INTERVENTION MEASURES AND THEIR EFFECTS ON FARMER MANAGED IRRIGATION SCHEMES IN TANZANIA:

A CASE STUDY OF MUSA MWINJANGA IRRIGATION SCHEME

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURAL ENGINEERING) OF SOKOINE UNIVERSITY OF AGRICULTURE

ABSTRACT

The study aimed at evaluating the effects emanating from intervention on farmer managed irrigation schemes (FMIS) was carried out at Musa Mwinjanga Irrigation scheme. The specific objectives were: (I) To evaluate the scheme rehabilitation status; (ii) To investigate the causes and magnitude of water losses; (iii) To evaluate water supply requirements; (iv) To assess and evaluate water management aspects of the system.

Results showed that the scheme has been operating at low efficiency. The conveyance, distribution, application and project efficiencies were found to be 53.6%, 53%, 59.8% and 31.7% respectively.

Low irrigation efficiencies have been attributed to high conveyance losses due to the pervious nature of volcanic soils and poor command of the canals. Most of the canals were found running below the field levels. Other reasons include high operation losses due to poor water management practices; lack of water control facilities; and application losses arising from poor land levelling.

The seasonal mean relative water supply (RWS) for plots varied between 0.96 and 2.92 due to inadequate irrigation scheduling and lack of flow measuring facilities. The overall seasonal mean RWS for the plots was found to be 1.83 with coefficient of variation of 0.354 and standard deviation of 0.647, indicating inequity of water distribution among the plots.

T-test results of RWS within blocks showed no significant difference in adequacy of supply at 5% significance level. This implies that farmers in sampled blocks were adequately irrigating at more or less equal proportion as per crops water requirements.

Organisation of the scheme was found to be fairly appropriate. However, operation and maintenance activities are not timely, effectively and efficiently carried out.

Natural drainage and slopes within the scheme are not efficiently used and managed hence the waterlogging problems in lowland areas of the central part of the scheme.

From the study, it is recommended that outstanding physical works left during phase-I should be accomplished. Damaged facilities should be repaired and farmers should be trained on proper water management aspects.

DECLARATION

I, **JUMA MZEE OMARI**, do declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has never been submitted for a degree in any other university.

Signature :--------------------------------

Date :----6/5/1997----

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DEDICATION

To my wife Mwatime Ahmed Mohammed and my daughter Asha, for their patience during the time of undertaking this study.

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LIST OF ABBREVIATIONS

ADB	African Development Bank
CDF	Capital Development Fund
CIDA	Canadian International Development Agency
CRWS	Cumulative Relative Water supply
E_p	Overall Irrigation efficiency
FAO	Food and Agriculture Organization of the United Nations
FMIS	Farmer-Managed Irrigation Scheme(s)
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit/German Technical Aid Agency
IIMI	International Irrigation Management Institute
IFAD	International Fund for Agricultural Development
ILO	International Labour organization
ILRI	International Institute for Land Reclamation and Improvement
IQ_R	Inter-quartile Ratio
JICA	Japan International Cooperation Agency
KZIU	Kilimanjaro Zonal Irrigation Unit
NIA	National Irrigation Administration
NSS	National Soil Service
OOPP	Objective Oriented Project Planning
OXFAM	Oxford Fund for Famine Relief
PL	Plot
PPMB	Project Preparation and monitoring Bureau
PRA	Participatory Rural Appraisal
RH	Relative Humidity

RRA	Rapid Rural Appraisal
RWS	Relative Water Supply
SACCAR	Southern Africa Centre for Cooperation in Agricultural Research
SNV	The Netherlands Development Organization
TPC	Tanganyika Planting Company
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
URT	United Republic of Tanzania
WC	Water Committee
WUA	Water Users Association

1. INTRODUCTION

1.1 Background Information

Irrigated agriculture in Tanzania, though in existence even in the pre-colonial era, started to gain importance when it appeared in the Second Five Year Plan (1969/70-1974/75) as a strategy for increasing agricultural production (PPMB, 1993). Small scale irrigation gained recognition in the light of poor performance of the expensive large scale irrigation projects (state owned irrigation projects mainly for sugar and paddy production) which were constructed in the first two decades after independence.

The agricultural policy of Tanzania accords high priority to the promotion of self-sufficiency and security of food production, to raising the living standards of the people, and to earning foreign exchange for the nation by improving agricultural output. The agricultural policy of Tanzania states "*It is clear that the country has big potential for the development of both small and large scale irrigation schemes. The 1974 reconnaissance of areas suitable for irrigation which was conducted in all regions will be scrutinized and updated by qualified personnel and existing schemes will then be rehabilitated as a matter of priority. New village schemes will be developed as quickly as this is possible, especially where they can be combined with the construction of mini-hydropower units. Large scale irrigation schemes will be developed on the basis of their economic viability and the least cost approach. In all cases, steps will be taken to ensure that the irrigation works are properly maintained and managed. The possibilities of having two or more crops per year from irrigated areas will be explored*" (FAO, 1983).

The role of irrigation in achieving these objectives is seen as a protection against drought and erratic rainfall, as well as a means of creating large volume of production and of opening up arable land in climatically marginal areas. In view of the above, the Government is currently emphasizing on rehabilitation/improvement of the farmer managed irrigation schemes as the only way to ensure sustainability of irrigated agriculture.

FMIS are those schemes in which the irrigation management (i.e operation and maintenance) is the responsibility of the water users themselves, with a very limited role played by the government. For several years, irrigated agriculture in Tanzania has been receiving assistance from various donors in a bid to develop it. The United Nations Development Programme (UNDP) assistance has been very substantial and useful in the development efforts of the irrigation sub-sector. Some of the UNDP assisted projects include: Project URT/86/012 and URT/90/016 - "Institutional Support to Irrigation Development" aimed at enhancing the capability of the Irrigation Section of the Ministry of Agriculture, Project URT/80/011 and URT/91/005 - "Development of Usangu Village Irrigation Project"; URT/84/002 and URT/86/009 - "Smallholder Oriented Rice Production Project"; Project URT/86/017 and URT/92/005 - "Rehabilitation of Traditional Irrigation Projects in Kilimanjaro and Arusha Regions". Other donor assisted irrigation sub-sector include ADB/UNCDF (Kitivo and Mwamapuli Irrigation Projects), CDF (Pawaga Irrigation Project), CDTF (a number of small scale irrigation projects in Hai, Mwanga and Same Districts), CIDA (Kimani Irrigation Project), FAO (Project

GCP/URT/092/NET - "Women in Irrigated Agriculture"), IFAD (Smallholder Development Project for Marginal Lands), ILO (Project URT/86/008 - "Pre-feasibility Study of Gichameda Irrigation Project"), JICA (Lower Moshi and Ndungu Irrigation Projects), OXFAM (Feasibility Study on Smallholder Irrigation in Miwaleni), SNV (a number of Small scale Irrigation Projects in Mwanga, Same, Kondoa Districts etc.).

The Government in cooperation with foreign donors have assisted on rehabilitating a number of small-scale farmer managed irrigation schemes aimed at improving water supplies. Tanzania has about 933,000 ha of land potentially irrigable from surface water excluding ground-water (PPMB, 1993). By the year 1980 about 144,000 ha were already under irrigation. However, since then, some of those schemes have either closed down or reduced their areas under irrigation. By the year 1990/91 cropping season, only 58,192 ha were under irrigation out of which 44,221 ha were under small scale traditional irrigation which included the seasonal flood-bunded irrigation practised mostly in Tabora, Shinyanga and Mwanza Regions as a method of harvesting rainfall water. The remaining 13,971 ha constituted irrigated land under modern/large scale irrigation schemes. Todate, about 80% of all the existing irrigation schemes in the country are under the management of farmers while the remaining 20% are managed by the Government (Masija and Kagubila, 1994). Improvements are necessary in the management of water at scheme as well as at farm level. The immediate steps to effect such improvements at scheme level require installation of water control structures and train farmers in their use.

Musa Mwinjanga is one of the eight traditional irrigation schemes covered in the project URT/86/017 for rehabilitation. The project aimed at improving water supplies and management at schemes as well as at farm level. The rehabilitation works were scheduled to be implemented in phases. The phased approach adopted in rehabilitating the schemes initially concentrated on increasing the reliability of irrigation water supplies through rehabilitation of control intake-weir and main canal, improved control of irrigation water distribution through installation of gated control structures at secondary canal heads, identification, investigation and evaluation of further works required to prevent water logging and salinity and for staged complete redevelopment with farmer self-help participation. Other phases in which the improvement would be extended to the secondary canals and on-farm irrigation practices (i.e. improvement of irrigation water management and on-farm irrigation facilities) are yet to be implemented.

The Musa Mwinjanga Irrigation Scheme was rehabilitated in the year 1989/90 with financial assistance from UNDP/FAO through project URT/86/017 (Rehabilitation of Traditional Irrigation Projects in Kilimanjaro and Arusha Regions). The scheme had the weir rehabilitated, stilling basin including protective works constructed and crest level raised. Sections with adequate water carrying capacities were provided for and improved with non-erosive slopes. This included the improvement of the main canal (with the designed discharge ranging between 850 to 770 l/s) for an assured diversion of water into the main canal; and improved part of the Musa Mwinjanga secondary canal. Flow control structures were constructed at heads of Musa Mwinjanga and Mzee Kondo secondary canals and eight tertiary canals. Nine culverts at canal-access road crossings were constructed. The rehabilitation of the above structures was done by the KZIU staff backstopped by FAO experts. Since commissioning of the project, farmers are still complaining despite the major rehabilitation works carried out at the scheme. They argued that water availability for irrigation purposes was far better before than after rehabilitation (Personal Communication, 1995).

1.2 Purpose and Objectives of the Study

Many FMIS do not perform as they could be expected despite their significant contribution towards subsistence food security in many countries world-wide (Manor and Chambouleyron, 1993).

Although the Government of Tanzania has been emphasizing on rehabilitation and improvement of the FMIS as the only way to ensure sustainability of irrigated agriculture, no study has so far been conducted to assess the causes and effects of problems emanating from rehabilitation of FMIS as a result of intervention. Abernethy (1986) stressed the need to have proper study in identifying areas needing improvements and support before any intervention is effected. Martin et al. (1986) also pointed out the need to have basic information before any intervention is made to help farmers. He emphasized on the need to know how farmers manage their systems; and in what, if any, aspect they could be helped from outside.

The main objective of this research was to assess the causes and effects of problems emanating from rehabilitation of FMIS as a result of intervention from outside. The study aimed at setting the stage for seeking appropriate solutions and provide a basis for setting guidelines for implementing future rehabilitation works. The specific objectives of the study were:

(I) To investigate the causes and magnitude of water losses in the system;

(ii) To evaluate irrigation water supply requirements;

(iii) To assess and evaluate water management aspects of the system.

1.3 Report Organisation

This report is further divided into the following chapters. Chapter 2 reviews the literature including the theories of performance of irrigation schemes. Chapter 3 contains materials and the methods used to obtain the results of the study. Chapter 4 discusses the results of the study. Chapter 5 contains conclusions and recommendations drawn from the study.

2. LITERATURE REVIEW

Increasing pressure on land in the highland areas has led to more extensive cultivation of the lowlands both by migrants and commuters from the upper areas. Consequently, progressively greater demands have been made on the furrows over the years. Kilimanjaro Region is endowed with a number of perennial rivers/water sources. For more than half a century, the local communities have developed and used traditional irrigation infrastructure diverting water from these perennial sources for agricultural use. Chapman (1986) reported that there are more than 300 traditional furrows in Kilimanjaro Region, many of which are more than 60 years old. These traditional schemes are simple in concept and represent basic construction features. However such infrastructure have remained inefficient in water use and therefore not fully dependable for efficient water management.

In the past, farmers used to build temporary weirs across the rivers and dig furrows to command the scheme areas. Concrete weirs were built later at many scheme sites to improve the abstraction efficiency. Many of the main furrows were provided with gated intakes but these were commonly damaged and the gates remained inoperable. Even when the intakes were in good condition it was apparent that little control was effected on intake discharges. Damage of or failure to operate the intake gate have often resulted in damage to main furrows. Severe bed and bank erosion of main furrows resulted in considerably oversized and inefficient channels with only limited command.

This chapter reviews the theoretical background of the causes and effects emanating from intervention on farmer- managed irrigation systems. It describes the hypotheses which enabled the researcher to analyse a number of causes and effects of the major problems affecting the rehabilitated FMIS; and then conclude and recommend on the most appropriate measures to be undertaken in order to reduce the impact of these problems.

2.1 Irrigation Water Management

Increasing food production to sustain the food requirements of the rapidly growing population would be relatively an easy task if irrigation infrastructures were made available. Governments world-wide have thus focused their attention on the development of irrigation systems as a means of attaining self-sufficiency in food and narrowing the ever widening gap between the rich and the poor. Farmer owned and managed schemes have thus become the focus of attention of those concerned in irrigation development. In the Philippines for example, about 63% of the total irrigated area or about 1.37 million hectares of land was under the management of individuals or groups of farmers (Angles et al., 1989) of which about 580,000 ha were irrigated by schemes owned and controlled by farmers and better known as communal Irrigation Systems (Bagadion and Korten, 1980). These systems were comparatively cheaper to construct and to maintain than the large scale irrigation schemes. They served to further the social and economic development of farmers, create and strengthen local organizations and subsequently increased the farmers' income.

Irrigation water management can be defined as the integrated processes of diversion, conveyance, regulation, measurement, distribution and application of the right amount of water at the right time, right place and the removal of excess water from the farms to promote increased crop production in conjunction with improved cultural practices (JICA/NIA, 1991). The objectives of water management are:

(I) to maximize water utilization through;

- supply of the right amount of water to meet crop requirement;
- more effective rainfall utilization;
- control or reduction of conveyance, distribution and application losses;
- adoption of suitable scheme of water distribution and application of irrigation water;
- tapping of return flow or re-use of water;
- reduce drainage problem;
- timely delivery of water to farms;
- active participation of farmers community;

(ii) To promote increased crop production through;

- proper land use;
- improved cultural practices;
- better farm management techniques.

Irrigation management has been weak in many of the FMIS in Africa (Speelman, 1990). Water being a scarce commodity but very important input for crop production, should be well managed (FAO, 1971). Galnoor (1980), cited by Sexton (1990), argued that water shortage is not simply the product of poor planning, instead, it represents a distinct phase in the development of a water system. For proper monitoring, the amount of water applied into the field should be measured and recorded. Such practices help in judging whether the amount of water deliveries match with the predicted quantities or distributed equitably, adequately, and timely among different farmers in an irrigation system (based on irrigation schedule).

2.1.1 Water Management Parameters

Water management parameters can be defined as the water management variables that should be investigated or firmed-up prior to be operating the irrigation system (Mallari, 1994). Operating the irrigation system to achieve the desired area to be irrigated needs careful planning. The sources of water and available discharge for irrigation from these sources should be well determined both quantitatively and qualitatively. The seasonal rainfall distribution as supplementary source of water should be assessed and evaluated to quantify the amount of water to be supplied from irrigation. In addition to the above, water management related parameters should as well be investigated.

Some of the factors affecting water management parameters are namely:

(I) evapotranspiration;
  - air temperature;
  - sunshine duration;
  - wind speed;
  - location, topography and type of crop grown;
  - growth stage of the plant;

(ii) rainfall;
(iii) percolation;
(iv) crop water requirement;
(v) water losses;
(vi) effective rainfall;
(vii) topography of the land.

With the above knowledge on water management parameters, irrigation engineers or managers of the irrigation systems can be able to determine and quantify the following aspects:

- Water supply requirement of the irrigation system on daily, weekly, decadal or monthly basis;
- The total command area which would possibly be serviced by the system based on the available water supply;
- The peak irrigation water requirement of the system considering the growth stage of the crops.

Recent studies on water utilisation in irrigation systems' operations showed that the causes of water crises in many farmer managed irrigation systems' operations is attributed partly to poor design but predominantly to problems of organization and management (Sagardoy et al., 1986). Uphoff et al. (1985), cited by Martin et al., (1986), pointed out the need to have basic information before any intervention is made to help farmers. They emphasized on the need to know how and how well do farmers manage their systems; and in what, if any, aspects could they be helped from outside assistance. They described the above aspects in the context of activities directly related to: (I) water i.e. acquisition, allocation, distribution and drainage; (ii) water controlling infrastructures i.e. design, construction operation and maintenance; (iii) organization of people who manage the irrigation system i.e. decision making, resource mobilization, communication, and management of conflicts. They further emphasized on the need to accurately evaluate water flow parameters such as efficiency, adequacy, equity, reliability and dependability. It is also important for the irrigation authorities to assist and train farmers in proper management and operation of their irrigation scheme.

Oad and Sampath (1991) related the measurement of water distribution parameters i.e. equity, adequacy, and dependability at any delivery point using the mean square prediction error theory. This method was observed to be useful in identifying the causes and levels of low water management performance in the system. Baskota and Thampa (1991) employed inter-quartile ratio (IQ_R) as the equity indicator. However, Abernethy (1991) observed that the tail end problem affects mainly the farmers at the down-stream end of the canals. He also observed that farmers at the head reaches of the canals are also affected by this problem due to poor water allocation.

The report made available as a result of a joint Evaluation Mission (January/February 1991) and a Tripartite Review Meeting (28 March 1991) on project URT/86/017 - "Rehabilitation of Traditional Irrigation Projects in Kilimanjaro and Arusha Regions" observed that the project was well designed in concept. Its labour based and staged re-development approach minimises costs and fosters community ownership aspect. It has the ability of transferring technology to the local professional staff in the relevant sector within the country. However, due to lagged implementation, the project progress was estimated at only about 20% to 30% of the Target.

2.1.2 Irrigation System Performance Indicators

Manor and Chambouleyron (1993) suggested the following indicators that should be used when evaluating performance of an irrigation system namely: (I) Irrigation efficiency; (ii) Water delivery performance; (iii) Organisation. Sakthivadivel et al. (1993) suggested the use of relative water supply (RWS) method to evaluate the adequacy of water supply to the field for any Irrigation scheme. This is a measure of reliability and quality of the system operation indicating how best the irrigation system is able to deliver the right amount of irrigation water to meet crop water needs. The method requires the use of the actual water deliveries measured and the supply demand during the growing season. Small and Ingersoll (1974) and Levine (1982), cited by Sakthivadiel et al. (1993), described the RWS as simply a ratio of water supply to the water demand associated with crops actually grown with the cultural practices actually used. Bos and Nugteren (1990) described the RWS as the inverse of the traditional concept of 'engineering efficiency' as used by irrigation engineers.

The concept of RWS suggested by Levine (1982), cited by Sakthivadivel et al. (1993), has proven to be a useful tool due to its ability in evaluating productivity, relative equity and adequacy of irrigation water supply to the fields. The concept of RWS is however a vital tool for understanding the performance of irrigation systems, and impact on performance behaviour of operation management staff and farmers at different stages during the growing season (Sakthivadivel et al., 1993). It has also proven useful in understanding the decision rules associated with the system operation.

Sakthivadivel et al. (1992) pointed out various RWS values and their indication in terms of the adequacy of water supply during the land preparation of paddy fields as: (I) RWS equals unity indicates that water deliveries matched with the crop water needs; (ii) RWS greater than unity indicating that the entire irrigated area is devoted to paddy rice; (iii) RWS less than unity indicates a rapid decline in the fraction of the area cropped to paddy rice; (iv) RWS below 0.8 indicates that there is practically no rice grown hence upland crops may be substituted (Levine, 1982, cited by Sakthivadivel et al., 1993).

Sakthivadivel et al. (1993) highlighted further the RWS values during crop growth period as: (I) RWS approximating 2.0 indicates monitoring and control to secondary canals, daytime monitoring, limited communication between the system managers and farmers, and relative farmer independence would still permit high yield; (ii) RWS equals 2.5 or greater indicates that systems with minimal operational control at the main system distribution level would be adequate to ensure that water will not be the limiting factor in crop production.

Sakthivadivel et al. (1992) pointed out the weakness of the RWS in assessing the adequacy of water supply as it fails to account for the use of drainage or for residual water left in the fields due to rain or over irrigation that can be used to supplement water requirements in the subsequent weeks. The concept of cumulative relative water supply (CRWS) was suggested over the RWS due to its ability of giving better representation of available water in the field level (Sakthivadiel et al., 1992, 1993). The CRWS is the cumulative value of the ratio of supply to the demand computed over a given time interval. It is against these facts that the aforementioned indicators were used to assess the irrigation performance of the study area.

2.2 Farmers' Participation

Development of these small but potentially important gravity schemes has been the concern of many agriculturally oriented countries, including Tanzania. Several approaches have been employed by various agencies in the development of irrigation systems. One of such techniques is the participatory approach in which the farmers are fully involved in planning, design and construction of the systems.

The concept of participation is frequently ignored either for fear that it will delay the project completion or being seen primarily as a way to reduce cost of operation and maintenance (Speelman, 1990). Lack of farmer participation often results in a host of problems during the operation stage. The proposal on rehabilitation of any farmer managed irrigation scheme should infact be presented, discussed and agreed upon with farmers. It has been realised that lack of farmers' participation in planning, design and construction stages usually results in location of canals and other water control structures which do not correspond to farmers' needs (IIMI, 1990). As a result these structures are abandoned or destroyed by the farmers. Participatory irrigation management is an approach which has received some inspiration from indigenous irrigation societies in Philippines; and has been promoted by the Government using various institutions and building techniques (Wijayaratna and Vermillion, 1994).

The essence of participation is to try to help farmers to consider their situation and diagnose their own problems, to build up their ability to analyse their situation and to decide on what further action to be taken. Madeley (1987) reports that the aided projects tend to perform badly often because people who were supposed to benefit were not consulted.

2.3 Diagnostic Analysis

Diagnostic analysis which refers to appraisal and analysis of existing irrigation systems with the objective to identify problems and to define the causes or constraints underlying these problems is fast gaining importance as an analysis tool. The analysis of an irrigation scheme can cover all aspects from the scheme i.e. the water source, the physical system, the farming system, the existing local organization and the institutional framework for irrigated agriculture in the region or even in the country as a whole (Bastiaansen, 1994). This is the so called "system-oriented approach" as opposed to the "problem-oriented approach" in which the collection and processing of data is restricted to the problem or problem area and the only aspects investigated are those, which seem to hamper the performance of the scheme. In reality however, diagnostic analysis is infact a combination of the two approaches with one of the approaches dominating.

Some of the main methodologies that have been used in diagnostic analysis include the "Objectives Oriented Project Planning" (OOPP); "Rapid Rural Appraisal" (RRA) and "Participatory Rural Appraisal" (PRA). Kihupi and Dihenga (1994) used OOPP to analyse the Mto wa Mbu irrigation project with considerable success.

