?

    ----

31. Which factors influence your decision as to which crops to grow?
    (a) Availability of assured market
    (b) Current price of the product
    (c) Availability of water
    (d) Rotational requirements
    (e) Availability of capital or labour

32. Do you allocate the same hecterage to each crop every season?
    (a) Yes (b) No

    If no, which crops do you allocate the biggest

hecterage?

----

33. Which kinds of customers do you have?
    (a) Private household
    (b) Hotels and restaurants
    (c) Institutions
    (d) on farm sales
    (e) Urban hawkers

34. Do you keep records of what you sell and spend?
    (a) Yes (b) No
    If no, how do you gauge your gross margin?

----

35. Effective support from the Government leaders together with other change agents has encouraged farmers to participate more in agricultural activities.
    (a) Yes (b) No
    If no, what have they done?
    (a) not caring
    (b) too forceful
    (c) Don't know

36. What other supportive factors apart from financial do you think could encourage farmers to participate fully in agricultural activities?

----

37. It is normally argued that leadership has a bearing on the efficiency of production. To what extent do you agree with the following statements concerning your leadership on this scheme?

	Opinion		
	agree	don't know	disagree
(a) leaders listen to farmer's view and allow them to discuss and make decisions concerning their activities	--	----	------
(b) leadership is carefree and that it does not make any follow up to ensure success of activities	----	-----	--

38. In any organisation good relationship between management and people is very important to ensure effective co-ordination and running of activities without suppressing one another.Since the introduction

of irrigation in this area, would you indicate to what degree you agree with the following statements bellow concerning the kind of relationship existing between management and farmers?

	Opinion		
	agree	don't know	disagree
(a) working relationship amongst farmers	----	-----	-
(b) working relationship between farmers and management	---	----	-----
(c) working relationship amongst management staff	----	----	-----

(d) would you please indicate how you co-ordinate?

----

39. In any group undertaking there must be conditions with which individuals are to comply in order to be members. Considering your scheme along the same line would you please answer the following questions?
   (a) what conditions should individuals fulfil in order to become members of the scheme?

   (b) are the conditions mentioned in (a) above soft enough to an extent of not discouraging many would be farmers not to participate in irrigated farming? (1) Yes (2) No
   (c) who sets the conditions?
   (1) farmers' board of directors
   (2) Irrigation system management
40. Some authorities argue that an economic change has been observed amongst farmers since the introduction of the scheme. Basing on the economic situation of the farmers, to what extent do you agree with the following statements?

	Opinion		
	agree	don't know	disagree
(a) The income of the farmers in the scheme has increased more than before the intro-diction of the scheme	----	------	--
(b) The income has increased slightly	-----	------	---
(c) The income has increased tremendously	-----	------	---

41. In any given organisation decision making is very important, for decisions affect even those who do not contribute when decisions are made. What do you have

to say on these questions?

	Opinion		
	agree	don't know	disagree
(a) management involve farmers as much as possible in solving individual farmer's problems	----	-------	---
(b) management guide you on how to analyses problems which you face in your daily life	----	-----	---
(c) agricultural activities are carried out under farmers' leadership with minimum management involvement	----	-----	--
(d) management visits farmers in their own homes and work place and advises them as individuals	----	-----	----
(e) management carries regular formal discussions with farmers regarding the best use of the furrow irrigation system	----	-----	----

42. Do you experience water borne diseases in the area and which type?

(a) Yes (b) No

(a) Malaria (b) Bilharzia (c) Chorela (d)Desentry
(e) All mentioned above

43. What measures are taken to control them/it?

(a) spraying
(b) Vaxination
(c) Water purification system installed
(d) Others

44. Different communities use various ways of getting leaders including voting or direct appointments. Would you please indicate below, how your farmers' board of Directors are put into leadership?

	Response to statement	
	(a) Yes	(b) No
(1) election through votes		
(2) arbitrary appointment		
(3) self appointment		
(4) proposed and supported		

45. What social changes to local people would you say have been brought about by the introduction of the irrigation scheme? ------------------------------
----

---

46. What do you think about the running of the scheme in general?

    (a) well run
    (b) not well run
    (c) don't know

47. If you were given a chance to run this scheme as a group of farmers, how do you think you would run it, or you feel it is not yet time for you to run the scheme?

    (a) not yet time
    (b) it is time

Appendix VI. Calculated factors and parameters on 5 sites

	SITE				
PARAMETERS	1	2	3	4	5
E_a (%)	26.3	26.45	26.45	26.3	26.45
TWR (%)	65.9	68.1	68.1	62.2	64.5
DPR (%)	7.76	5.42	11.47	11.44	9.0
A_o (m^2)	0.0051	0.0051	0.0051	0.0051	0.0051
r	0.523	0.524	0.429	0.459	0.437
f_o (m^3/min/m)	0.0008	0.0008	0.0008	0.0008	0.0008
k (m^3/min/m)	0.0142	0.00054	0.0236	0.0236	0.036
Tot.runoff (m^3)	7.77	7.23	8.80	8.60	8.05