2.4 Organization

Organization can be defined as a group of people who coordinate their activities in order to achieve common objectives. Any organization has a form or structure. An organizational structure cannot be bad or good but it may be appropriate or inappropriate (Kerziner, 1992). Whatever form of organisation, it must be developed so that each individual should have a clear description of the authority, responsibility, and accountability necessary for the flow of work to proceed.

Manor and Chambouleyron (1993) described a well organised irrigation system as the one which maintains a good linkage between the top and the bottom management, effectively carrying out proper operation and maintenance of the system and ensures that the irrigation rules are adhered to by the individual members and capable of resolving conflicts among farmers.

Sagardoy (1986) described qualities of a well organized irrigation scheme. According to him, a well organized irrigation scheme should be accountable to water distribution activities, system maintenance, collection of water charges or similar charges, assist and deliver extension services to farmers. It should be capable of delivering other services like finance, agricultural and basic infrastructure to the irrigation community.

Ostrom and Benjamin (1991) described a theoretical framework which consists of predictors of a well functioning irrigation project. These include the presence of clearly defined irrigation project boundaries, fair proportion between the benefits received and the contributions made by each irrigator member, collective decision making arrangements, accountable monitoring, gradual sanctions against rule violations, governmental recognition of farmers to organize and address different functions. Abernethy (1991) has cautioned that the ability of farmers to manage the system normally reduces especially in areas where the rehabilitation works were undertaken by the government or international donor agencies. Gelles (1988), cited by Vincent (1990), pointed out the importance of avoiding oversimplification and stereotypes of the community, communal institution, and of interaction between them. He emphasized on the need to understand how different local institutions are used by many different social groups and families to deal with water management issues.

Hobley and Shah (1996) reported that the overriding factors that determine the effectiveness of local organizations is the nature of the resources to be managed in terms of its divisibility and its ability to produce a flow of short-term as well as long-term benefit.

2.5 Possible Causes of Problems in FMIS

Chapman (1990) cited several constraints on successful development of irrigation activities in Tanzania. According to his report, the following major constraints have been highlighted:

- Failure of planners, in their development program, to appreciate the resources, particularly of trained personnel, equipment and finance necessary to adequately plan, design, construct, commission and operate irrigation projects.
- Failure to take heed of sources identified by the task force on National Agricultural Policy for failures of previous Government development activities in irrigation and the continued concentration of investment on sophisticated and expensive irrigation systems.
- Inadequate project preparation and poor project planning, designing and constructing of irrigation schemes which were due to serious shortage of National competence.
- Failure to concentrate limited resources on limited number of viable projects.

- Inadequate operational support to completed schemes in smallholder sector due to failure to involve farmers in scheme planning and implementation; failure to establish and train farmers' organizations to undertake operation and maintenance; failure to support farmers in operation and maintenance.
- Failure to develop extension packages for irrigated agriculture and by the ineffectiveness for extension services.
- Failure to implement a coordinated manpower development program in all disciplines required for irrigation development.

During the design stage of an irrigation system, there may be some inaccuracies in the point values of parameters used, i.e. they may be overestimated or underestimated. The processed input data may also be miscalculated due to insufficient or inaccurate basic data. There may even be some serious flaws in the design procedure itself which until recently had not been detected or had not become apparent, and have eluded prompt and appropriate rectifications (Labiano, 1994). During actual irrigation operations, a number of drastic changes in the scheme may actually happen. These changes may be due to significant change in the rainfall pattern, change in the usual dominant crops, there may occur lesser amounts of stream flows and rainfall than those predicted and used in the design of the facilities and of the water management plans etc. These deviations in the predicted situation will surely give rise to a number of problems in the operation of irrigation systems.

3 MATERIALS AND METHODS

This chapter describes materials and methods used in this study. It gives the general background of the study area and instrumentation used to measure and obtain various parameters required to fulfil the study objectives.

3.1 Background of the Study Area

3.1.1 Location and Size

Musa Mwinjanga Irrigation Scheme is located within the legal boundaries of Mijongweni village of Kikafu South ward in Hai district of Kilimanjaro region in the north eastern Tanzania. It lies between the latitudes 3°23' and 3°27' South of the equator with longitudes 37°16' and 37°20' East. The scheme lies some 9 km south east of Moshi Township. It is bounded by Weruweru river on the north to south east, Kikafu river on the south to west and Kikafu chini village on the north west. The location of Musa Mwinjanga Irrigation Scheme is shown in Figure 3.1. The Mijongweni village in which the Musa Mwinjanga Irrigation Scheme is within, is formed by five suburbs namely Kijiweni, Miembeni, Kiyungi, Mijongweni chini and Ofisini. Figure 3.2 shows the five suburbs which form the Mijongweni village. The scheme comprises a gross area of about 676 ha. of nearly flat arable land which can be commanded by a gravity irrigation system.

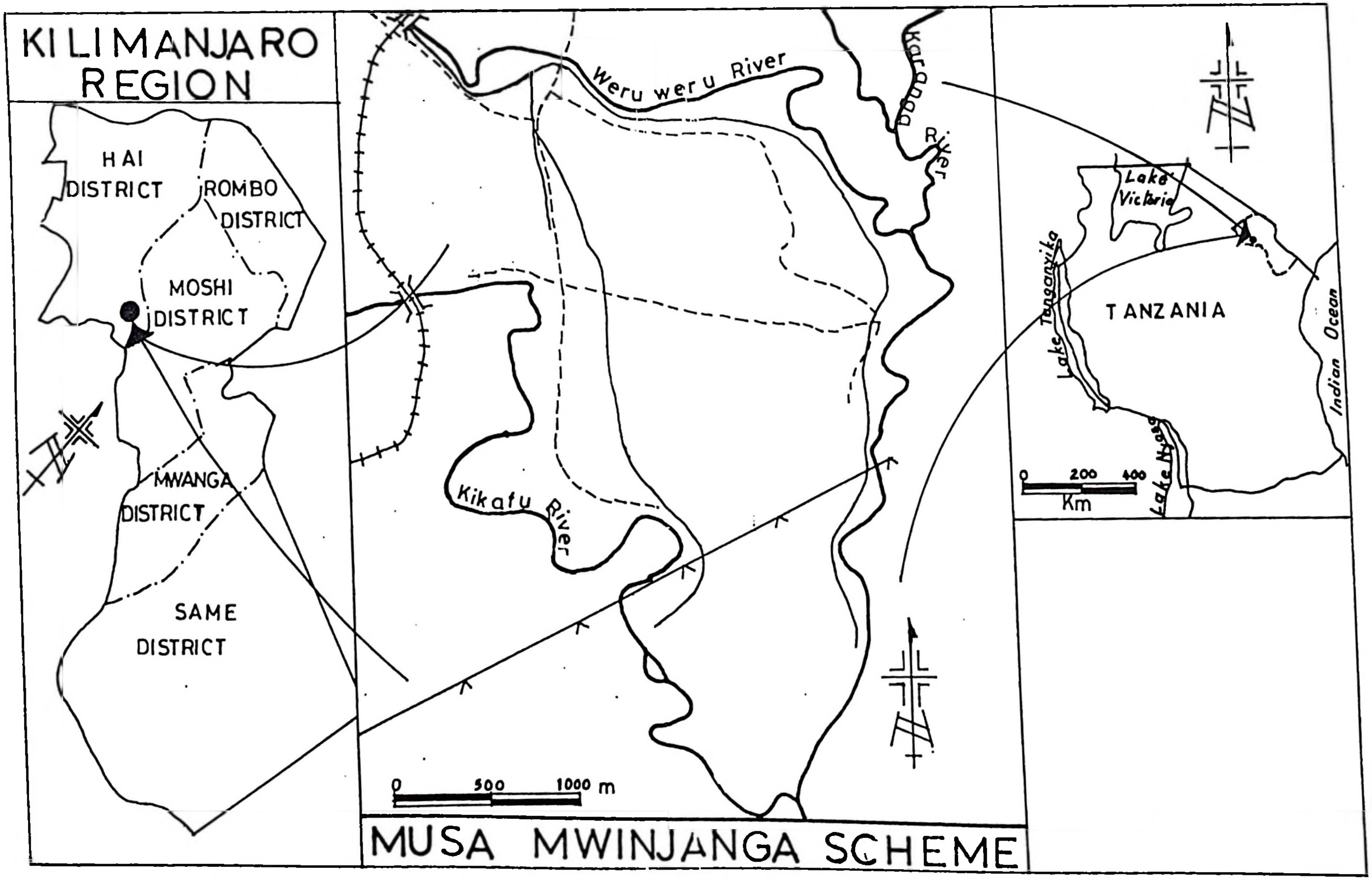


Fig. 3.1 Location Map of Musa Mwinjanga Irrigation Scheme

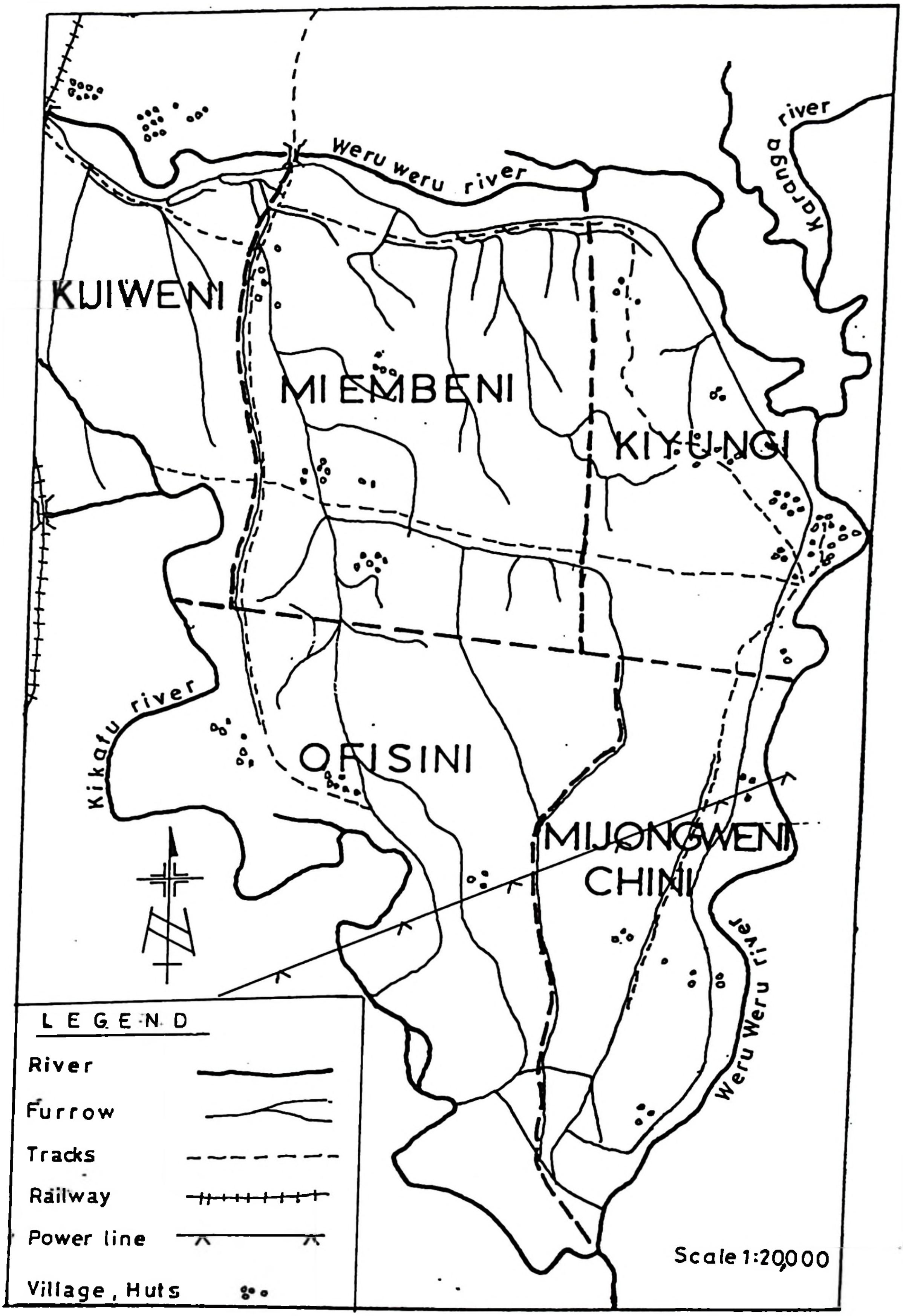


Fig. 3.2 Suburbs Forming Mijongweni Village

SOURCE: KZIU - Moshi

3.1.2 Climate

Climatological recordings are not done at Musa Mwinjanga Irrigation Scheme. The meteorological station no: 93.37/004 located at Moshi airport at altitude 813 m, latitude 3°21' and longitude 37°20' and some 6 km north west of the study area was chosen as relevant to represent the weather conditions of the latter. This station has long meteorological records (more than 30 years records) of which the information available was used to build up a picture of local climatic condition of the scheme since other climatic stations are located further from the scheme area.

The climate within the scheme area can be described as hot semi arid in accordance with Kopen's classification (Landon, 1984) with two rainy seasons. The rainfall in the area is basically orographic, brought about by the south east trade winds hitting Mt. Kilimanjaro (Kips and Ndondi, 1990). Rainfall decreases sharply with increasing distance from the Mt. Kilimanjaro. The rainfall pattern is weakly bimodal. The most important rains fall in the period mid March to May, whereas the short rains occur in November to December. However, the climate is largely divided into a dry season extending from June to October and a rainy season from November to May.

Abdel-Dayem (1990) estimated that the northern tip of the scheme at altitude 780 m above mean sea level receives a mean annual rainfall of about 700 mm whereas on the southern tip at altitude 741 m only about 600 mm are received annually. On the other hand, the rainfall distribution map in the Lower Hai area (JICA, 1989) shows that the study area receives a mean annual rainfall of about 700 mm. Table 1.1 of Appendix 1 gives the mean daily rainfall based on 26 years record (1970-1995) collected from Moshi Airport Meteorological Station out of which the mean annual rainfall has been estimated at 943 mm. The overall rainfall distribution in the study area is generally poor with about 65% of the total rains falling in the period of less than three months (i.e. from mid March to May). Figure 3.3 presents the mean daily rainfall pattern of the of the study area.

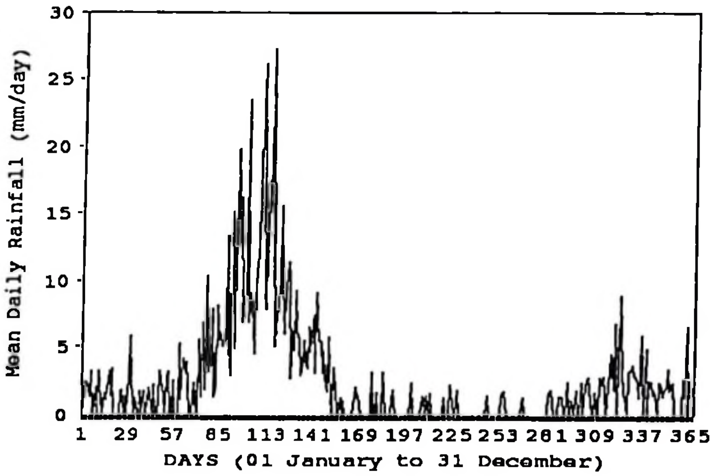


Fig. 3.3 Mean Daily Rainfall of Musa Mwinjanga Scheme

The variation in mean monthly temperature was found small which can be described as fairly constant over the year. The hot season lasts from October to April with mean monthly temperatures ranging from 24°C to 26°C with a possible rise in temperature of up to 34°C. The coolest months are July and August with the mean monthly temperatures ranging from 20°C to 21°C with maximum temperature of 30°C. The daily dew point temperature varies between 18.5°C in April and 13.7°C in September. Tables 1.2, 1.3 and 1.4 of Appendix 1 show the daily maximum, minimum and dew point temperatures respectively of the study area.

The mean monthly maximum relative humidity (RH) ranges from 81% in February and March to 91% in May; with possible rise to 94%. The mean monthly minimum RH varies from 41% in February to 63% in May; with possible rise to 67%. The annual average RH has been estimated at 67%. Tables 1.5 and 1.6 of Appendix 1 present the maximum and minimum RH respectively.

The mean monthly sunshine hours range from 9 h/day in January to 4.5 h/day in June; with possible rise to 9.9 h/day. The annual total sunshine hours is estimated at 2,516 hours. The daily sunshine hours is given in Table 1.7 of Appendix 1.

The wind speed varies from 268 km/day in March to 54 km/day in June with an annual average of 126 km/day. The prevailing wind condition in the scheme area can be described as light to moderate. The daily wind run of the area is given in Table 1.8 of Appendix 1.

The mean daily evaporation varies widely from 4.1 mm/day in June to 9.2 mm/day in February. The annual total potential evaporation is about 2,490 mm. In April and May a moisture surplus exists (rainfall higher than the potential evaporation) whereas in all other months there is a moisture deficit. Table 1.9 of Appendix 1 presents daily evaporation of the area based on 11 years of record (1985 to 1995).

3.1.3 Topography

A detailed topographical survey for the Musa Mwinjanga Irrigation Scheme (Figure 3.4) was carried out in early 1988 by the KZIU staff. The topographical map of the scheme at scale 1:5,000 with contour interval of 1 m was then prepared. The ground surface elevation above mean sea level varies between 743 and 781 m. The base map was produced based on aerial photographs of scale 1:20,000. The maps revealed the land of fairly flat with an average slope of 2%, sloping towards the south.

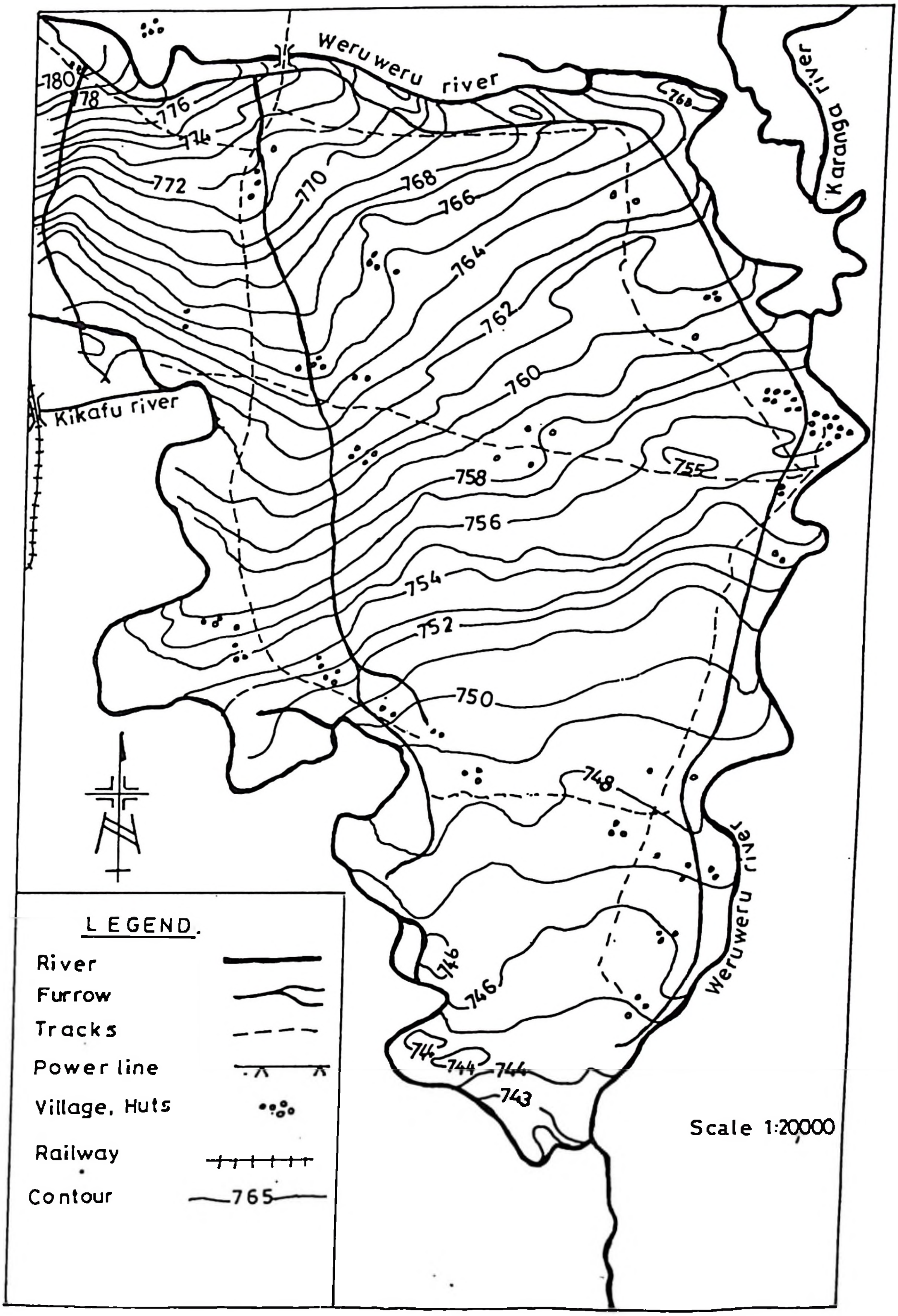


Fig. 3.4 Topographical Map of Musa Mwinjanga Scheme

SOURCE: KZIU - Musa Mwinjanga Scheme Design Notes

3.1.4 Geology and Landform

Musa Mwinjanga Irrigation scheme is located for a greater part on a Volcanic outwash plain of very low relief (Kips and Ndondi, 1990). The scheme is bordered in the west by a north south low fault scarp with adjacent foot slope stretching out eastward into the scheme. The extensive Volcanic outwash plain is false-flat with an inclination of about 1% in the northern part of the scheme.

3.1.5 Soil and Land Classification

Detailed soil and land classification surveys for the scheme were carried out in the year 1989/90 by the National Soil Service (NSS) at the request of the project URT/86/017 (Kips and Ndondi, 1990). The specific purpose of land classification investigation was to classify land with respect to suitability to certain forms of land utilization and management. The land classification investigation focused on the assessment and evaluation of the soil condition, topographic features and drainage condition.

The total scheme area surveyed was 676 ha. The soils within the scheme were grouped according to physiographic units (Fig. 2.1 of Appendix 2). Four broad physiographic units were identified namely Volcanic outwash plain (O-soils), shallow bottom land or Mbuga (B-soils), river flood plain (R-soils) and foot slope of minor scarp (F-soils). About 567 ha, equivalent to 85% of the total scheme area is dominated by O-soils. B-soils occupy only 8 ha equivalent to 1.2% of the total scheme area. R-soils dominate about 70 ha equivalent to 10.4% and F-soils occupy 21 ha equivalent to 3.1% of the scheme area. All soils were found relatively young and only slightly weathered. They differed in depth, drainage, texture, and sodicity levels and were non saline. Table 2.1 of Appendix 2 presents the quality of soil samples of Musa Mwinjanga Irrigation Scheme determined in March 1989. Detailed description of scheme soils based on previous findings and the results of the study are well discussed in chapter 4.

3.1.6 Hydrology

There are three major rivers flowing through the study area from mount Kilimanjaro to the south, viz. the Weruweru, Karanga and Kikafu rivers. Among the three rivers, Weruweru river is the major source of irrigation water to the Musa Mwinjanga irrigation scheme. The Weruweru river joins the Karanga and Kikafu rivers at the north eastern and southern tips of the scheme respectively.

3.1.7 Cropping Pattern and Calendar

During rehabilitation stage, it was estimated that 300 ha of maize, 250 ha of paddy, 30 ha of bananas and 20 ha of vegetables would be irrigated during the wet season. The areas estimated to be under irrigation during dry season included 200 ha of maize, 150 ha of paddy, 30 ha of banana, 20 ha of vegetables and 50 ha of beans. There is no fixed cropping pattern at Musa Mwinjanga Irrigation Scheme. Individual farmers are free to plant any type of crops according to their preference. Nevertheless, according to farmers, the cropping pattern and calendar of the scheme can be summarized as shown in Table 3.1.

Table 3.1 Cropping Pattern and Cropping Calendar for Musa Mwinjanga Irrigation scheme

Crop	Planting Dates	Harvesting Dates
Maize (wet)	15 to 30 March	15 July to 01 Aug.
Maize (dry)	30 Oct to 15 Nov.	01 to 15 March
Rice (wet)	15 to 25 January	15 to 25 May
Rice (dry)	15 to 30 July	15.Nov. to 01 Dec.
Beans	30 July to 15 August	01 to 15 November
Banana	15 March	15 March
Vegetables	01 August to 01 Sept.	01 Nov. to 01 Dec.

3.1.8 Irrigation Water Quality

Kips and Ndondi (1990) described the quality of irrigation water for the scheme after the laboratory analysis of the samples taken from the main canal near the intake structure, Mzee Kondo and Musa Mwinjanga secondary canals as having low electrical conductivity. The electrical conductivity ranged between 0.14 to 0.18 mS/cm indicating that the irrigation water has a low salinity hazard. Table 3.1 of Appendix 3 gives the quality of water samples taken from the canals during the soil survey carried out in March 1989. Additional water samples were collected from the main, secondary and tertiary canals and taken for the laboratory analysis with the view to determine the present salinity levels of the irrigation water.

3.2 Data Collection

Rehabilitation of farmer managed irrigation schemes require to have prior information on the performance of the irrigation, drainage and agricultural components of the systems. Availability of hydrometeorological data for the area concerned is of great importance in planning the cropping pattern, irrigation service area and irrigation scheduling. This information is helpful in evaluating the present condition and determining the necessary improvements for the irrigation schemes. Since the study touches social as well as technical issues, appropriate approaches were adopted for collecting necessary additional information which helped in identifying the causes and effects of problems emanating from rehabilitation and eventually working out possible solutions.

3.2.1 Participatory Rural Appraisal

Although participatory rural appraisal methods (PRA) have not been specifically designed for diagnostic analysis of farmer managed irrigation, there are nevertheless strong indications that the participatory approach is resulting in more efficient and more effective development (Mascarenhas et al., 1991). It is for this reason that the PRA approach has been adopted as a cost-effective means of collecting data within a short period of time during the study period.

Some of the methods of PRA as presented by Mascarenhas et al. (1991) e.g. transect walks and participatory transects with key-informants; use of resident researchers and village analysts for investigation and data collection; use of diagrams; and inventory of traditional management systems and local resources were adopted.

In addition, other more specific techniques in diagnostic analysis of farmer managed irrigation such as "resource-based top-down" which describes the system starting with the water source and working its way down to the farm and eventually beyond that to the main drainage outlet; "performance-based bottom-up" which is based on the system performance such as frequency of conflict or complaint by farmers, adequacy of water delivery, etc; and "key probes" which are investigations starting with questions which experience shows can lead efficiently to good action and/or information were also used.

Various bits of information were collected through direct observations in the field, published reports of the government and other institutions, and through discussion with the local population. The discussions were held with village leaders as a group, farmers as individuals, the village agricultural extension staff responsible for the area and personnel in government and other institutions (i.e. KZIU, Regional Irrigation Office, District Irrigation Officer etc). In the case of discussions with farmers, a few farmers from among many candidates were selected (sampling frame). The number of sample farmers were determined using the criteria adopted by JICA/NIA (1991) as shown in Table 3.2. The sample farmers were chosen at random and the questions were mostly open-ended.

Table: 3.2 Criteria for Sampling Number of Respondents

Area (Ha)	Number of Respondents
< 50	20
51 - 100	30
101 - 200	40
201 - 300	50
301 - 400	60
> 400	70

SOURCE: JICA/NIA (1991)

Fifty individual farmers, eight water masters (*wagawa maji*), Water Committee and the village leaders, village extension staff, Hai District and the Regional Irrigation Officers, KZIU staff including the Zonal Irrigation Engineer and the National Project Coordinator for project URT/92/005 were interviewed in accordance with the basic key probes shown in Appendix 4.

3.2.2 Present Condition

The field visits were carried out through and around the scheme area. The objectives of the visits were as summarized below:

- To acquaint with the nature and type of the agricultural system of the area;
- To inspect the local irrigation practices;
- To observe and examine the possible causes and effects of problems affecting the Musa irrigation scheme.

3.2.3 Scheme Layout

The source of irrigation water to the scheme is from the Weruweru river. Water diversion to the scheme is effected by means of an intake-weir constructed across the river. Water is distributed over the area through a system of earthen irrigation canals. Musa Mwinjanga main canal supplies water directly to two secondary canals (i.e. Mzee Kondo and Musa Mwinjanga secondary canals) and a number of tertiary canals. At the farm level, the command is mostly gained by a farmer blocking the canal and digging a small ditch to lead water to field. Upland crops (i.e. maize and beans) are mainly cultivated in borders; whereby the land is divided into small plots of different sizes and shapes, enclosed by temporary earthen bunds. Paddy is normally cultivation in basins having permanent bunded plots which are kept submerged and are drained at crop ripening and harvest.

The present irrigation and drainage network map based on information gathered from the KZIU, Water Committee (WC) and field observations was prepared (Fig. 3.5). The map includes the canals' condition indicating the canals organization and alignment, names, length; names, numbers and locations of headgates, turnouts and division boxes; numbers and locations of the check points of flow capacities.

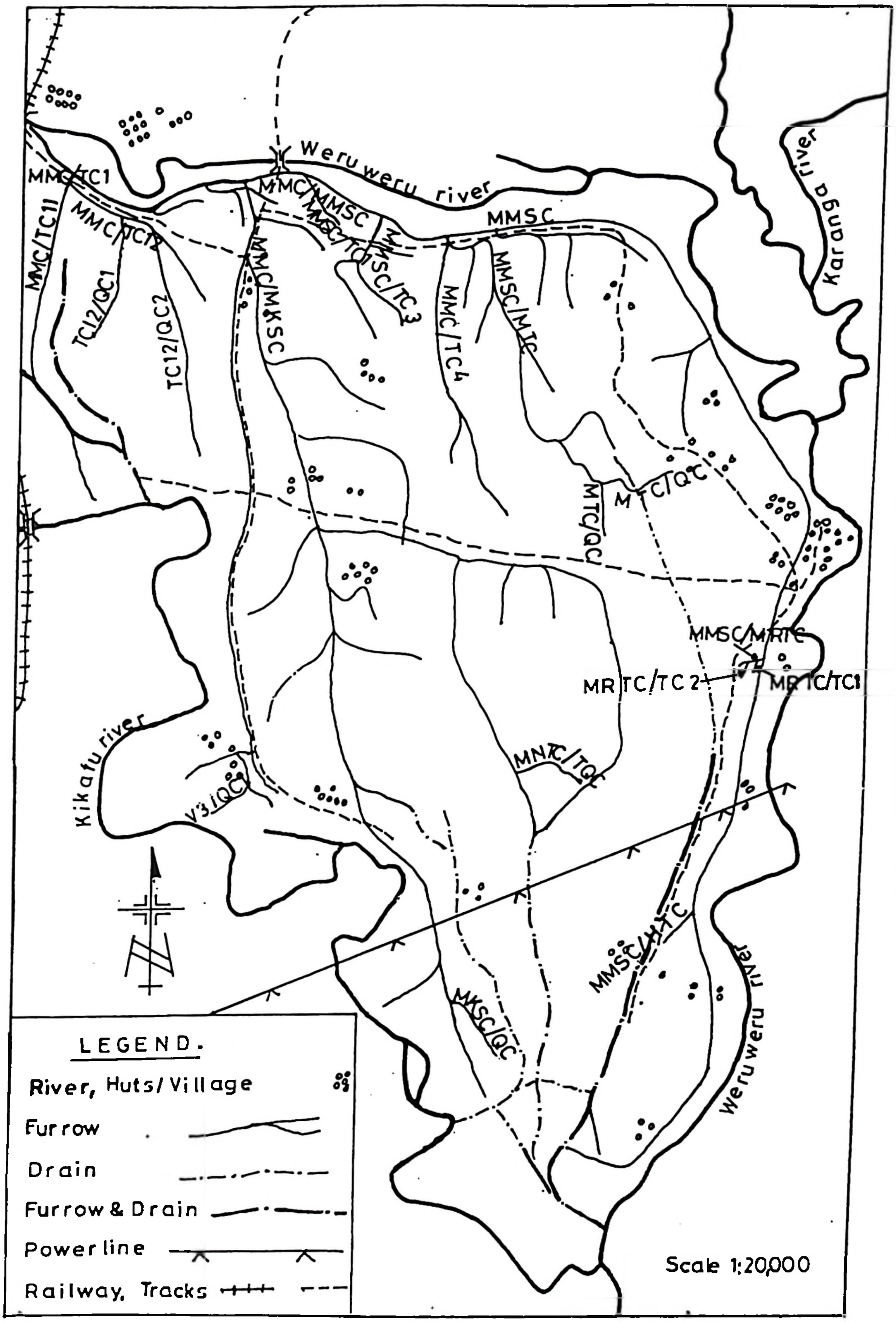


Fig. 3.5 Irrigation and Drainage Network of Musa Mwinjanga Irrigation Scheme

SOURCE: KZIU - Design Notes

3.2.4 Meteorological Data

Daily values of rainfall and rainfall pattern, and daily average values of temperatures, relative humidity, wind speed and sunshine hours (26 years record) were obtained from the meteorological station no: 93.37/004 located at Moshi airport at altitude 813 m, latitude 3°21' and longitude 37°20' situated about 6 km. North-West of the study area.

Table 3.3 gives the summary of meteorological records derived from 26 years data collected at Moshi airport meteorological station. These data were used to estimate crop evapotranspiration, effective rainfall, net and supply irrigation requirements and irrigation delivery scheduling for the study area. During the rehabilitation stage the KZIU used rainfall data of the former Kiyungi sisal estate station no. 93.37/029 (Table 1.10 of Appendix 1), formally located near the confluence of Kikafu and Weruweru rivers, now within TPC sugar-cane estate as representative station for the scheme.

Table 3.3 Summary of Meteorological Records

Station: Moshi Airport Lat. 3°21', Long. 37°20', Alt. 813 m

Registered Station Number: 93.37/004 Period: From 1970 to 1995 (26 years)

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily Max. Temperature (°C)	32.1	33.0	32.3	29.2	26.8	25.7	25.4	26.2	28.5	30.7	31.3	31.3
Daily Min. Temperature (°C)	17.9	18.2	19.0	19.5	18.5	17.1	16.2	16.0	16.3	17.4	18.3	18.2
Daily Mean Temperature (°C)	25.0	25.6	25.7	24.4	22.7	21.4	20.8	21.1	22.4	24.1	24.8	24.8
Daily Dew-point Temperature (°C)	16.4	16.2	16.6	18.5	18.0	15.5	14.3	13.8	13.7	14.1	16.0	17.0
Max. Relative Humidity (%)	84	81	81	90	91	88	87	87	81	85	86	86
Min. Relative Humidity (%)	43	41	46	58	63	58	53	50	43	39	43	48
Mean Relative Humidity (%)	64	61	64	74	77	73	70	69	62	62	65	67
Wind Speed (km/day)	138	147	167	110	70	62	69	92	150	192	178	135
Sunshine Hours (h/day)	9.0	8.9	7.7	6.3	4.6	4.5	4.6	5.3	7.0	8.1	8.3	8.3
Monthly Evaporation (mm)	243	267	251	166	122	122	141	168	220	270	271	257
Monthly Rainfall (mm)	45	32	122	379	169	18	15	7	6	24	71	55

3.2.5 Hydrological Data

The Weruweru river (a perennial river) is the main source of water for irrigation in the scheme. The nearest gauging station is 1 DD 6A, having a catchment area of 98 km^2, located 5 km upstream of the scheme's intake weir. The daily river flows at this station were collected from the Regional Water Engineer's office in Kilimanjaro region. The data collected covered a period of 11 years (i.e. 1978-1988). These data were used to generate the daily dependable flows (at 80% probability of exceedance) at the intake weir location.

During rehabilitation stage, a design discharge of 0.85 m^3/s was used as an estimate for the irrigation system capacity. Farmers in the area are concerned with water availability for irrigation which is rather problematic during part of the dry season thus leaving part of the scheme area without irrigation.

3.2.6 Organization

A review on the existing scheme's organizational set-up was done. Individual farmers and the village leaders were interviewed to give their opinion and suggestion with respect to the performance of the scheme's organization set-up.

The Water Users Association (WUA) has not yet been established at Musa Mwinjanga Irrigation Scheme. There exists a Water Committee (WC) which is responsible for water management in the scheme. Physical observations on how different operations and maintenance activities are carried out by farmers at a scheme level were made. Detailed information on the situation of WC was gathered from informal interview with WC's leaders and individual farmers. Additional information was obtained from the records and reports maintained by the Committee. This information was used for the preparation of workable water distribution and farming plans of the scheme.

3.3 Field Measurement

The whole irrigation scheme was divided into three sample blocks namely block I, block II and block III to represent the upper, middle and tail end of the scheme. Every individual block was then subdivided into three sub-blocks to represent upstream, middle and downstream. Sample plots PL1, PL3, PL5 (maize) and PL2, PL4, PL6 (paddy) were selected from block I to represent upstream region of the scheme. Sample plots PL7, PL10 (maize) and PL8, PL9 (paddy) were selected from block II to represent the midstream region of the scheme. the downstream region of the scheme was represented by plots PL11 and PL12 (maize) selected from block III. Canals flow measurements including determination of canal water losses, deliveries, irrigation efficiencies and scheduling were determined based on the data collected from the selected blocks, sub-blocks and plots.

3.3.1 Soil Salinity and Water Quality

Eight soil sampling sites were demarcated in the field. An auger was used to collect soil samples in the field. Water samples were collected from the Musa Mwinjanga canal, Musa Mwinjanga and Mzee Kondo secondary irrigation canals and a few of the tertiary canals. The soil and water samples collected from the fields were analysed at the KZIU laboratory to determine their corresponding electrical conductivities. The laboratory results were used to compare and evaluate the present salinity levels in relation to the levels that prevailed during rehabilitation stage.

3.3.2 Flow Measurement

Discharges at upstream, middle and downstream of each of the selected plots in sub-blocks were measured during each irrigation event. The measurements were aimed at determining the canal water losses and irrigation efficiencies. The amount of water discharged through the intake and along the Musa Mwinjanga main canal was measured. The discharge measurements were also carried out along the Musa Mwinjanga and Mzee Kondo secondary canals, and a few of the tertiary and quaternary canals.

Irrigation water losses from the intake-weir to the field plot inlets were divided into conveyance and operational losses. .Other losses considered were those occurring within the field plots which are known as application losses. All measurements were carried out without interfering with the flows in the canals as fixed by the farmers themselves.

The conveyance and operational losses were estimated on the basis of inflow-outflow method using a current metre. The application losses were estimated as the difference between the total volume of water supplied into the irrigation plots and the total volume of water required by plants during each irrigation application. These data were used to estimate the conveyance, field canal, distribution, application and the overall project irrigation efficiencies for scheme.

3.3.3 Soil Infiltrability

Soil infiltration measurements were carried out using double ring infiltrometer method and limited to O-soils type O1, O4, O8 and O11 (Fig. 2.1 of Appendix 2). The infiltration test in the field was conducted according to the procedure outlined by ILRI (1974). Depth readings were taken at periodic intervals. The intervals between observations were taken at 2, 5, 10, 20, 30 and 60 minutes until almost a steady rate was attained. The basic infiltration rate was assumed as the rate obtained when the change of intake rate was equal to about 10%. The locations of the infiltration test sites are presented in Figure 2.1 of Appendix 2.

3.4 Irrigation Efficiency

The main purpose of irrigation is to replenish the soil moisture in the root zone, depleted through evapotranspiration, with sufficient water required to meet crop needs. The movement of water through an irrigation system, from its source to the crop can be regarded as three separate operations namely; conveyance, field canal and field application (Doorenbos and Pruitt, 1977). Water losses are normally expressed as irrigation efficiencies. These include: conveyance, field canal and application efficiencies. The combination of conveyance and field canal efficiency is known as distribution efficiency. Project efficiency is obtained as the ratio between water made directly available to the crop and that released at the headworks. It can also be expressed as the combination of distribution and application efficiencies.

3.4.1 Conveyance Efficiency

The amount of water discharged through the intake into the Musa Mwinjanga main canal, Musa Mwinjanga and Mzee Kondo secondary canals and a number of tertiary canals was measured using a current metre and recorded. Table 5.1 of Appendix 5 shows discharges and conveyance efficiencies of Musa Mwinjanga main canal, Musa Mwinjanga and Mzee Kondo secondary canals and tertiary canals.

3.4.2 Field Canal Efficiency

The discharges at upstream and downstream of the quaternary canals in the selected sub-blocks were measured using a current metre and recorded. These data were used to estimate the field canal efficiency. Table 5.2 of Appendix 5 gives the discharges and efficiency of quaternary canals based on the data obtained from the field during the study period.

3.4.3 Field Application Efficiency

Actual areas of the sample plots PL1, PL3, PL5 (maize) and PL2, PL4, PL6 (paddy) in block I; plots PL7, PL10 (maize) and PL8, PL9 paddy) in block II; and plots PL11, PL12 (maize) in block III were estimated based on farmers interview. The water deliveries into the plots were measured and the duration of water applications, from the beginning to the end of each irrigation event were recorded. The current metre was used to measure deliveries into individual plots. Data obtained were used to estimate the field application efficiency. The water deliveries and application efficiencies are presented in Table 5.3 of Appendix 5.

3.4.4 Overall Project Efficiency

The overall project efficiency (Ep) represents the efficiency of the entire operation between the river diversion point (the scheme's intake weir) and the rootzone of the crops grown in the irrigated area. The project efficiency is the product of conveyance, field canal and field application efficiencies. In other words, it can be described as a combined efficiency of the distribution (a combination of conveyance and field canal) and application efficiencies.

3.5 Data Analysis

3.5.1 Canal Seepage Losses

The seepage losses in the Musa Mwinjanga main canal, Musa Mwinjanga and Mzee Kondo secondary canals and tertiary canals were calculated using the following expression:

$$Q_s = \frac{Q_u - Q_o - Q_d}{D} \times 1000 \qquad (1)$$

Where:

Q_s = Seepage loss within a one kilometre reach (l/s/km);

Q_u = Discharge at upstream section of the measured reach (l/s);

Q_o = Sum of all Discharges abstracted from the measured reach of the canal (l/s);

Q_d = Discharge at downstream section of the measured reach (l/s);

D = Distance apart between the two sections of the measured reach (m).

3.5.2 Basic Infiltration Rate

The infiltration data were analysed using standard procedures (Walker and Skogerboe, 1987) to determine the steady-state infiltrability which was taken as an estimate for deep percolation losses.

Natural logarithms of the measured accumulated values of infiltration depths (**D**) and time elapsed (**T**) were determined. The relationship between the accumulated infiltration depths and their corresponding accumulated time elapsed were determined using linear regression analysis. The regression constant (**C**) and the slope (**n**) of the straight lines that best fit the two variables were determined.

The relationship between the accumulated time elapsed (**T**) and the accumulated infiltration depth (**D**) was determined through the expression:

$$D = C \times T^{n} \tag{2}$$

Where: **D** = Accumulated infiltration depth (mm);

T = Time elapsed (min);

C = Constant;

n = Constant.

The infiltration capacity curve (I) was represented by the following expression:

$$I = 60 \times C \times n \times T^{n-1} \tag{3}$$

Where: **I** = Soil infiltration capacity (mm/h);

T = Time elapsed (min);

C = Constant;

n = Constant.

The time elapsed to arrive at the basic intake rate was given by the equation:

$$T = 600 \times (n-1) \tag{4}$$

Where: **T** = Time elapsed (min);

n = Constant.

The basic infiltration rate (I_b) was then determined from the expression:

$$I_b = 60 \times C \times n \times [600 \times (n-1)]^{n-1} \tag{5}$$

Where: I_b = Soil infiltration capacity (mm/h);

C = Constant;

n = Constant.

3.5.3 Dependable Rainfall

Dependable rainfall is the rainfall that can be expected at a set number of years out of a total number of years. The weekly dependable rainfall were derived from 26 years of record (i.e. 1970-1995) using INSTAT Program developed by Stern et al. (1992). Dependable rainfall at 80% probability of exceedance were used to determine effective rainfall. Figure 3.6 shows the values of weekly dependable rainfall for wet, normal and dry years.

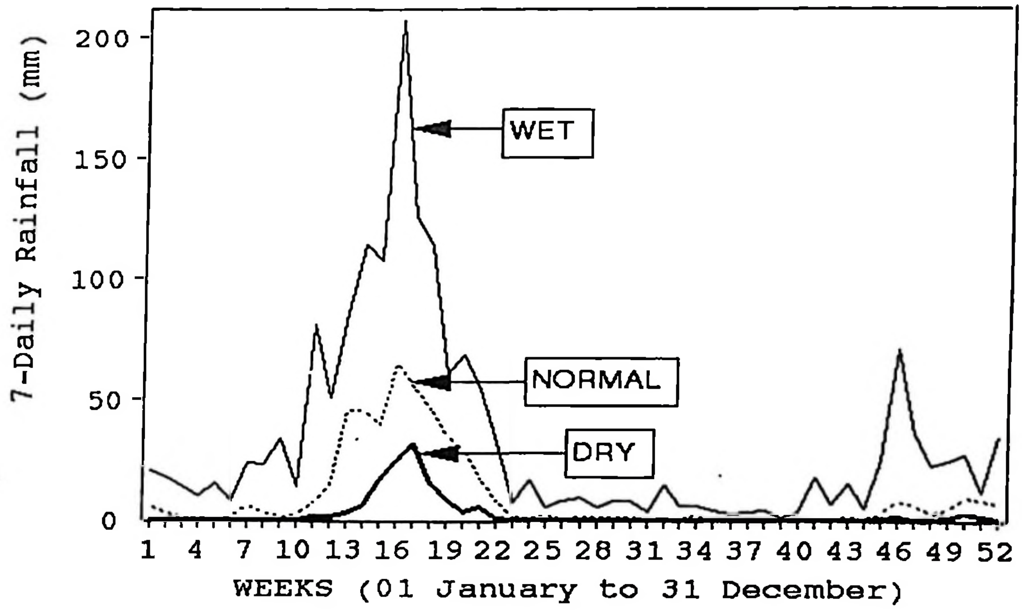


Fig 3.6 Weekly Dependable Rainfall (at 20%, 50% and 80% Probability of Exceedance)

3.5.4 Effective Rainfall

The effective rainfall (**P_e**) is the fraction of rainfall that is effectively used by the plant-soil system for evapotranspiration. A number of empirical formulae have been developed for estimation of **P_e**. Effective rainfall was estimated using the USDA SCS (1969) approach (Abdulmumin et al., (1991), where the weekly dependable rainfall values (section 3.5.3) were the main input to the model. The **P_e** values were used to determine the net and gross irrigation requirements and irrigation efficiencies. However the RWS and CRWS were determined using actual rainfall received during the season.

3.5.5 Dependable Flow

Dependable flow is the flow that can be expected at a set number of years out of a total number of years and was determined on daily basis. The catchment area ratio method was used to transfer the daily flow data from station 1 DD 6A to the scheme intake location. This was done by multiplying the daily flows by the catchment area ratio. RAINBOW Program (Raes et al., 1990) was used to estimate dependable flows (at 80% probability of exceedance) at the scheme intake. Table 6.1 of Appendix 6 gives the estimate of daily dependable flows at the scheme intake derived from data of gauging station 1 DD 6A. Figure 3.7 shows the dependable river flows pattern (at 80% probability of exceedance) at scheme intake derived from 11 years of record. These values were compared with the granted water right and what was actually being abstracted vis-a-vis irrigation water requirements.

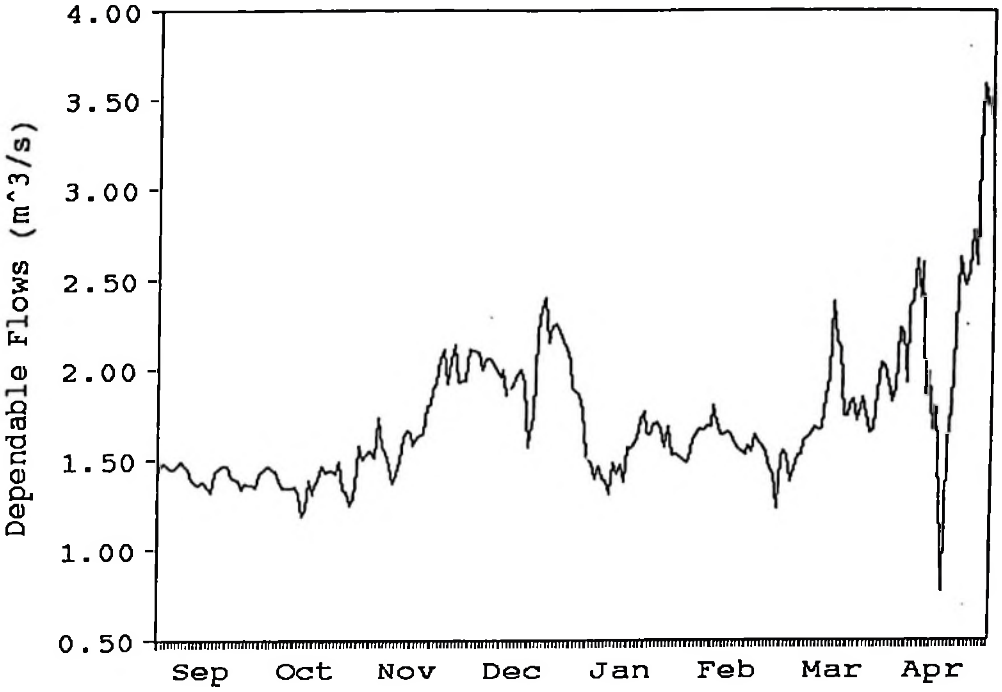


Fig. 3.7 Dependable Flows at Musa Scheme Intake

3.5.6 Irrigation Water Requirement

Based on the cropping patterns adopted by farmers during the study period, the irrigation water requirement of Musa Mwinjanga irrigation scheme was estimated on daily basis using daily climatic data according to the method recommended by Doorenbos and Pruitt (1977). This is done through stepwise procedure involving the calculation of the reference crop evapotranspiration (ET_o), the crop water requirement (ET_c) and the values for crop coefficients (K_c), effective rainfall (P_e), leaching requirements (LR) and efficiency.

(a) Reference Crop Evapotranspiration (ET_0)

The **ET_0** can be defined as the rate of water used by a standard crop of grass growing under optimum condition (Raes, 1996*a*). It is a measure of the effect of climatic condition on crop water use. The climatic data necessary for estimating the **ET_0** were collected from Moshi airport meteorological station. The climatic version of the INSTAT program was used to calculate **ET_0** (Table 7.1 of Appendix 7) using the modified Penman method according to Doorenbos and Pruitt (1977).

(b) Crop Water Requirement (ET_c)

The **ET_c** is defined as "the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in a large field under non-restricted soil condition, including soil water and fertility, and achieving full production potential under the given growing environment". It was derived from the **ET_0** calculated from climatic data and **K_c** values for the different crop growth stages. The **ET_c** was estimated as:

$$ET_c = ET_o \times K_c \tag{6}$$

Where: **ET_c** = Crop water requirement (mm/day);

ET_0 = Reference crop evapotranspiration (mm/day);

K_c = Crop coefficient.

(c) Net Irrigation Requirement (I_n)

(I_n) was estimated using the general expression:

$$I_n = ET_c - P_e \qquad (7)$$

for upland crops; and

$$I_n = ET_c - P_e + SP \qquad (8)$$

for low land paddy rice.

Where: I_n = Net irrigation requirement (mm/day);

ET_c = Crop water requirement (mm/day);

P_e = Effective rainfall (mm/day);

SP = Seepage and percolation (mm/day).

(d) Leaching Requirement (LR)

The accumulation of salts in the root zone is referred to as soil salinity. The level of salinity is mostly affected by the quality of irrigation water, soil factors affecting drainage, the availability of water (rainfall) to leach the profile, method of irrigation and the prevailing cultural practices (Abdulmumin et al., 1991). The **LR** can, therefore, be defined as the minimum amount of irrigation water that must percolate below the rootzone in order to maintain soil salinity at a given crop tolerant level. It is a function of drainage characteristic. The **LR** requirement was calculated as:

$$LR = \frac{EC_w}{5 \times EC_e - EC_w} \times \frac{1}{E_l} \tag{9}$$

Where: **LR** = Leaching requirement;

EC_w = Electrical conductivity of irrigation water (mS/cm);

EC_e = Electrical conductivity of the soil saturation extract corresponding to the yield level, that can be tolerated for the particular crop (mS/cm);

E_l = Leaching efficiency (fraction).

(e) Crop Irrigation requirement

The irrigation requirement of a crop was obtained by the equation:

$$\frac{I_n}{1-LR} \tag{10}$$

(f) Conveyance Efficiency

Conveyance efficiency is the efficiency of the main, secondary and tertiary canals to convey water from the scheme's headworks to the block inlets. This is calculated as the ratio of water received at the block inlet to the water delivered at the headworks (intake). The conveyance efficiency was calculated as:

$$E_c = \frac{Q_d + Q_2}{Q_c + Q_1} \tag{11}$$

Where: Q_1 = Discharge inflow from other sources (l/s);

Q_2 = Non-irrigation deliveries from conveyance system (l/s);

Q_c = Discharge diverted at the headworks (l/s);

Q_d = Discharge delivered at block inlets (l/s);

E_c = Conveyance efficiency.

(g) Field Canal Efficiency (E_b)

The E_b is the efficiency of quaternary canals to convey water from the block inlets to the field inlets. It is defined as the ratio of water received at the field inlet to water received at the block inlet. The farm efficiency was calculated as:

$$E_b = \frac{Q_f + Q_3}{Q_d} \tag{12}$$

Where: E_b = Field canal efficiency;

Q_f = Discharge furnished into the fields (l/s);

Q_3 = Non-irrigation deliveries from the quaternary system;

Q_d = Discharge delivered into the quaternary canals system.

(h) Field Application Efficiency (E_a)

The **E_a** is defined as the ratio of actual volume of water required in the field (for crop needs) to the total volume of water applied in the field. The field application efficiency was calculated according to Bos and Nugteren (1982) approach as follows:

$$E_a = \frac{V_f}{V_m} \tag{13}$$

Where: E_a = Field application efficiency;

V_m = Volume of irrigation water furnished into the fields (l);

V_f = Volume of water needed for crop evapotranspiration (l).

(i) Overall Project Efficiency (E_p)

The E_p was estimated as a product of water conveyance, field canal and application efficiencies. This can also be estimated as a product of water distribution and application efficiencies.

3.5.7 Water Supply Requirement (Q)

Irrigation water supply requirement (Q) was calculated as:

$$Q = \frac{10}{E_p} \times \sum \frac{A \times I_n}{1 - LR} \qquad (14)$$

Where:
Q = Supply requirement (m^3/irrigation interval);
A = Acreage under a given crop (ha);
LR = Leaching requirement;
E_p = Overall project efficiency.

3.5.8 Irrigation Scheduling

Alternative irrigation schedule based on available water supplies and land under irrigation was prepared. IRSIS Program (Raes et al., 1988) was used to determine the irrigation schedule for upland crops. BIRIZ Program (Raes, 1996*b*) was used to prepare the irrigation schedule for paddy rice. Also an evaluation of the irrigation scheduling as practised by the farmers was done using the IRSIS Program. Alternative schedule and the scheduling actually practised by the farmers were then compared.

3.5.9 Adequacy of Irrigation Water Supply

The adequacy of water delivery is a measure of the reliability of supply and, in turn, a measure of the quality of system operation (Sakthivadivel et al.,1992). Volume of water deliveries (water depth), effective rainfall (assumed total rainfall), net irrigation requirements and seepage and percolation were used to assess the adequacy of irrigation water for the irrigated plots in the selected blocks. This was done by computing both relative water supplies (RWS) and the cumulative relative water supplies (CRWS). The adequacy of water supply was evaluated from the following expression:

$$RWS = \frac{IW+P_e}{E+SP+LSP} \tag{15}$$

For land preparation in paddy fields.

$$RWS = \frac{IW+P_e}{I_n+SP} \tag{16}$$

For paddy crop growth period.

$$RWS = \frac{IW + P_e}{I_n} \tag{17}$$

For upland crop.

Where: **RWS** = Relative Water Supply;

IW = Irrigation Water delivery (mm);

P_e = Effective Rainfall (mm);

I_n = Net Irrigation Requirements (mm);

SP = Seepage and Percolation (mm);

LSP = Land soaking and ponding (mm);

E = Evaporation (mm).

During the time of field data collection, most of paddy fields were already transplanted with rice hence no data on land soaking and ponding were collected. The RWS for land preparation in paddy fields were based on the SP value computed by Koirala (1990) for the Musa irrigation scheme.

4. RESULTS AND DISCUSSION

This chapter presents and discusses the results of the study undertaken to assess the causes and effects of problems emanating from rehabilitation of FMIS with particular reference to Musa Mwinjanga irrigation scheme; aimed at setting the stage for seeking appropriate solutions and provide a basis for setting guidelines for implementing future rehabilitation works. The results include: (i) the causes and magnitude of water losses in the system; (ii) irrigation water supply requirements; (iii) water management aspects of the system.

4.1 Irrigation and Drainage

The history, lay-out and description of the scheme have been well elaborated elsewhere (Chapman, 1986; Abdel-Dayem, 1990; Kips and Ndondi, 1990; Koirala, 1990). A short review of these reports with additional information based on the farmers interview and actual field observations, measurement and results are given below.

4.1.1 Existing Irrigation System

The scheme net area commanded by the canal systems was estimated at 600 ha (i.e. 398 ha of upland crops and 202 ha of paddy). The source of water for irrigation is from Weruweru river where water diversion is effected by means of a concrete weir built across the river, through a gated intake structure in which the main canal follows the right bank of the river. The peak design discharge of the intake was estimated at 850 l/s. The scheme layout of the present irrigation system is shown in Figure 3.5 of chapter 3.

The first offtake MMC/TC1 is located at a distance 310 m down stream of the intake. It commands a net area of about 40 ha (maize 25 ha of upland crops and 15 ha of paddy) in the north western part of the scheme. The offtake was constructed by the KZIU during rehabilitation to supply water continuously to both Dutu (MMC/TC11) and Kaurwa (MMC/TC12) tertiary canals. The designed capacity of the offtake was estimated at 60 l/s during peak irrigation requirements envisaged to command a net area of 52 ha. The check and turnout gate constructed within the vicinity of this offtake were damaged and are not operational. Wheels and locking mechanism including spindles were damaged. The V-notch weir installed for measuring the amount of water discharged through the offtake into tertiary canals (MMC/TC11) and (MMC/TC12) are also damaged. It was observed that the abstractions to the fields commanded by offtake MMC/TC1 are made directly from the tertiary canals without division boxes.

There is an illegally constructed quaternary canal at 10 m upstream of offtake MMC/TC1. The canal abstracts water directly from the main canal through ungated structure and commanding an area of about 1 ha of onions. This area was not considered as part of the irrigation service area but was left for rainfed agriculture. The farmer used to block the main canal at the existing culvert so as to create enough head to irrigate his field. This practice has caused serious damage to the main canal and access road upstream of offtake MMC/TC1.

The second offtake was constructed at chainage 580 m downstream of the intake structure. This offtake supplies water to tertiary canal MMC/TC2 commanding an area of 3 ha of maize. The offtake was designed to abstruct a maximum discharge of 29 l/s estimated to command a net area of 8 ha of upland crops. The check cum turnout structure constructed during rehabilitation is still in good operational condition. The V-notch weir installed was silted up making it difficult to measure the amount of water abstractions into tertiary canal MMC/TC2. The tertiary canal was full of weeds/grasses and silt deposition.

The third offtake is located at chainage 750 m down stream of the intake. This offtake draws off water from the main canal into tertiary canal MMC/TC3 commanding an area of 4.2 ha of maize. The design discharge of this offtake was estimated at 37 l/s expected to irrigate 5 ha of upland crops. The offtake which includes a check, turnout and V-notch weir is still operational. The tertiary canal MMC/TC3 was found full of weeds/grasses. This has caused blockage and decreased velocity resulting in frequent overtopping of canal banks and wastage.

The tertiary Canal MMC/TC3 was not fully excavated. The reason behind is the presence of a big depression across the path of the canal which requires a huge volume of earth fill. The canal was designed to irrigate areas on the left bank of MKSC which are still under rainfed agriculture. Despite the farmers joint efforts to fill the depression, they have not yet succeeded. This operation requires the use of heavy earth moving equipment like bulldozer, wheel loader and trucks of which the farmers are not capable of hiring. According to the farmers, the depression was left unfilled during rehabilitation due to breakdown of the bulldozer owned by the KZIU. The farmers, through their leaders, are communicating with various Government and private institutions for assistance to acquire the earth moving equipment to carry out the earthwork operation.

Another canal, illegally excavated 6 m upstream of offtake MMC/TC3, conveys water directly into the river without commanding any peace of land. Due to this negligence about 30 l/s is continuously lost which would otherwise be used to irrigate crops at the downstream areas.

There is a combination of check drop, turnout and a reinforced concrete Parshall flume at chainage 920 m. The Musa Mwinjanga main canal terminates at this point. The flow is divided between two major branches i.e. the Mzee Kondo secondary canal MMC/MKSC and Musa Mwinjanga secondary canal MMC/MMSC. The fourth offtake supplies water to Mzee Kondo secondary canal MMC/MKSC by means of a gated structure constructed during phase I of the rehabilitation program. The secondary canal (MMC/MKSC), which commands more than half of the scheme area, flows across the contours traversing through to the south and terminates near the Weruweru and Kikafu rivers confluence. Delivery through the offtake commands about 380 ha (220 ha of upland crops and 160 ha of paddy). The offtake was designed to abstract 404 l/s during peak to irrigate a net area of 320 ha (i.e. 220 ha of upland crops and 100 ha of paddy) on continuous basis. The offtake is in good operational condition except the reinforced concrete parshall flume which measures discharges to MMC/MKSC lacks a meter gauge in its stilling chamber which makes it difficult to know the exact amount of water delivery into the secondary canal MMC/MKSC. There are seven tertiary canals (Dismas, Barabarani, Joseph, Ali, Msikitini, Tumbo and Lewi) abstracting water from both sides of secondary canal MMC/MKSC with other fields getting water directly from the secondary.

Musa Mwinjanga secondary canal MMC/MMSC gets its share through the check drop commanding a net area of about 121 ha of both paddy and upland crops. The canal flows parallel to Weruweru river and terminates near the Weruweru and Kikafu rivers confluence. The design capacity of the check was estimated at 320 l/s. The canal feeds a number of tertiary and quaternary canals along its way. There are five offtakes constructed during phase I of rehabilitation program designed to abstract water from the Musa Mwinjanga secondary canal. These canals are estimated to irrigate a total of 104 ha (i.e. 31 ha of upland crops and 73 ha of paddy). On the other hand, there are over 50 farmes' locally diverted offtakes abstracting water directly from Musa Mwinjanga secondary canal. These offtakes feed water to short branch canals which are mostly shallow and full of weeds. These offtakes were estimated to command about 111 ha located on the eastern to south eastern part of the scheme area.

The two in one offtakes (i.e. fifth and sixth offtakes) are located at chainage 1,150 m. The fifth offtake supplies water to tertiary canal MMSC/TC5 commanding a net area of 2.1 ha of maize. The design capacity of this offtake was estimated at 29 l/s to command a net area of 4.0 ha of upland crops. The sixth offtake was designed to command a net area of 1.5 ha with design capacity 11 l/s. The offtake has never been put into operation because the tertiary canal MMSC/TC6 is yet to be excavated. All water control structures at this location are still good operational condition except for a V-notch weir installed at tertiary canal MMSC/TC5 which needs to be repaired.

There are two branch canals offtaking from Musa Mwinjanga secondary canal which were illegally excavated between chainage 920 m and 1,150 m. Both branch canals command a total net area of about 3 ha. This area was left uncommanded due to the effect of the depression mentioned above. The first branch commands about 2 ha of maize. A substantial length of the access road has been affected as a result of uncontrolled water from this branch canal which commands a net area of 1 ha. The abstractions to these branches are effected by means of locally diverted offtakes.

The seventh offtake is located at chainage 1,450 m. The offtake was designed to command a net area of 16.5 ha (i.e. 6.5 ha upland crops and 10 ha of paddy). The designed discharge of the offtake was estimated at 40 l/s. The offtake is currently commanding a net area of only 9.5 ha (i.e. 6 ha of maize and 3.5 ha of paddy). The turnout, check and V-notch structures at this location were all damaged beyond repair. The abstractions are currently effected by traditional means (i.e. pegging sticks) to divert water into the tertiary canal MMSC/TC7.

The eighth offtake is located at chainage 1,800 m. It was designed to supply water to tertiary canal MMSC/TC8 with the designed discharge of 80 l/s. This canal was expected to command a net area of 69 ha (i.e. 9 ha of upland crops and 60 ha of paddy). It was observed that the tertiary canal MMSC/TC8 commands a total of 72 ha (i.e. 20 ha of upland crops and 52 ha of paddy) at present. The water control structures at this offtake are still operational except for the check gate that needs to be repaired.

The ninth offtake is located at chainage 1,900 m. This offtake was designed to supply water to tertiary canal MMSC/TC9. The designed discharge through the offtake was estimated at 32 l/s to irrigate a net area of 13 ha (i.e. 10 ha of upland crops and 3 ha of paddy). The tertiary canal MMSC/TC9 is presently commanding a net area of 16 ha (i.e. 12 ha of upland crops and 4 ha of paddy). The water control structures at this offtake are not functioning well due to the damage inflicted on the operating gates.

A number of farmers' locally diverted offtakes exist downstream of chainage 1,900 m. These offtakes abstruct water directly from MMSC to command a total area of about 80 ha of mainly upland crops. No permanent water control structures were built during the phase I of the rehabilitation program. The net area envisaged to be commanded by these offtakes was estimated at 111 ha (i.e. 108 ha of upland crops and 3 ha of paddy).

4.1.2 Soil

A detailed soil survey for the scheme was carried out in the year 1989/90 by the National Soil Service (NSS) at the request of the project URT/86/017 (Rehabilitation of traditional irrigation projects). The most important findings of the surveys are summarized below with additional discussions based on the field observation and the results of the soil samples collected from the field during the study.

The soils within the scheme were grouped according to their physiographic units (Fig. 2.1 of Appendix 2). Four broad physiographic units were identified namely Volcanic outwash plain (O-soils), shallow bottom land or Mbuga (B-soils), river flood plain (R-soils) and foot slope of minor scarp (F-soils). All soils are relatively young and only slightly weathered. They differ in depth, drainage, texture, and sodicity levels and are non saline.

The soils of the Volcanic outwash plain (O-soils) are mostly dark in colour with uniform texture and moderately structured. Textures range from clay to silt loam and sandy loam. Most of these soils are well drained. However, the soils of the shallow depressions in the centre of the outwash plain are somewhat poorly drained because of their reduced topsoil as a result of prolonged wet land rice cultivation.

A layer of cemented gravel and tuffite (re-deposited and cemented fine Volcanic ash) was found at varying depth below the soil profiles. The presence of this layer at shallow depth obstructs root growth and forms a drainage barrier giving rise to perched ground watertable. The shallow soils (20-50 cm thick) occupy about 8% of the scheme area. The rest of the area is covered by soil profiles varying between moderately deep (50-100 cm thick) to very deep (> 150 cm thick).

The soils of Mbuga (B-soils) are poorly drained clays with shallow ground water levels. They are dark brown and dark grey in colour representing typical rice soils. The soils are very deep and have sodic properties.

The soils of the river flood plain (R-soils) are well drained and dark brown in colour. They are periodically receiving fresh sediments during flood. The flood plain soils are layered with predominantly loamy and silty textures and small sandy lenses in places.

The soils of the foot slope of minor scarp (F-soils) are very deep, well drained and reddish brown clays.

The test in 1:2.5 soil extract revealed very low electrical conductivity in both topsoil as well as subsoils. Table 4.1 gives the electrical conductivity results of the soil samples collected during the field study. The results (Table 4.1) show that the levels of electrical conductivity for soil types O1, O4, O8 and O11 range between 0.09 and 0.28 mS/cm. Kips and Ndondi (1990) reported the values as ranging between 0.06 and 0.29 mS/cm in O-soils, 0.13 and 0.64 mS/cm in B-soils, 0.12 and 0.17 mS/cm in R-soils and 0.11

mS/cm in F-soils. The results indicate that there has been no significant change in the levels of electrical conductivity of the scheme soils for the past 7 years. Table 2.1 of Appendix 2 shows the fertility analysis results of the scheme soils taken at 0-20 cm depth based on the soil surveys carried out by the NSS in March 1989.

Table 4.1 **Results of Electrical Conductivity Levels of Soils in Musa Mwinjanga Scheme**

Depth (cm)	0-10	10-35	35-55	55-80	80-115	115-140	
Soil Type	mS/cm						Average
O1	0.24	0.12	0.06	-	-	-	0.14
O4	0.15	0.10	0.08	0.07	0.09	-	0.10
O8	0.42	0.20	0.22	-	-	-	0.28
O11	0.24	0.08	0.05	0.06	0.05	0.05	0.09

Kips and Ndondi (1990) described the infiltration rates in the scheme soils with respect to depth and texture of the soils and with sodicity levels. According to their report, the infiltration rates vary from very low (1 to 3 mm/h) in the paddled clay rice growing soils of mapping unit O3, 07, O8 and B2 to moderately rapid (66 to 88 mm/h) in the silt loams of unit O13 and the sandy loams of unit O14.

The soil infiltration test was carried out during the field study. Two tests were performed in soils of each of the four mapping units mentioned above. Table 4.2 gives the results of the basic infiltration rates of the scheme soils of mapping units O1, O4, O8 and O11. From the results (Table 4.2), it can be concluded that there is no significant difference between the basic infiltration rates obtained during the rehabilitation and those prevailing at present.

Table 4.2 Basic Infiltration Rates of Musa Mwinjanga Irrigation Scheme Soils (Mapping Units O1, O4, O8 and O11)

Mapping Unit	Basic Infiltration Rates (mm/h)			
	Site No. 1	Site No. 2	Average	1989/90
O1	53.1	53.6	53.4	54.0
O4	37.6	29.2	33.4	34.0
O8	4.4	7.7	6.1	3.0
O11	28.1	26.2	27.2	28.0
Average	30.8	29.2	30.0	29.8

4.1.3 Irrigation Water Quality

Kips and Ndondi (1990) described the quality of water for the scheme after the laboratory analysis of the samples taken from the main canal near the intake structure, Mzee Kondo and Musa Mwinjanga secondary canals as having low electrical conductivity (Table 3.1 of Appendix 3). The electrical conductivity ranged between 0.17 and 0.18 mS/cm indicating that the irrigation water has a low salinity hazard. Table 4.3 gives the results of water quality for the scheme as obtained during the field study. From the analysis results (Table 4.3) it can be concluded that there are no significant changes on the levels of electrical conductivity of irrigation water in the past seven years.

Table 4.3 Results of Electrical Conductivity Levels of Irrigation Water at Musa Mwinjanga Scheme

Location	Sample No.	Ecw (mS/cm)
Musa Mwinjanga Main Canal		
- Close to the intake	MMC1	0.172
- At Chainage 310 m	MMC2	0.173
- At Chainage 520 m	MMC3	0.174
- At chainage 920 m	MMC4	0.174
Mzee Kondo Sec. Canal		
- Close to the offtake	MKSC1	0.174
- At chainage 500 m	MKSC2	0.178
- At chainage 1500 m	MKSC3	0.183
Musa Mwinjanga Sec. canal		
- Close to the offtake	MMSC1	0.174
- At chainage 500 m	MMSC2	0.177
- At chainage 150 m	MMSC3	0.182

4.1.4 Water Right and Water Abstractions

The water utilization (control and regulation) act was inacted in the year 1974 and then supplemented by a subsidiary legislation in the Government Notice No. 242 published in October, 1975. During the period, the total number of water rights in Weruweru river system was 36 of which the abstractions amounted to about 3.86 m^3/s (JICA, 1989).

The discharge of the Weruweru river in the dry season, however, often falls below the water rights' amount. The reasons for water shortage may be attributed to withdrawal of water by existing or new furrows and insufficient rainfall in the upper catchment in recent years. It is, therefore, important to have discussions and careful adjustment between the agencies concerned, when any development projects including rehabilitation of irrigation facilities are planned.

The Musa Mwinjanga irrigation scheme has a water right granted by the authority of only 0.014 m^3/s (JICA, 1989). In 1990, the village authority had requested the Government for a total water right amounting to 0.6 m^3/s. Nevertheless the Government has kept silent and no action has been taken so far to grant the requested water right. During the rehabilitation phase, the scheme gross irrigation water requirement was determined as 0.85 m^3/s expected to meet the crops' needs in the peak month of January. The actual amount of water abstractions through the intake weir to irrigate the scheme area can, at present, be estimated on the bases of the average monthly spot discharge measurements shown in Table 4.4. However, it is difficult to estimate the amount of water abstractions into the secondary, tertiary and quaternary canals. This is due to the absence of discharge measuring facilities at canal heads. Most of the V-notch weirs installed during rehabilitation were either silted up or damaged by farmers and were not operational.

Table 4.4 Average Monthly Mean Abstractions at Musa Mwinjanga Intake

Month	Discharge (l/s)			
	1988[1]	1989[1]	1990[1]	1995/96[2]
January	-	464	-	470
February	-	480	-	471
March	-	380	307	476
April	-	-	-	-
May	-	-	-	-
June	-	-	-	-
July	-	368	-	-
August	-	463	-	-
September	-	463	-	-
October	-	582	562	-
November	-	-	473	494
December	428	-	-	484

[1] Monthly spot measurements carried out by the KZIU.

[2] Average abstractions measured during the field study.

\- No measurements were taken.

4.2 Cropping Pattern and Calendar

Cropping pattern can be defined as the arrangement of crops in sequence on a particular land in a given growing season; whereas the cropping calendar shows the schemes of planting and reaping.

There is not any fixed cropping pattern at Musa Irrigation scheme. Individual farmers are free to plant any type of crop according to their preference. However, based on the farmers interview, a semblance of the cropping pattern of the scheme is briefly outlined in the following paragraphs.

The main wet season crop is maize which is normally planted with rains in mid to end of march and harvested in mid to end of July. Maize is normally intercropped with dry beans or groundnuts, planted after the first weeding of maize i.e. two weeks after sowing of maize. These crops are basically rainfed but supplementary irrigation is necessary due to rainfall unreliability and uneven distribution. Vegetable crops like tomatoes and onions are also grown during wet season though in small proportions.

Paddy is the second main wet season crop normally planted in seed beds early to end of December. The transplanting is done from early January to mid February and harvested from mid May to mid June. Paddy is planted in bunded fields in the Mbuga and imperfectly drained parts of the O-soils. Most of the paddy fields observed were neither puddled nor levelled. Depending on the availability of labour, beans are planted on the O-soils early July, after harvesting of paddy, thus utilizes the available residual moisture of the soil.

Maize is also the main dry season crop. This is normally planted from mid to end of October and harvested around mid February to early March. Maize is sometimes intercropped with beans during the dry season. however there are cases whereby beans are grown in pure stands.

Paddy is the second main dry season crop which is usually planted in seed beds from mid May to mid June. The transplanting is done around mid July to mid August and harvested from mid November to mid December.

The total irrigated area during the dry season is smaller compared to that irrigated during the wet season. This is due to limited water availability during the dry season.

In addition to the seasonal crops mentioned above, there are several perennial crops found scattered around the study area. These include fruit trees like citrus, mango and banana. Banana is the only crop being irrigated among the perennial crops found in Musa Mwinjanga scheme area.

According to Chapman (1986) the cropping intensity of the scheme is 110%. Agro-economic performance report (Koirala, 1990) estimated the total cultivated area during the wet season at 543 ha with an annual cropping intensity of 154%. The total cropped area in the scheme during the wet season, according to the design notes at KZIU, is 600 ha with a corresponding annual cropping intensity of 133%. However, based on the farmers interview and field observations, the irrigated area can be estimated at 500 ha (wet season) and 320 ha (dry season) with a corresponding annual cropping intensity of 136%.

4.3 Irrigation Water Management

Proper rehabilitation of FMIS provides the means to control water abstractions. It helps to improve the hydraulic performance of the irrigation and drainage canals system and leads to a decrease in the water losses and an increase in the commanding area. The objective of rehabilitation is to improve the traditional irrigation schemes in three ways (Baban, 1994): (i) to secure reliable source of irrigation water by rehabilitating permanent intake weirs; (ii) rehabilitation of canals system in order to increase efficiencies; (iii) increase field irrigation efficiency through proper training of field extension staff and farmers.

Although the project URT/86/017 has succeeded in achieving the first goal through rehabilitation of the intake weir, there is not much evidence that the second and the third goals have been achieved. Apart from the rehabilitation of Musa Mwinjanga main canal, control structures at the heads of Musa Mwinjanga and Mzee Kondo secondary canals and a few tertiary canals, most of the tertiary and quaternary canals are still in poor operating condition. As a result farmers are using water without proper control.

About 90 percent of all water control structures (i.e. the gated offtakes, checks and measuring devices) constructed during rehabilitation have been damaged and are not operational. The information obtained from the KZIU has revealed that, minor rehabilitation works were carried out in the year 1991 to re-install the damaged facilities. Despite the effort made by the executing agency, the farmers had again repeated the same malpractice of cannibalising the re-installed facilities. The absence of effective water distribution and control structures has compounded the difficulty of water allocation and control.

It was observed that the secondary and most of the tertiary canals were of irregular cross sections with small capacities and large wetted areas. Most of these canals were excavated below the ground surface and have no command over the adjacent lands. It is a common practice to see a farmer blocking the canal by means of wooden sticks, mud and banana leaves so as to create water head just enough to command his/her field.

4.4 Irrigation Water Requirements

Two cropping seasons can be identified in the scheme area. The wet season is from December to July during which about 65% of the annual precipitation falls (Table 1.1 of Appendix 1). According to the farmers, irrigation is mainly supplementary especially during the sowing and germination stages in wet cropping season. The cropping intensities are expected to be higher during this season as the areas outside the command of the irrigation canals can be cultivated for rainfed crops. Chapman (1986) has reported that with supplementary irrigation the crop production may reach a 100% or more in the case of maize. The dry season extends from September to February. The area cultivated during this season is mainly dependent on the availability of irrigation water. Areas outside the canal commands and about half of the area within the canal commands often remain fallow during the dry season. The greater part of the affected fields are at the tail of the scheme. The results and discussions herein are based on the net irrigation requirements in the dry season.

The mean daily net irrigation requirements (**I_n**) were calculated after deducting the corresponding rainfall from the crop water requirements in that particular day during the growing season. The average value of 3.4 mm/day was added to account for seepage and percolation losses (SP) during crop maintenance period in paddy field plots. The value of 9.0 mm/day was added to account for seepage during the 20 days land preparation period. The **I_n** were determined based on the planting dates of crops grown in the selected field plots PL1, PL3, PL5, PL7, PL10, PL11 and PL12 (maize); and PL2, PL4, PL6, PL8 and PL9 (paddy). The daily maximum $\mathbf{I_n}$ values derived from the selected maize and paddy field plots were assumed to represent the mean daily net irrigation requirements for the season. These values were used in the analysis of irrigation supply requirements. Tables 4.5 and 4.6 present the results of weekly mean daily and weekly total net irrigation requirements for maize and paddy respectively. Figure 4.1 and 4.2 give the patterns of the weekly mean daily net irrigation requirements for maize and paddy respectively as compared to $\mathbf{ET_c}$, $\mathbf{P_e}$ and **SP**.

From Table 4.5 and 4.6, and from Figure 4.1 and 4.2, it is clear that the peak net irrigation requirements for maize and paddy were found to be 5.7 mm/day (0.66 l/s/ha) and 15.0 mm/day (1.74 l/s/ha) respectively. The peak requirement for maize occurs in the second week of February whereas for paddy it occurs in the first week of October. Irrigation is fully required for maize and paddy during the season (i.e. from September to April).

Table 4.5 **Net Irrigation Requirements for Maize**

Month	Date	Week No.	ET_c		P_e		I_n		
			(mm/day)	(mm/week)	(mm/day)	(mm/week)	(mm/day)	(mm/week)	(l/s/ha)
Sep/Oct	27-03	1	1.7	5.1	0.0	0.0	1.7	5.1	0.20
Oct	04-10	2	1.7	11.9	0.0	0.0	1.7	11.9	0.20
	11-17	3	1.9	13.3	0.0	0.0	1.9	13.3	0.22
	18-24	4	2.0	14.0	0.0	0.0	2.0	14.0	0.23
	25-31	5	2.8	19.6	0.0	0.0	2.8	19.6	0.32
Nov	01-07	6	3.6	25.2	0.1	0.7	3.5	24.5	0.41
	08-14	7	4.3	30.1	0.4	2.8	3.9	27.3	0.45
	15-21	8	5.1	35.7	0.2	1.4	4.9	34.3	0.57
	22-28	9	5.2	36.4	0.0	0.0	5.2	36.4	0.60
Nov/Dec	29-05	10	5.1	35.7	0.2	1.4	4.9	34.3	0.57
Dec	06-12	11	4.9	34.3	1.4	9.8	3.5	24.5	0.41
	13-19	12	4.9	34.3	1.6	11.2	3.3	23.1	0.38
	20-26	13	4.9	34.3	0.5	3.5	4.4	30.8	0.51
Dec/Jan	27-02	14	5.1	35.7	0.0	0.0	5.1	35.7	0.59
Jan	03-09	15	5.1	35.7	0.0	0.0	5.1	35.7	0.59
	10-16	16	5.2	36.4	0.0	0.0	5.2	36.4	0.60
	17-23	17	5.3	37.1	0.0	0.0	5.3	37.1	0.61
	24-30	18	5.6	39.2	0.0	0.0	5.6	39.2	0.65
Jan/Feb	31-06	19	5.6	39.2	0.0	0.0	5.6	39.2	0.65
Feb	07-13	20	5.7	39.9	0.0	0.0	5.7	39.9	0.66
	14-20	21	5.5	38.5	0.0	0.0	5.5	38.5	0.64
	21-27	22	5.6	39.2	0.0	0.0	5.6	39.2	0.65
Feb/Mar	28-05	23	5.1	35.7	0.0	0.0	5.1	35.7	0.59
Mar	06-12	24	4.5	31.5	0.3	2.1	4.2	29.4	0.49
	13-19	25	3.6	25.2	0.6	4.2	3.0	21.0	0.35
	20-24	26	2.9	14.5	1.2	6.0	1.7	8.5	0.20
TOTAL				777.7		43.1		734.6	

Table 4.6 Net Irrigation Requirements for Paddy

Month	Date	Week No.	ET_c		P_e		S&P		I_n		
			(mm/day)	(mm/wk)	(mm/day)	(mm/wk)	(mm/day)	(mm/wk)	(mm/day)	(mm/wk)	(l/s/ha)
Sep	06-12	1	5.0	35.0	0.0	0.0	3.4	23.8	8.4	58.8	0.97
	13-19	2	5.3	37.1	0.0	0.0	5.1	35.7	10.4	72.8	1.20
	20-26	3	5.5	38.5	0.0	0.0	9.0	63.0	14.5	101.5	1.68
Sep/Oct	27-03	4	6.0	42.0	0.0	0.0	9.0	63.0	15.0	105.0	1.74
Oct	04-10	5	6.0	42.0	0.0	0.0	9.0	63.0	15.0	105.0	1.74
	11-17	6	6.3	44.1	0.0	0.0	5.1	35.7	11.4	79.8	1.32
	18-24	7	6.5	45.5	0.0	0.0	3.4	23.8	9.9	69.3	1.15
	25-31	8	6.2	43.4	0.0	0.0	3.4	23.8	9.6	67.2	1.11
Nov	01-07	9	6.0	42.0	0.1	0.7	3.4	23.8	9.3	65.1	1.08
	08-14	10	6.2	43.4	0.4	2.8	3.4	23.8	9.2	64.4	1.06
	15-21	11	6.1	42.7	0.2	1.4	3.4	23.8	9.3	65.1	1.08
	22-28	12	5.9	41.3	0.0	0.0	9.0	63.0	14.9	104.3	1.73
Nov/Dec	29-05	13	5.9	41.3	0.2	1.4	3.4	23.8	9.1	63.7	1.05
Dec	06-12	14	5.6	39.2	1.4	9.8	3.4	23.8	7.6	53.2	0.88
	13-19	15	5.6	39.2	1.6	11.2	3.4	23.8	7.4	51.8	0.86
	20-26	16	5.6	39.2	0.5	3.5	3.4	23.8	8.5	59.5	0.98
Dec/Jan	27-02	17	5.9	41.3	0.0	0.0	3.4	23.8	9.3	65.1	1.08
Jan	03-09	18	5.9	41.3	0.0	0.0	3.4	23.8	9.3	65.1	1.08
	10-16	19	5.9	41.3	0.0	0.0	3.4	23.8	9.3	65.1	1.08
	17-23	20	6.0	42.0	0.0	0.0	3.4	23.8	9.4	65.8	1.09
	24-30	21	6.4	44.8	0.0	0.0	3.4	23.8	9.8	68.6	1.13
Jan/Feb	31-06	22	6.4	44.8	0.0	0.0	3.4	23.8	9.8	68.6	1.13
Feb	07-13	23	6.5	45.5	0.0	0.0	3.4	23.8	9.9	69.3	1.15
	14-20	24	6.3	44.1	0.0	0.0	3.4	23.8	9.7	67.9	1.12
	21-27	25	6.5	45.5	0.0	0.0	3.4	23.8	9.9	69.3	1.15
Feb/Mar	28-05	26	6.6	46.2	0.0	0.0	3.4	23.8	10.0	70.0	1.16
Mar	06-12	27	6.6	46.2	0.3	2.1	3.4	23.8	9.7	67.9	1.12
	13-19	28	5.9	41.3	0.6	4.2	3.4	23.8	8.7	60.9	1.01
	20-26	29	5.2	36.4	1.2	8.4	3.4	23.8	7.4	51.8	0.86
Mar/Apr	27-02	30	4.6	32.2	4.1	28.7	3.4	23.8	3.9	27.3	0.45
Apr	03-04	31	4.3	8.6	1.7	3.4	3.4	6.8	6.0	12.0	0.69
TOTAL				1257.4		77.6		901.4		2081.2	

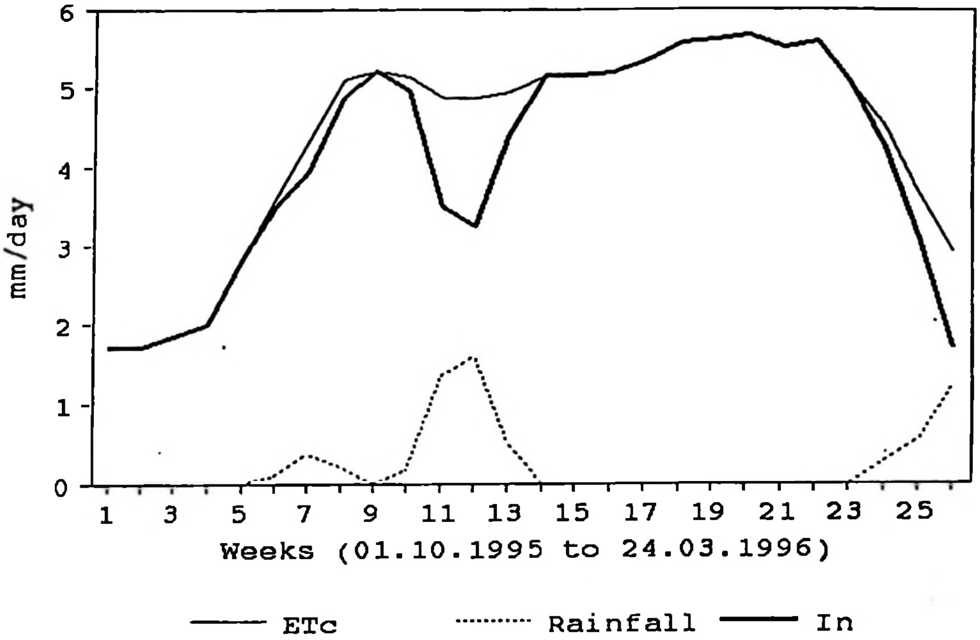


Fig 4.1 Weekly Mean Daily Net Irrigation Requirement of Maize

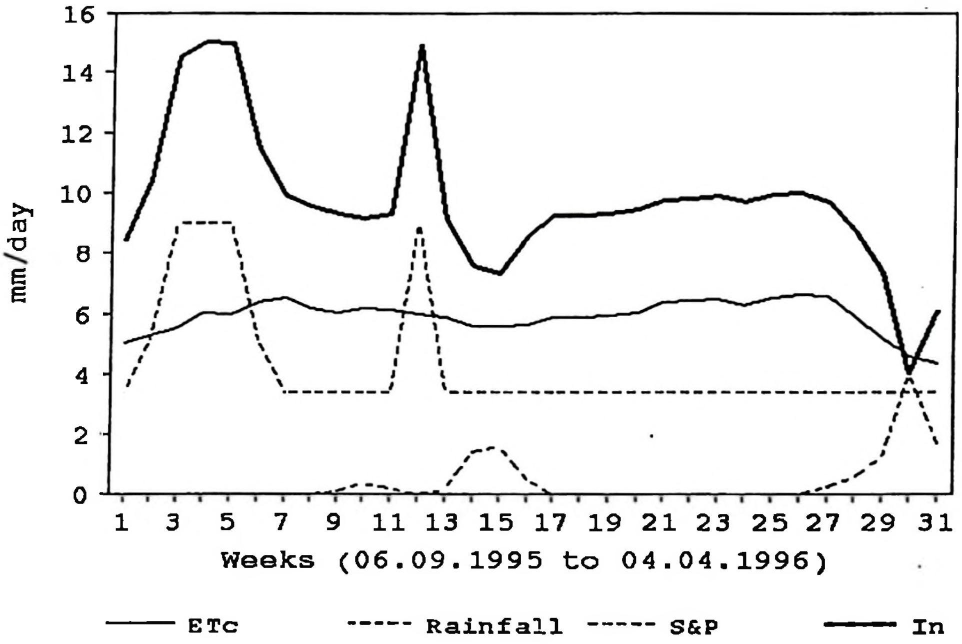


Fig. 4.2 Weekly Mean Daily Net Irrigation Requirement of Paddy

4.5 Irrigation Water Losses

The field measurements of canal water losses had the following objectives:

(i) to determine seepage losses from unlined canals and to locate reaches with excess seepage as a basis for lining considerations;

(ii) to determine the exact amount of water conveyed in the canal system during operation;

(iii) to determine the amount of water wasted during field application.

There are many irrigation canals of various lengths and sizes forming the irrigation canal systems of Musa Mwinjanga Irrigation scheme. Table 4.7 gives the total length of the main, secondary and tertiary canals at Musa Irrigation Scheme as estimated during the field study. Detailed irrigation water losses are presented in Tables 5.1 through 5.5 of Appendix 5. There are other quaternary canals which transport water to the field plots and their total length may considerably exceed the lengths of the main, secondary and tertiary canals put together (Fig. 3.5 of chapter 3).

Table 4.7 Estimated Lengths of the Main, Secondary and Tertiary Canals (Musa Mwinjanga Scheme)

Canal	Length (km)
Musa Mwinjanga Main Canal	
● Tertiary Canals	0.92
● Musa Mwinjanga Secondary canal	
- Tertiary Canals	4.77
● Mzee Kondo Secondary Canal	
- Tertiary Canals	3.53

Dayem (1990) estimated the length of the tertiary and lower level mapped canals in Musa Mwinjanga Irrigation Scheme at about 17,000 m compared with the 10,975 m length of main and secondary canals. His estimate was solely based on the 1:5,000 scaled topographical maps. During the field study period, the flow measurements were carried out in the main, secondary, a few tertiary canals and at the inlet to field plots with a view to determine the water losses.

4.5.1 Conveyance Losses

The seepage rate from the unlined canals depends mainly on the soil characteristics, depth of the soil profile and depth of the watertable in the vicinity of the canal. As already mentioned (section 4.1.2), the soil type of the scheme area varies widely. The basic infiltration rates of the soils range from 0.3 to 8.0 cm/h.

The canal conveyance losses are too high because of the pervious nature of volcanic soils and poor command due to most of canals running below the field levels. The results of conveyance losses based on inflow-outflow method are summarized in Table 4.8 and detailed in Tables 5.1 to 5.3 of Appendix 5.

Table 4.8 Canal Conveyance Losses at Musa Mwinjanga Scheme

Location	No. of Measurements	Length of Measured Reach (m)	Loss (%)
Musa Mwinjanga Main Canal	27	920	9.8
Musa Mwinjanga sec. Canal	5	275	9.7
Mzee Kondo secondary Canal	5	600	12.7
Tertiary canals	5	1 885	18.1

Although, it is apparent that the canals lose an appreciable amount of water, it should be expected that part of this water is recovered as return flow in a canal at a lower ground elevation. This can be ascertained by studying elevations, gradients, depths of barrier, canal layout and groundwater flow patterns which are beyond the scope of this study. It was difficult to estimate how much return flow occurs and its contribution to the total flow of the canals.

Canal losses are aggravated by canal erosion due to an increase in the wetted perimeter. This case was frequently happening in the scheme area and could be easily noticed. The erosion results from bad alignment, high velocities and erosion type of soils. Unculverted road crossings cause serious erosion problems, spillage and waste of water.

Other reasons of canal conveyance losses may be due to direct evaporation from water surfaces, which increases at the eroded canal sections due to the increased canal width. It was observed that farmers were not satisfactorily cleaning the canals despite the information obtained from the Water Committee of organizing this work once or twice a year. Bank vegetation was quite heavy specially near the intake structure and along both the main and secondary canals. Weeds in the canals and wild vegetation along the canal banks may consume a considerable part of the water conveyed by the canals through evapo-transpiration. It is believed that their water consumption can be justified by stability they provide to the canal banks (Abdel-Dayem, 1990).

Table 4.9 gives the results of the canal conveyance losses measured in other schemes in the Kilimanjaro region (JICA,1990) in small earthen canals using the ponding method for different lengths of the canals.

Table 4.9 Conveyance Losses in Other Small Earthen Canals

Canal length (m)	500	750	1000	1250
Conveyance (%)	6.4 - 9.1	9.8 - 14.2	13.5 - 19.6	17.3 - 25.6

4.5.2 Operational Losses

This type of losses is attributed mainly to lack of water control structures and absence of proper water management. As mentioned earlier, there is no clearly defined irrigation schedule or plan for operating the available gates at Musa Mwinjanga irrigation Scheme. Moreover, there are no discharge records available with the Water Committee to confirm what was happening before. Based on the average monthly abstractions shown in Table 4.4, it is evident that the scheme was not abstracting water according to the demands given in Tables 4.5 and 4.6.

4.5.3 Field Application Losses

Among the different factors which influence the magnitude of on-farm application losses are land levelling, irrigation method and water management. Land levelling, in the scheme area is very poor and it is a major reason for high application losses (Table 5.4 of Appendix 5). Farmers upstream use too much water than what is required for crop evapotranspiration. Excess water percolates through the profile and recharges the groundwater table which may rise to within the root zone and causes waterlogging in low-lying lands. Farmers on the high-lying lands practice the so called field-to-field irrigation whereby water moves from a plot up-slope to an adjacent plot down-slope through a cut on the levee/bund within a strip of paddy field plots. However, farmers on low-lying lands do not have such an opportunity and thus face waterlogging problems which tremendously reduce yield. Hitherto, no attempt has been made to assess the field application losses in this scheme.

Puddling of paddy fields is rarely practised. This contributes to high application losses especially with a high water consuming crop such as paddy.

4.6 Irrigation Water Supply Requirements

The main objective of rehabilitation of the traditional irrigation schemes is to improve water supply and increase efficiency of the systems. Abstraction of unnecessary water can be avoided completely. Provision of control and offtake structures for water distribution to secondary, tertiary and quaternary canals will eliminate the losses through the uncontrolled branches used at present. The improvement of damaged head reaches will decrease seepage losses and provide better command on the irrigated areas.

To demonstrate the effect of physical improvements and system management on water losses, the irrigation efficiency was evaluated on the basis of field monitoring during the year 1995/96 dry season. The conveyance, field canal, distribution, application and the overall irrigation efficiencies were estimated on the basis of the inflow-outflow method, on the measured canal discharges and the net irrigation requirements. The values of the net irrigation water requirements used were the net values computed after deducting the effective rainfall. They were based on the existing cropping pattern, intensities and the crop evapotranspiration corresponding to the weather conditions in the study area and the crops' growth stages. According to the results of the analysis the present overall irrigation efficiency of Musa Mwinjanga irrigation scheme is 39.0%. The design figure for irrigation efficiency after completion of rehabilitation work for the scheme was estimated at between 35% to 40% (Dayem, 1990; Koirala, 1990). This was just an assumption based on expected distribution efficiency of 70% to 80% and application efficiency of 50%. JICA (1990) assume an overall irrigation efficiency of 25% in the study carried out for the development of the Lower Hai and Lower Rombo areas. Table 4.10 presents the results of irrigation efficiencies whereas Table 4.11 gives a comparison of irrigation efficiencies between different blocks and detailed in Table 5.5 of Appendix 5.

Table 4.10 Irrigation Efficiencies

Type of Efficiency	Location	I (%)	II (%)	III (%)	PLANNED (%)
Conveyance Efficiency	Upstream	95	60	25	85
	Midstream	80	68	29	85
	Downstream	69	72	-	85
	Mean	81	43	27	85
Distribution Efficiency	Upstream	93	60	25	70
	Midstream	80	33	29	70
	Downstream	68	36	-	70
	Mean	80	43	27	70
Application Efficiency	Upstream	52	102	81	50
	Midstream	56	109	84	50
	Downstream	70	84	-	50
	Mean	59	98	82	50
SCHEME OVERALL EFF (%)			39		35

Table 4.11 Comparison of Irrigation Efficiencies Between Different Blocks

Efficiency		I/II	I/III	I/PLANNED	II/III	II/PLANNED	III/PLANNED
Conveyance Efficiency	T-Statistic	3.374	5.482	0.492	1.472	4.996	40.796
	C-Stat. at (5%)	2.776	3.182	2.776	3.182	2.776	3.182
	Confid. Interval	7	23	-17	-19	19	53
		69	85	25	51	65	62
	C-Stat. at (1%)	4.604	5.841	4.604	5.841	4.604	5.841
	Confid. Interval	-14	-4	-31	-47	3	49
		90	111	38	79	80	66
Distrib. Efficiency	T-Statistic	3.342	5.586	1.422	1.409	3.182	32.564
	C-Stat. at (5%)	2.776	3.182	2.776	3.182	2.776	3.182
	Confid. Interval	6	23	-10	-20	3	39
		69	84	31	51	51	47
	C-Stat. at (1%)	4.604	5.841	4.604	5.841	4.604	5.841
	Confid. Interval	-14	-2	-23	-49	-12	35
		89	109	44	81	66	51
Application Efficiency	T-Statistic	4.289	3.200	1.679	1.718	6.600	28.622
	C-Stat. at (5%)	2.776	3.182	2.776	3.182	2.776	3.182
	Confid. Interval	14	0	-6	-14	28	28
		65	46	24	47	69	36
	C-Stat. at (1%)	4.604	5.841	4.604	5.841	4.604	5.841
	Confid. Interval	3	-19	-16	-39	15	25
		81	65	34	72	82	39

4.6.1 Conveyance Efficiency

The overall conveyance efficiency of the main, secondary and tertiary canals at Musa Mwinjanga irrigation scheme was found to be 53.6% (Table 5.5 of Appendix 5) which indicates poor performance of the system. Abdulmumin et al. (1990) and Doorenbos and Pruitt (1977) recommended the acceptable canal conveyance efficiencies to be within the range of 90% to 80% for schemes with effective management and 70% to 65% for schemes with respective problematic communication and less effective management. During rehabilitation, the overall canal conveyance efficiency for the scheme was estimated at 85% which has never been achieved by farmers.

The analysis to compare the canal conveyance efficiency between blocks was done using a T-distribution test. The results of the analysis indicate that the canal conveyance efficiencies of block I and block II are not significantly different since the calculated T-statistic of 3.374 is less than the critical T-statistic of 4.604 at 1% level of significance. .However at 5% level of significance, the conveyance efficiencies are statistically different.

The results of a statistical comparison of canal conveyance efficiencies between block I and block III revealed that the conveyance efficiencies of the two blocks were not significantly different at 1% level of significance, but differed significantly at 5% level of significance.

The comparison made for block I against the planned conveyance efficiency and block II against block III showed no significant difference at both 1% and 5% levels of significance.

The statistical comparison between the conveyance efficiencies of both blocks II and III against the planned value has shown that there is significant difference between the blocks and planned value at both 1% and 5% levels of significance.

4.6.2 Distribution Efficiency

The overall distribution efficiency (i.e. the efficiency of canals from the intake to the inlet to the field) was estimated at 53% (Table 5.5 of Appendix 5) which indicates poor performance of the system. Abdulmumin et al. (1991) and Doorenbos and Pruitt (1977) classified the canal distribution efficiencies based on rotational supply with management and communication as adequate (100% to 65%), sufficient (65% to 55%), insufficient (55% to 40%) and poor (40% to 30%). During rehabilitation, the overall canal distribution efficiency for the scheme was estimated at 70%.

The comparison made for block I against block II, block I against block III and block II against the planned distribution efficiency showed no significant difference between the values at 1% level of significance but differed significantly at the 5% level of significance.

The analysis to compare the distribution efficiencies of block I against the planned value and block II against block III showed no significant difference between the values at both 1% and 5% levels of significance.

The statistical comparison between the distribution efficiencies of block III against the planned value has shown that there is significant difference between the values at both 1% and 5% levels of significance.

4.6.3 Field Application Efficiency

The overall field application efficiency in Musa Mwinjanga irrigation scheme was found to be 73.6% (Table 5.5 of Appendix 5) which indicates fair skill of farmers in managing water in their fields. Abdulmumin et al. (1991) and Doorenbos and Pruitt (1977) recommended field application efficiencies ranging from 60% to 80% in basins and levelled borders. During rehabilitation, the overall field application efficiency for the scheme was estimated at 50% which is still less than the minimum recommended value. A statistical analysis to compare field application efficiencies of block I against the planned value and block II against block III indicated no significant difference between the values at 5% level of significance. Based on the statistical comparison (Table 4.11), It can be concluded that there exists a fair distribution of water between blocks I and II; and between blocks II and III at the 5% level of significance. However, the comparison between the application efficiencies of both blocks II and III against the planned value showed significant difference between the values at both 1% and 5% levels of significance.

The increase in irrigation efficiency depends on how much physical improvements are made and the level of operation and management of the system. Although the phase-I of rehabilitation program was an important and necessary step towards improving irrigation efficiency of the system, there is still more to be done. Provision of culverts for road crossing especially with secondary canals is badly needed to stop water losses at these intersections. Improved alignment and cross section of these canals are also necessary to reduce the conveyance losses and hence increase the efficiency.

Improved on-farm water management including land levelling and better land preparation practices should be a target to achieve higher irrigation efficiencies. The self-help participation of farmers in doing this involves challenges that may require money, time and effort.

Even with improvement of the system efficiency, the overall water use efficiency of the scheme will still be low, unless good control on system management is adopted by farmers.

4.7 Assessment of Irrigation Water Losses

At present there is no clear relationship between the water abstractions from the rivers to the schemes (Table 4.4) and the net irrigation water requirements (Tables 4.5 and 4.6). Under the current water abstraction practices one of the following situations would surely arise:

- The supply just sufficient to meet the irrigation system losses and the crop water requirements. The losses in this case are determined by the system efficiency.
- The abstraction less than the amount required to cover the system losses and the crop water requirements. In this case part of water remaining after the irrigation losses would not be sufficient to meet the crop demands.
- The abstraction exceeds the irrigation water losses and the crop requirement. The rest of the water would be wasted as operational losses.

Water losses for the scheme were computed as a percentage of the sum of distribution and application losses to the volume of water abstracted in the first two situations (Table 4.12). Operational losses, which are taken to be equal to the extra amount of water abstracted, were added in the third situation. The latter two situations often occur in the scheme due to the absence of water control and measuring facilities and adequate water management. The assessment of water losses was however based on the net irrigation requirements (Tables 4.5 and 4.6), area cultivated (200 ha of paddy and 280 ha of upland crops), water abstraction from the intake (Table 4.4) and overall irrigation efficiency of 39% (Table 5.5 of Appendix 5).

Table 4.12 Assessment Results of Water Losses at Musa Scheme

Month	Date	Net Required Flow (l/s)	Abstraction (l/s)	Losses (l/s)				Available Water for the Crops
				Distribution	Operation	Application	Total	
Sep	06-12	11.6	481	226.1	176.0	67.3	469.4	11.6
	13-19	36.0	481	226.1	151.6	67.3	445.0	36.0
	20-26	59.3	481	226.1	128.3	67.3	421.7	59.3
	27-03	89.4	481	226.1	98.2	67.3	391.6	89.4
Oct	04-10	107.8	482	226.5	80.2	67.5	374.2	107.8
	11-17	144.7	482	226.5	43.3	67.5	337.3	144.7
	18-24	168.1	482	226.5	19.9	67.5	313.9	168.1
	25-31	173.5	482	226.5	14.5	67.5	308.5	173.5
Nov	01-07	215.9	494	232.2	0.0	69.1	301.3	(192.7)
	08-14	176.1	494	232.2	16.6	69.1	317.9	176.1
	15-21	140.6	494	232.2	52.1	69.1	353.4	140.6
	22-28	175.7	494	232.2	17.0	69.1	318.3	175.7
Dec	29-05	180.6	487	228.9	9.4	68.1	306.4	180.6
	06-12	201.2	484	227.5	0.0	67.7	295.2	(188.8)
	13-19	190.9	484	227.5	0.0	67.7	295.2	(188.8)
	20-26	259.7	484	227.5	0.0	67.7	295.2	(188.8)
Jan	27-02	257.9	480	225.6	0.0	67.2	292.8	(187.2)
	03-09	284.1	470	220.9	0.0	65.8	286.7	(183.3)
	10-16	306.9	470	220.9	0.0	65.8	286.7	(183.3)
	17-23	300.0	470	220.9	0.0	65.8	286.7	(183.3)
	24-30	270.3	470	220.9	0.0	65.8	286.7	(183.3)
Feb	31-06	311.3	471	221.4	0.0	65.9	287.3	(183.7)
	07-13	253.1	471	221.4	0.0	65.9	287.3	(183.7)
	14-20	221.9	471	221.4	0.0	65.9	287.3	(183.7)
	21-27	192.6	471	221.4	0.0	65.9	287.3	(183.7)
Mar	28-05	120.3	475	223.3	65.0	66.4	354.7	120.3
	06-12	117.0	476	223.7	68.7	66.6	359.0	117.0
	13-19	38.3	476	223.7	147.4	66.6	437.7	38.3
	20-26	20.2	476	223.7	165.5	66.6	455.8	20.2
Apr	27-02	15.4	476	223.7	170.3	66.6	460.6	15.4
	03-04	8.6	476	223.7	177.1	66.6	467.4	8.6

Numbers in parentheses indicate that the supplies were less than the irrigation requirements.

From Table 4.12 it is clear that the crop water requirements were met fully during the months of September, October, November, March and April. Operational losses that occurred during the months were too high. These losses may be to reasons as mentioned in section 4.5.2. Water deficits occurred in the months of December, January and February. This is shown by the values in the parentheses (Table 4.12) whereby water deliveries into the field plots were less than the net irrigation requirements.

4.8 Adequacy of Irrigation Water Supply

The results of the seasonal maximum, minimum and mean RWS for the selected plots are presented in Table 4.13. Plot PL3 showed the highest maximum RWS of 4.32 whereas plot PL9 showed the lowest maximum RWS of 1.56 (Table 4.13). The variation of the seasonal maximum RWS for the plots gave a coefficient of variation equal to 0.329 with mean of 2.79 and standard deviation of 0.916. The variation of the seasonal minimum RWS for the plots gave a coefficient of variation equal to 0.277 with mean of 1.14 and standard deviation of 0.317. Plot PL2 showed the highest mean RWS of 2.92 whereas plot PL12 showed the lowest mean RWS of 0.96. The overall seasonal mean RWS for the plots was found to be 1.83 with coefficient of variation of 0.354 and standard deviation of 0.647. These variations are indicative of ineffective irrigation schedule (poor water distribution by farmers) and lack of adequate water control and measuring facilities at the distribution and farm level.

Table 4.13 Results of Relative Water Supplies Within Plots

Block	Plot	RWS			
		Maximum	Minimum	Mean	Crop
I	PL1	3.77	1.36	2.32	Upland
	PL2	3.80	1.45	2.92	Paddy
	PL3	4.32	1.20	2.84	Upland
	PL4	3.19	1.37	2.10	Paddy
	PL5	2.43	1.67	2.09	Upland
	PL6	2.34	1.09	1.48	Paddy
II	PL7	2.77	1.07	1.55	Upland
	PL8	1.92	0.73	1.09	Paddy
	PL9	1.56	0.69	1.14	Paddy
	PL10	3.52	1.13	1.75	Upland
III	PL11	2.03	1.29	1.68	Upland
	PL12	1.77	0.67	0.96	Upland
MEAN		2.79	1.14	1.83	
STD		0.916	0.317	0.647	
CV		0.329	0.277	0.354	

It was also observed that no systematic sharing of water deliveries were practised by farmers. The prevailing situation encourages the individual farmers to manipulate the flows in the irrigation canals.

The average overall RWS was found to be 1.88 (for upland fields) and 1.75 (for Paddy fields). This indicates that farmers who planted upland crops were principally using more water than those who grew paddy. The RWS for the selected sub-blocks in the three blocks are presented in Table 4.14.

Table 4.14 Result of Relative Water Supplies Within Blocks

Block Location	I	II	III	CRITICAL
Upstream	2.62	1.36	1.67	1.00
Midstream	2.31	1.14	0.96	1.00
Downstream	1.78	1.74	-	1.00
N	3	3	2	3
AVERAGE	2.24	1.41	0.97	1.00
STD	0.42	0.30	0.51	0.00

It is clear (Table 4.14) that block III which is situated downstream of the scheme has the lowest mean RWS of 0.97. This indicates the normal tail end syndrome common in irrigation schemes. The highest mean RWS of 2.24 was observed in block I whereas block II showed a mean RWS of 1.41. All sub-blocks showed a mean RWS of more than 1.00 with the exception of the mid sub-block in block III which gave a mean RWS of 0.96. The trend of the mean RWS (Table 4.14) indicates that the upstream farmers use more water while the downstream farmers suffer.

The distribution of weekly mean RWS values within individual blocks is presenred in Figure 4.3.

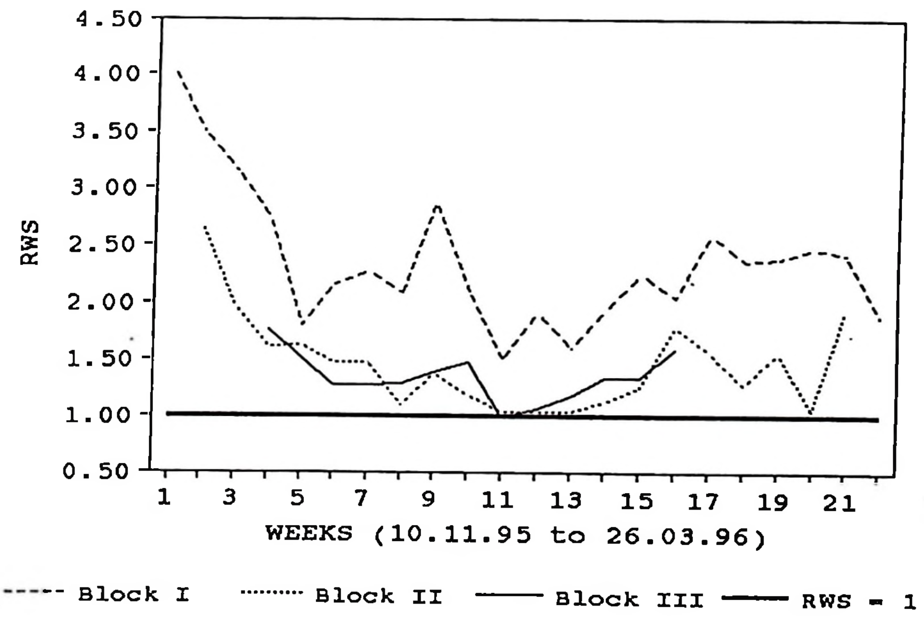


Fig. 4.3 RWS of Blocks I, II and III

The weekly mean RWS values (Figure 4.3) indicate that the actual RWS values were above the critical RWS level for most of the time in all the blocks. At the same time a general trend of gradually declining RWS values over time was observed. This trend was probably due to many farmers irrigating during that particular irrigation period. The distribution of computed RWS values of block I compared to other blocks indicates high RWS values throughout the season. This could possibly be due to its location i.e. upstream. Similarly, the distribution of computed RWS values for block I and II showed no significant difference. However the overall distribution of the computed RWS values indicates that all blocks received adequate supply due to the fact that the actual RWS of all blocks was greater than 1.00.

A plot of cumulative CRWS of the individual blocks as a function of time is shown in Figure 4.4. It can be observed that the adequacy of water supply within blocks was equal to or greater than 1.00, except in block III which received supplies of less than 1.00 from 4 to 9 week.

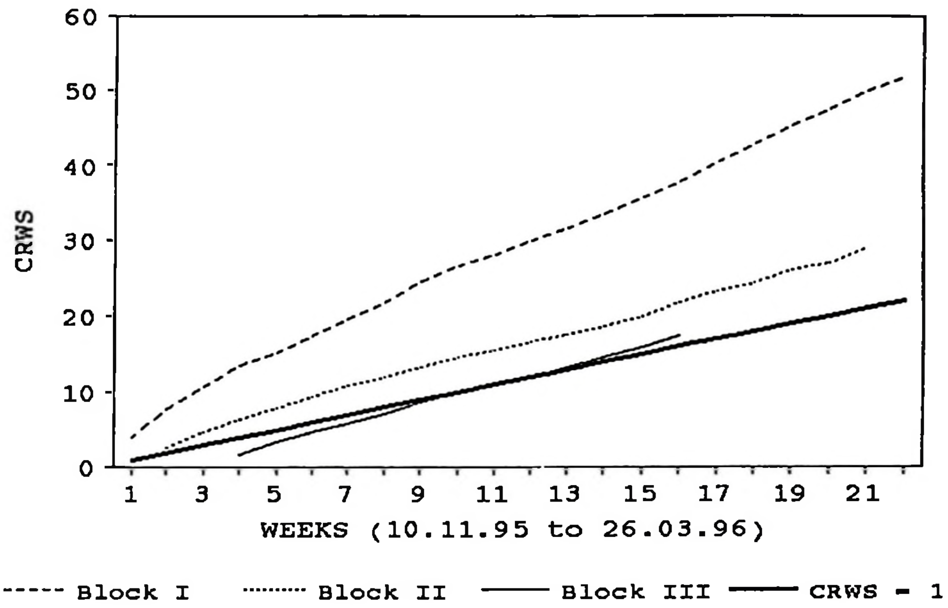


Fig. 4.4 CRWS of Blocks I, II and III

Table 4.15 Comparison of Relative Water Supplies Between Blocks

	I/II	I/III	I/CRITICAL	II/III	II/CRITICAL	III/CRITICAL
T-Statistic	2.749	2.235	5.062	0.277	2.349	1.179
C-Stat. at (5%)	2.776	3.182	2.776	3.182	2.776	3.182
Confid. Interval	-0.01	-0.39	0.56	-1.02	-0.07	-0.53
	1.66	2.24	1.92	1.21	0.90	1.16
C-Stat. at (1%)	4.604	5.841	4.604	5.841	4.604	5.841
Confid. Interval	-0.56	-1.49	0.11	-1.94	-0.39	-1.24
	2.21	3.34	2.36	2.14	1.22	1.87

Statistical analysis to compare the RWS values between different blocks is presented in Table 4.14. According to the results, there was no significant difference between the RWS values of blocks I and II at 5% level of significance. Likewise, the comparisons made for block I against III, II against III, II against critical and III against critical values showed no significant difference at 5% level of significance. This implies that the overall RWS in the three blocks were not significantly different. Deliveries to individual farmers' field plots were more or less in equal proportion vis-a-vis crop water requirements. There was a significant difference between the computed RWS values of block I and the critical value at both 5% and 1% levels of significance.

4.9 Irrigation Scheduling

Irrigation scheduling can be defined as planning of the timing and the depth of future irrigations with a view to apply irrigation water at the right time, the right amount and the right place. The results of the evaluation of the actual scheduling for upland crops; and planning of the required scheduling for both upland crops and paddy rice are presented and discussed in the following paragraphs. The water distribution plan for Musa Mwinjanga scheme as proposed during phase-I of rehabilitation is presented in Table 9.1 of Appendix 9.

4.9.1 Scheduling for Upland Crops

Figures 4.5(a) and 4.5(b) presents the results of the evaluation of the actual and planning scheduling for upland crop in field plot PL1. Graphical evaluation of the actual and planning scheduling for upland crops in other studied field plots are presented in Appendix 8. Tables 4.16 and 4.17 give their respective global rainfall depths, irrigation application depths, rainfall and irrigation efficiencies.

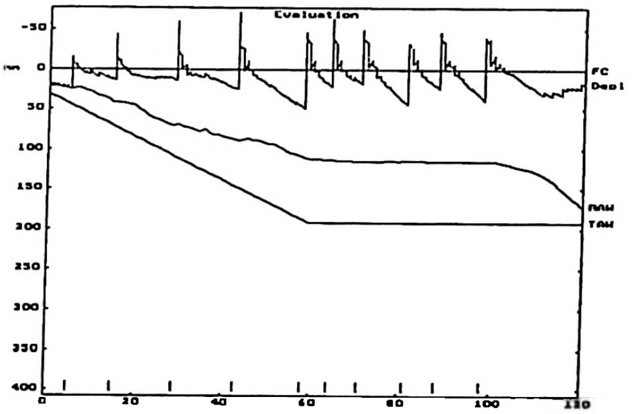


Fig. 4.5 (a) Evaluation Scheduling of Upland Crop (PL1)

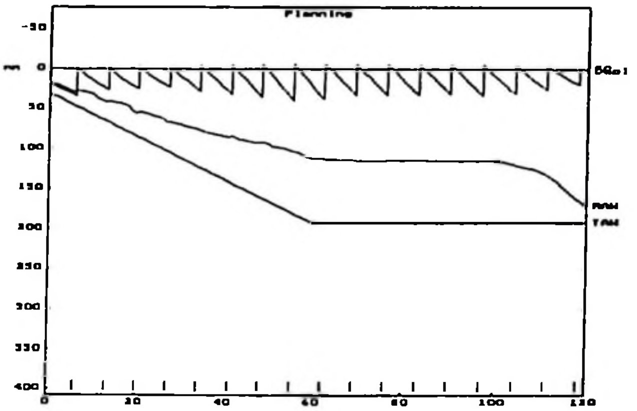


Fig. 4.5 (b) Planning Scheduling of Upland Crop (PL1)

Table 4.16 Global Evaluation of Actual Scheduling

Plot	Rainfall Depth (mm)	Irrigation Depth (mm)	Rainfall Efficiency (%)	Application Efficiency (%)
PL1	216.4	738.0	92.4	57.7
PL3	221.1	820.0	77.0	59.5
PL5	183.9	595.0	87.0	61.8
PL7	195.3	467.0	94.6	85.5
PL10	197.3	536.0	93.6	80.5
PL11	201.8	525.0	89.2	77.7
PL12	201.8	504.0	93.3	78.3

Table 4.17 Global Planned Irrigation Scheduling

Plot	Rainfall Depth (mm)	Irrigation Depth (mm)	Rainfall Efficiency (%)	Application Efficiency (%)
PL1	9.9	608.1	100.0	100.0
PL3	8.0	514.5	100.0	100.0
PL5	10.0	585.0	100.0	100.0
PL7	10.1	586.8	99.5	100.0
PL10	11.1	592.2	100.0	100.0
PL11	11.1	582.4	100.0	100.0
PL12	11.1	589.8	100.0	100.0

Evaluation of the actual Field application efficiency of the selected upland cropped plots, considering the soil type, ranged from 57.7% to 85.5% with an overall mean of 71.5% and standard deviation of 11.5% (Table 4.16). The overall mean application efficiency obtained (Table 4.16) is more or less the same as that computed in section 4.6.1 (73.6%).

The proposed global net irrigation depths for the studied plots are shown in Table 4.17 with depths ranging from 514.5 to 608.1 mm among the studied upland cropped plots.

4.9.2 Scheduling for Paddy Rice

The results of the seasonal planned irrigation requirement of paddy rice using BIRIZ program is presented in Table 4.18. The values are based on the results of the planned irrigation scheduling presented in Figure 4.6 and Table 4.19.

Table 4.18 Seasonal Planned Irrigation Requirement of Paddy

Rice Cycle: Medium Irrigated Area: 200 ha

Period : From 16 September till 3 February

Parameter	mm
Land Soaking	180.00
Evapotranspiration	823.49
Water Head	150.00
Percolation	437.50
Salinity Control	0.00
Effective Rainfall	(9.05)
Losses (distribution)	395.48
Seasonal Irrigation Requirement	1977.42

Footnote: Number in the bracket indicates a negative value.

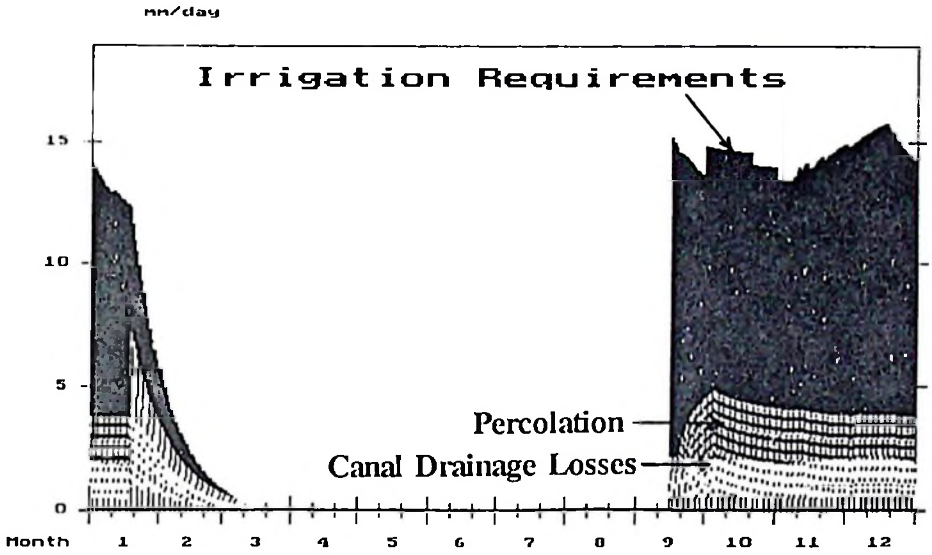


Fig. 4.6 Planned Irrigation Scheduling of Paddy Rice

Table 4.19 presents the results of the water fluxes (i.e. irrigation requirements, runoff and Seepage and percolation losses) on decadal basis.

Table 4.19 Decadal Irrigation Water Fluxes

		Irrigation Requirement	Towards Drain	Towards WaterTable
		mm	mm	mm
September	decade 1	0.00	0.00	0.00
	decade 2	74.01	10.72	7.66
	decade 3	140.39	21.02	36.74
	Month	214.40	31.74	44.39
October	decade 1	147.50	20.65	46.76
	decade 2	146.07	20.45	44.39
	decade 3	154.11	21.58	46.25
	Month	447.68	62.68	137.40
November	decade 1	135.15	18.92	40.69
	decade 2	140.78	19.71	39.73
	decade 3	146.25	20.48	38.44
	Month	422.19	59.11	118.86
December	decade 1	150.61	21.09	38.03
	decade 2	155.89	21.82	38.12
	decade 3	161.53	22.61	41.73
	Month	468.03	65.52	117.88
January	decade 1	133.79	18.73	37.68
	decade 2	123.18	28.08	37.32
	decade 3	86.97	54.48	33.79
	Month	343.94	101.29	108.78
February	decade 1	42.70	27.49	17.93
	decade 2	22.43	15.55	9.71
	decade 3	9.50	7.35	4.25
	Month	74.63	50.39	31.88
March	decade 1	5.50	5.38	2.67
	decade 2	1.05	2.46	0.92
	decade 3	0.00	0.00	0.12
	Month	6.55	7.84	3.71
April	decade 1	0.00	0.00	0.00

The seasonal irrigation requrement for paddy rice was found to be 1,977 mm. This value is equivalent to 19,774.2 m^3/ha. The monthly irrigation requirement of paddy rice ranges from 6.5 in March to 468.0 mm in December (Table 4.19). The peak irrigation requrement amounting to 161.5 mm occurs in the third decade of December (Table 4.19).

4.10 Drainage of Musa Mwinjanga Irrigation Scheme

There can be no suitable irrigated agriculture without proper attention to drainage (Kips and Ndondi, 1990). The significance of drainage, until very recently, was not recognized as necessary practice in many traditional irrigation schemes (Baban, 1994). This is true due to the fact that farmers in the scheme have been relying on natural drainage and land slopes to drain excess water caused by rain storms and over-irrigation. Neither the natural drainage nor the land slopes are adequate to facilitate drainage of the excess water from the irrigated fields in Musa Mwinjanga irrigation scheme. This situation has encouraged the development of waterlogging conditions. Farmers have no good control of irrigation water and irrigation is practised without much organization and planning.

The study on soils and land suitability for irrigated agriculture (Kips and Ndondi, 1990) classified the soils of Musa Mwinjanga irrigation scheme into four groups. Section 4.1.2 revealed that some of the drainage problems are due to the soils types of the agricultural land. The soil groups and their effects on drainage are herein briefly discussed.

- O-Soils: These soils consist of textural class ranging from Clay to silt loam. Most of these soils are well drained, however, the central shallow soils of the outwash are somewhat poorly drained. In areas where the shallow soils underlaid by a layer of re-deposited and cemented fine volcanic ash, the land becomes water logged and therefore drainage is required.

- B-Soils: These soils are poorly drained clays accompanied with shallow ground-water levels and are typically wet-land rice soils.

- R-Soils: These soils consist of layers of loam and silt textured soils which are well drained.

- F-Soils: They are thick, well drained with moderately developed structure. As a result of the steep slope of the land, the surface runoff has eroded the soils and gullies have accordingly developed. Provision of proper drainage facilities capable of intercepting the surface runoff would tremendously reduce the erosion hazard.

The drainage problem now affecting the scheme can be said to have been caused specifically by the following factors:

(i) Lack of proper irrigation water control facilities and poor irrigation water management (i.e. distribution efficiency amounting to 53% and application efficiency equal to 73.6%);

(ii) Type of soils and topography of the land;

(iii) Lack of adequate drainage facilities.

The above factors have long been recognized but so far the problem has not yet been solved mainly due to lack of funds for training farmers on proper water management aspects and the necessity of levelling/grading of their fields including provision of adequate drainage facilities.

Rainfall is neither uniform in intensity and distribution nor falls when it is needed. Moreover, it does not often rain in quantities just enough to recover the soil moisture to its field capacity. Therefore, any excess rainfall will percolate down to the groundwater table. When the rate of rainfall exceeds the infiltration rate of the soil water will fill in the surface depressions and move laterally as surface runoff.

The rainy season starts in November till May in the study areas. With deep soils, the soil moisture storage is usually depleted during the preceding dry season. When the rainfall increases in March the soil moisture storage is rapidly replenished and watertable rises high. In areas with shallow soils, the rise of watertable is faster and more surface runoff occurs. The main rainy season is therefore characterized with floods as reported by farmers during the interview.

Abdel-Dayem (1990) addressed the drainage problem affecting the Musa Mwinjanga irrigation scheme and proposed some solutions to those problems. Unfortunately his recommendations have not yet been effected todate.

The preliminary layout of the drainage system proposed by Abdel-Dayem (1990) is shown in Appendix 10. It consists of three main drains flowing south. The first main drain is located east of Kaurwa tertiary canal. This was proposed to take the advantage of the existing natural stream which would be remodelled to adequate design width and depth. The length of this proposed drain is 600 m and estimated to serve about 55 ha. The land surface in this area is some how steep and a minimum of two drop structures would be required.

The second drain was proposed to the east of Mzee Kondo secondary canal. The drain was estimated to serve about 135 ha with a proposed total length of 3,300 m. The third drain would be constructed to the east near Musa Mwinjanga secondary canal. The drain would follow the course of an existing small ditch excavated by farmers to drain the waterlogged area at the centre of the scheme. The area to be served by this drain was estimated at 210 ha with a length of about 2,700 m. Both drains would run along the edges of a central depression to intercept any lateral flow from the high-lying lands and eventually meet southwards in one common outfall draining into Weruweru river. Four crossing culverts were proposed at the intersection of the second and third drains with service roads.

4.11 System Operation and Maintenance

It is generally argued that FMIS often perform quite well when compared to Government managed irrigation systems (Pradhan, 1989; Benjamin et al., 1994 as cited by Mishra and Molden, 1996). Features of a well managed FMIS are that: (i) timely decisions are made concerning operation and maintenance; (ii) resources are mobilized by the farmers independently of Government budget allocations; (iii) management activities are quite sensitive to local needs and opportunities.

Musa Mwinjanga irrigation scheme lacks permanently built on-farm water control structures. Accordingly no systematic irrigation operations are actually being made at present. Irrigation is practised often without any control despite the major rehabilitation undertaken during the phase I of the rehabilitation program.

There is a Water Committee (under a village Chairman) responsible for executing operation and maintenance of the system. This Committee is composed of eight people elected by the Village Administrative Government. It consists of a chairman, secretary and six members. Apart from the Water Committee, there are eight Water Masters (commonly known as *wagawa maji*) who are responsible for water allocation to farmers in their respective blocks. It is a common practice that Water Masters meet with the water users of their respective areas once a week. The water supply schedules/allocations are set during the meeting whereby individual farmers know when to irrigate and duration of water application. According to physical observation and interview with farmers, it was apparent that formal training in water management and farming was not a common practice to in area.

One of the major tasks of the WC is to go around the whole scheme and assess the areas mostly affected by water shortage. In case the WC find such areas, they ask the Water Masters to release some amount of water to help the affected farmers. The WC has also the responsibility of organizing minor repairs and maintenance through farmers' self-help participation. In case of a major repair, the WC requests the District office (District Irrigation Officer) through the Village Chairman to repair the damaged facility.

The WC collects levy (*kimada*) equivalent to Tsh. 10,000/= imposed and charged on farmers who are not the natives of the area (commuters).

Apart from the levy mentioned above, no water fee is collected from farmers and the operation and maintenance is carried out on a voluntary basis at present.

4.12 Organization

The organizational structure of the Musa Mwinjanga irrigation scheme is presented in Figure 4.7.

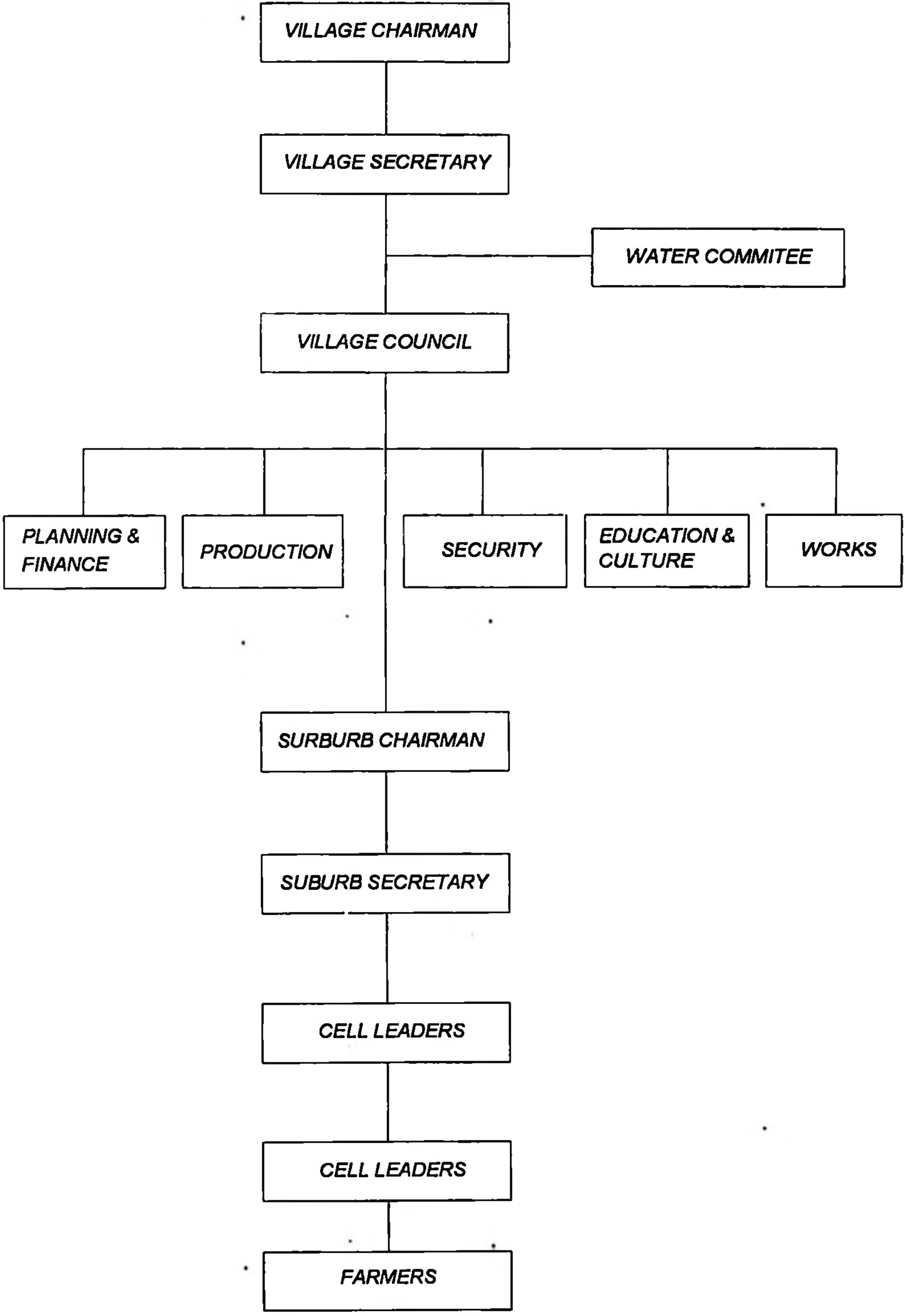


Fig. 4.7 Organization structure of the Musa Mwinjanga scheme

SOURCE: Personal Communication (1995)

Diemer (1990), cited by Wester et al. (1995), pointed out that for a FMIS to succeed, the organization structure should correspond with the local political system. A close look at the organizational structure of Musa Mwinjanga irrigation scheme (Fig. 4.7) revealed that the organization set-up of the scheme appears to be fairly appropriate. During the interview with village leaders, it was revealed that all functional members of the organization are provided with job descriptions related to their line of duties and responsibilities.

4.12.1 Duties and Responsibilities

The village chairman is elected by the local community. He is the incharge of the overall management of the Mijongweni village in which the Musa Mwinjanga irrigation scheme is situated. The chairman is responsible for organizing meetings scheduled to discuss matters related to irrigation and implementation of directives from higher authorities as related to village activities and administration.

The village executive secretary is appointed by the District Development Committee. He is responsible for keeping records and minutes of every meeting, handles correspondence and safeguards the records of the village, collects taxes and convey the same to the District council; and implements directives from higher authorities as related to village activities and administration.

The village Government Council has the responsibilities of planning development activities within the village.

The members of the Water committee are elected by the village government. They assist the Water Masters in the proper implementation of water allocation schedules specifically, the rotation on hourly basis and collection of levy from commuters.

Water Masters are elected by the local communities within their respective sub systems. The Water Masters are incharge of the proper distribution of water. Their main duties and responsibilities are to see to it that water allocation schedules are properly implemented, conduct regular field inspection of the sub systems and prepare plans for water distribution within their respective sub systems. They are incharge of time keeping for water allocation during rotation on hourly basis.

Results of physical observation and interview conducted to individual farmers and leaders showed that the organization has experienced a number of problems related to irrigation management. Despite having a fairly appropriate organization structure, there was no proper control of water within the scheme. A number of water control structures at the heads of tertiary canals were damaged and no efforts have been made to replace them. Farmers were still using water without control. Duration of irrigation application including irrigation intervals set by the Water Masters were not effectively being observed by farmers.

4.12.2 Incentives in the Organization

Incentives are what one gets from his organization as a reward or compensation for being a productive/useful member. The only members of the organization who receive incentives include the village secretary (paid salary by the District Council), the chairman and secretary of the WC (paid 30% of the total sum collected out as levy). The Water Masters are given 1 day (12 hours) a week to irrigate their fields as their incentive. No incentives are given to other members of the organization including the village chairman.

The organization structure of Rehabilitation of Traditional irrigation Schemes in Kilimanjaro and Arusha regions is shown in Figure 4.8. The Musa Mwinjanga Irrigation scheme is one among the locally managed irrigation schemes falling within framework of this organization structure.

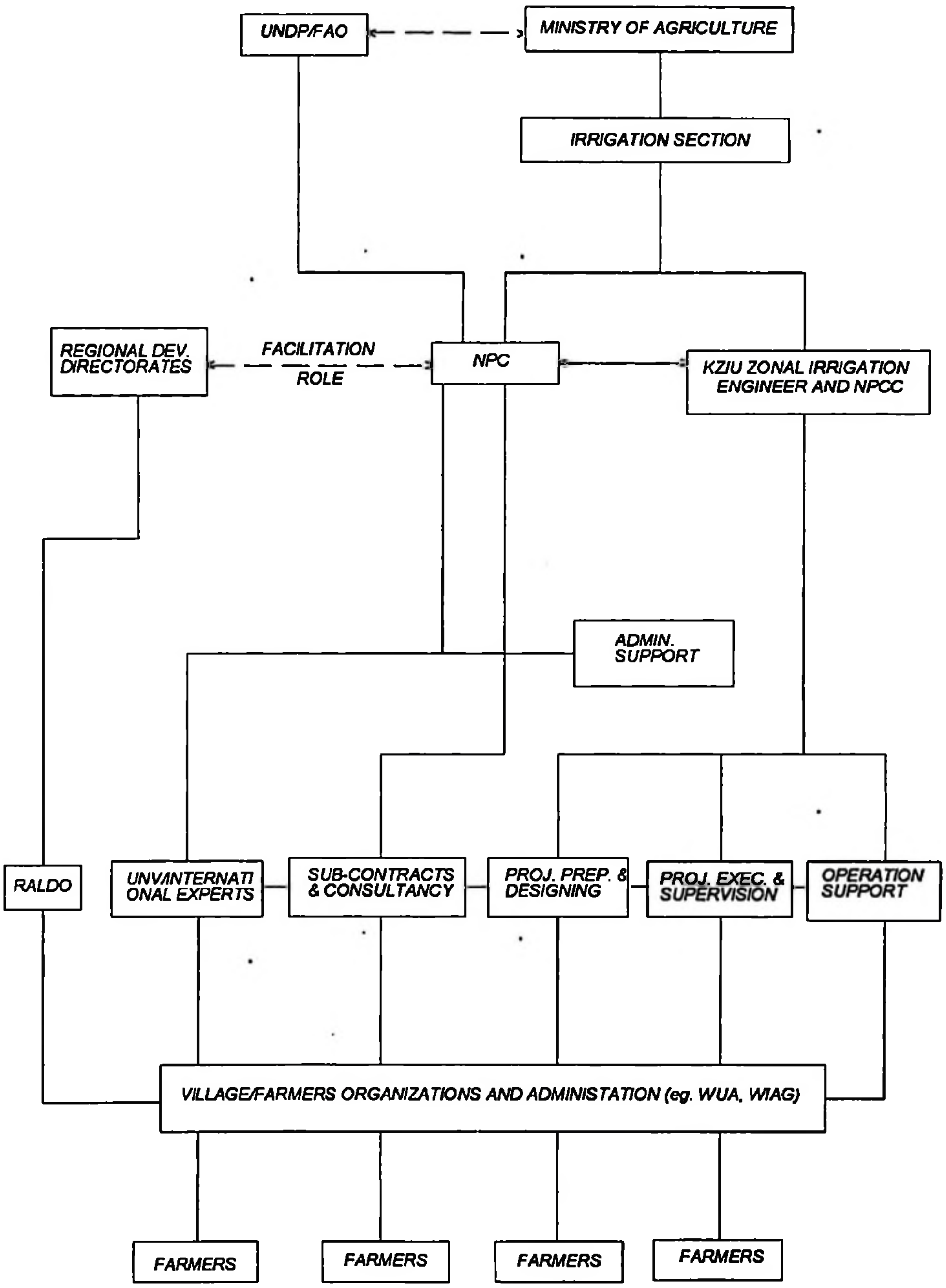


Fig. 4.8 Organization Structure for Rehabilitation of Traditional Irrigation Schemes in Kilimanjaro and Arusha Regions

SOURCE: PPMB (1993)

5. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations drawn from the results of the study carried out to elucidate the effects emanating from intervention on FMIS with particular reference to Musa Mwinjanga irrigation scheme. This is aimed at setting the stage for seeking appropriate solutions and provide a basis for setting guidelines for implementing future rehabilitation works.

5.1 Conclusions

The following conclusions can be made from the study results:

- Rains falling during the wet season are the major cause of the waterlogging problem in the scheme area. Under the prevailing poor drainage conditions, surface runoff results in flooding of the lowland areas.

- Proper operation and maintenance of the irrigation system will effectively reduce irrigation water losses and provide adequate supply to the fields. Poor routine maintenance has contributed to growth of weeds in almost all the irrigation canals network, hence causing high canal seepage and evapotranspiration losses in the system.

- Stealing and illegal withdrawal of irrigation water are the order of the day since the by-laws are never adhered to by many individual farmers and are in-fact not enforced. The attitude of farmers to interfere with irrigation water distribution has increased in the resent three years as a result of inadequate water supply among the farmers during the dry seasons. This has led to illegal operations of the offtake gates and damages of most of the already rehabilitated irrigation facilities in the system.

- The present condition of the irrigation system facilities suggests that the farmers were not well prepared to properly run the scheme immediately after the phase I of rehabilitation. This conclusion stands valid taking into consideration the extent and magnitude of damages caused by farmers to the irrigation water control structures which were constructed under the rehabilitation program in the year 1989/90. No efforts have been made to bring back the facilities to operational state. The farmers are once again waiting for assistance, if any, from the government for restoration of the damaged facilities.

- The present farm irrigation practices in the study area are very poor causing considerable irrigation water losses and hence waterlogging particularly in areas commanded by secondary canal MKSC and tertiary canal MMC/TC11 and MMC/TC12.

- The organisational structure of the scheme is fairly appropriate, however water management problems still exist.

- The rehabilitated scheme's intake, main and part of Musa Mwinjanga secondary canal, aimed at improving water supply to the scheme, have little effect on the overall irrigation efficiency. This has resulted in more irrigation water losses due to increased water supply under low irrigation efficiency. Under the current field conditions, it will not be possible to irrigate the whole 600 ha during the off-season. The conveyance and distribution efficiencies of the canals system was found to be 53.6% and 53% respectively. This implies that substantial water losses occur in the canals system.

- Poor canals alignment, unculverted crossings and missing water control and distribution works are the main reasons of conveyance water losses. The lengths of the tertiary and quaternary canals are several times the length of the main and secondary canals. However there is a strong evidence that part of the canal seepage water re-enters the system as return flow due to the sloping topography, but this should be verified through thorough ground-water flow investigation.

- The presence of soil micro-relief and poor land levelling/grading are the main reasons for the high field application losses. The latter is especially important in paddy fields where puddling is not adequately practised and the infiltration rate is high.

- The topography, soils and geology of the area play an important role in the development of drainage problems. The steep slopes and sudden changes in ground surface elevation result in lowlying lands and depressions to which surface runoff collects and leads to waterlogging and development of swampy areas. The high infiltration rate in some areas and presence of shallow barriers aggravate the problem.

- The existing natural and man made drains are not well maintained to the extent that most of them are silted up and fully covered by weeds and aquatic plants. This situation has encouraged the extension of the swamps and waterlogging in the surrounding areas. The system is infact lacking proper and adequate drainage facilities capable of evacuating the accumulated excess water from the system.

- The construction of drainage canals will improve both the crop production and the environmental conditions. This will reduce the risk of water-borne diseases and transport through the area will be easier due to the elimination of swamps and waterlogged areas.

- The soils in the scheme are generally salt-free/non-saline with electrical conductivity levels ranging from 0.172 to 0.183 mS/cm. The irrigation water has likewise low salt content ranging from 0.09 to 0.14 mS/cm. The salinization process in the scheme is counteracted by leaching especially during the wet seasons.

- The long-term improvement of the system will only be realized after the complete rehabilitation of water control and distribution structures, culverts, good canal alignment, possible canal lining, land levelling and improved water management practices envisaged to be implemented in the follow-up phases of rehabilitation. These improvements will increase the scheme irrigation efficiency, save water and allow more lands to be irrigated. Moreover it will reduce the water-logging and salinity.

- Farmers in the upper, middle and tail ends receive water in more or less equal proportions. This is shown by the RWS (Table 4.15). Nevertheless, the lowest mean RWS was realised at the downstream block.

5.2 Recommendations

- The outstanding physical works left during the rehabilitation phase should be accomplished. This will facilitate water delivery that is adequate, equitable and dependable to maximize crop production.

- Water measuring devices should be installed at heads of the canals to enable monitoring of flows conveyed to the main and distribution canals.

- The drainage works should be introduced as soon as possible and should include the rehabilitation of the existing natural and man-made drains, excavation of other new drains with their associated structures capable of meeting the drainage requirements of the scheme in both the wet and dry seasons.

- The rehabilitation of the drainage system should be phased out starting with: (i) the main drainage system aiming at providing an outlet for evacuation of excess irrigation water accumulating and entrapped inside the scheme; (ii) The secondary drainage system to collect farm drainage water; and (iii) Other minor (i.e. tertiary and quaternary) drainage systems.

- The canal seepage losses should be monitored seasonally in order to establish long term realistic values.
- Technical and economical feasibility of canal lining should be examined on the basis of the findings of intensive monitoring of canal seepage losses in which the possibility of re-use of seepage water intercepted by the drainage system should be considered as an alternative.

- The irrigation water committee (WC) should be assisted by the Government through its Zonal, Regional and District irrigation departments in setting plans and training of Water Masters/Operators to properly operate the system according to the actual crop water requirements. The practical achievement of this will be realized if the means for measuring canal discharges are provided in the scheme so as to help farmers to control water abstraction and distribution into the fields.

- The on-farm irrigation practices should be monitored and evaluated in the representative farms, over the growing season, of which the long-term application efficiency will be assessed.

- In areas with soils having high infiltration rates (i.e. > 6.5 cm/h), irrigation in small basins and good land levelling are recommended if uniform water distribution is to be achieved.

- The currently introduced irrigation water fee amounting to Tsh. 10,000/= per acre per season now being levied to farmers who are not natives of Musa Mwinjanga village should effectively be used for activities related to O&M of the scheme extended to all farmers in the area.

- It is recommened that the farmers who are natives of the area should be advised on the need to pay a token water charge, however small, in cash or in kind to meet the O&M activities.

- KZIU in cooperation with the Regional and District agricultural officers, and other relevant institutions and/or the farming community should help farmers to form a strong WUA capable of carrying out proper operation and maintenance of the scheme. A well functioning WUA would help in providing education, other services such as water distribution, canal maintenance, credits on agricultural inputs, extension and markets to farmers produce. Allocation of a professional scheme officer is highly recommended in this regard.

- Local arrangements should be made to assign some responsible farmers with the task of guarding all the control structures. A token amount of money should be decided on and used to motivate them.

- The Water Masters should be motivated so as to keep them away from bribes (especially from commuters).

REFERENCES

Abdel-Dayem, M.S. (1990) *Drainage for Waterlogging and Salinity Control*, FAO, Moshi, Tanzania, pp 87.

Abdulmumin, S., Bastiansen, J., Martin, S. Rijks, D. and Gbeckor-Kove, N.A(1991) *Application of Climatic Data For Effective Irrigation Planning and Management*, Geneva, Switzerland, pp 163.

Abernethy, L.C. (1986) *Performance Measurement in Canal Water Management*: A Discussion. ODI/IIMI Irrigation Management Network Paper 86/2d August 1986 London, U.K. pp 25.

Abernethy, L.C. (1991) Overview of Performance Measurement in Farmer Managed Irrigation Systems. In: *Proceedings of an International Workshop of Farmer-Managed Irrigation System Network*, held at Mendoza, Argentina, 12-15 November 1991, (Manor, S. and Chambouleyron, J. (Eds.), 1993), IIMI, Colombo, Sri Lanka, pp 266.

Angles, H.L., Gavino, R.B., Cubos, A., Sayco, T.B. and Sariano, D. (1989) *A Community Managed Irrigation System*, Irrigation System Management Improvement Program, Revised Ed, Central Luzon State University, Nunoz, Nueva Ecija-3120, Philippines.

Baban, R.T. (1994) *End of Assignment Report: Construction*. Rehabilitation of Traditional Irrigation Projects - Kilimanjaro Zone, Draft Report, Project URT/92/005, Moshi, Tanzania, pp 96.

Bagadion, B.U. and Korten, F.F. (1980) *Development of Viable Irrigators' Association*. Agricultural Administration, Philippines, Vol. 7, pp 273-297.

Banskota, M. and Thampa, G. (1991) Performance Evaluation of selected Farmer-managed Irrigation Systems in Nepal. In: *Proceedings of an International Workshop of Farmer-Managed Irrigation System Network*, held at Mendoza, Argentina, 12-15 November 1991, (Manor, S. and Chambouleyron, J. (Eds.), 1993), IIMI, Colombo, Sri Lanka, pp 266.

Bastiaansen, J. (1994) *Diagnostic Analysis of Farmer Managed Irrigation*. Training Module, NATURA/NECTAR, EC PROGRAMME.

Bos, M.G. and Nugteren, J. (1982) *On Irrigation Efficiencies*. 3rd Ed, Publication No: 19, ILRI, The Netherlands. pp 138.

Chapman, C. (1986) *Rehabilitation of Traditional Irrigation Schemes (Phase I)*, TCP/URT/4522, FAO, Rome.

Chapman, C. (1990) *Smallholder Irrigation Development Priorities*, ISID, Field Document No: 14, Ministry of Agriculture and Livestock Development, Dar-es-salaam, Tanzania.

Doorenbos, J. and Pruitt, W.O. (1977) *Crop Water Requirements*, Irrigation and Drainage Paper 24, FAO, Rome, pp 144.

FAO (1971) *Irrigation Practice and Water Management*, Irrigation and Drainage Paper No: 1, Rome.

FAO (1993) *National Irrigation Development Plan*. Project URT/90/016, Institutional Support for Irrigation Development, Ministry of Agriculture, Dar-es-salaam, Tanzania, pp 89.

IIMI (1990) *News Letter of The Farmers Management Irrigation Network*, International Irrigation Management Institute, Paper No.7, Colombo, Sri Lanka.

ILRI (1974) *Drainage Principles and Applications*, Vol. III, Publication No. 16, International Institute For Land Reclamation and Improvement, Wageningen.

JICA (1989) *The Feasibility Study on Lower Hai and Lower Rombo Agricultural Development Project*, Japan International Cooperation Agency, Interim Report, Tanzania. pp 83.

JICA/NIA (1991) *Diversified Crop Irrigation Engineering*, Japan International Cooperation Agency in cooperation with National Irrigation Administration, NIA, Quezon City, Philippines. pp 386.

Kerzner, H. (1992) *Project Management: A System Approach to Planning, Scheduling and Controlling*, 4th Ed, Norstrand Reinhold, New York.

Kihupi, N.I. and Dihenga, H.O. (1994) *Diagnostic Analysis of Farmer Managed Irrigation*: Mto wa Mbu Irrigation Project Case Study, Training Module, NATURA/NECTAR, EC PROGRAMME.

Kips, Ph.A. and Ndondi, P.M. (1990) *Soils and Land Suitability For Irrigated Agriculture of Musa Mwinjanga and Kikafu Chini Irrigation Schemes* (Hai District, Kilimanjaro Region), Detailed Soil Survey, Report D28, Ministry of Agriculture, NATIONAL SOIL SERVICE, Mlingano Agricultural Research Institute, Tanga, Tanzania, pp 99.

Koirala, K.P. (1990) *Economic Performance Report, Musa Mwinjanga Traditional Irrigation Scheme*, URT/86/017, FAO, Moshi, Tanzania. pp 45.

Labiano, B.S.(1994) *Crises Management in Irrigation System Operations*, DCIEP-NIA, Quezon City, Philippines. pp 12.

Landon, J.R. (Ed.) (1984) *Booker Tropical Soil Manual, A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropical and Subtropics*, Booker Agric. Ltd, Longman, Harlow, U.K.

Madeley, J. (Ed) (1987) *The Struggle For Self Sufficiency in International Agricultural Development*, Pharos Publishing House ltd, Becks, V.K, March/April 1987, 4(2):24.

Mallari, J. (1994) *Water Management Parameters*. In: Training Course on Water Management and Operation and Maintenance of Irrigation Systems, NIACONSULT inc., Quezon City, Philippines. pp 435.

Manor, S. and Chambouleyron, J. (Eds) (1993) *Performance Measurement in Farmer-Managed Irrigation Systems*. Proceedings of an International Workshop of Farmer-Managed Irrigation System Network, held at Mendoza, Argentina, 12-15 November 1991, IIMI, Colombo, Sri Lanka, pp 266.

Martin, E., Yoder, R. and Groenfeldt, D. (1986) *Farmer-Managed Irrigation: Issues*. ODI/IIMI Irrigation Management Network Paper 86/3c November 1986, London.

Mascarenhas, J. (1991) *Participatory Rural Appraisal*. Proceedings of the February 1994 Bangalore PRA Trainers Workshop, Sustainable Agriculture Programme, Intern. Institute for Environment and Development, London, U.K.

Masija, E. H. and Kagubila, M. (1994) *Irrigation Experience in Tanzania*. Paper Presented at The National Irrigation Held at The Kilimanjaro Hotel, Dar es salaam, Tanzania, 12-13 May 1994, pp 10.

Mishra, V.S. and Molden, D.J. (1996) *Management Turnover in the West Gandak Irrigation System, Nepal*. Short Series on Locally Managed Irrigation, IIMI, (1996), paper No. 14, Colombo, Sri Lanka, pp 18.

Oad, R. and Samath, R.K. (1991) Performance Measure for Improving Irrigation Management. In: *Proceedings of an International Workshop of Farmer-Managed Irrigation System Network*, held at Mendoza, Argentina, 12-15 November 1991, (Manor, S. and Chambouleyron, J. (Eds.), 1993), IIMI, Colombo, Sri Lanka, pp 266.

Hobley, M., and Shah, K. (1996) *What Makes Local Organization Robust? Evidence From India and Nepal*, ODI, Overseas Development Administration, Natural Resources Perspectives Paper No: 11, London, UK, pp 6.

Ostrom, E. and Benjamin, P. (1991) Design Principles and Performance of Farmer-Managed Irrigation Systems in Nepal. In: *Proceedings of an International Workshop of Farmer-Managed Irrigation System Network*, held at Mendoza, Argentina, 12-15 November 1991, (Manor, S. and Chambouleyron, J. (Eds.), 1993), IIMI, Colombo, Sri Lanka, pp 266.

PPMB (1993) *Rehabilitation of Traditional Irrigation Schemes in Kilimanjaro/Arusha - Phase 1B Proposal*, Agricultural Planning and Marketing Division, Project Planning and Monitoring Bureau, Report No. PPU/19/93, Ministry of Agriculture, Dar-es-salaam, Tanzania.

Raes, D. (1996*a*) *Irrigation Agronomy*. Interuniversity Programme in Water Resources Engineering, Katholieke Universiteit/Vrije Universiteit, Leuven, Belgium. pp 145.

Raes, D. (1996*b*) *BIRIZ Program*. Center for Irrigation Engineering, Leuven, Belgium.

Raes, D., Song, Z., Mallants, D. and Wyseure, G. (1988) *IRSIS Program*. Center for Irrigation Engineering, Leuven, Belgium, pp 119.

Raes, D., Song, Z., Mallants, D. and Wyseure, G. (1990) *RAINBOW Program*, Reference Mannual-1990, Center for Irrigation Engineering, Leuven, Belgium, pp 44.

Sagardoy, J.A. (1986) *Organization and Maintenance of Irrigation Schemes*, FAO paper No. 40, Rome.

Sakthivadivel, R., Fernando, N. and Merrey, D.J. (1992) Performance of Irrigation Settlement Schemes: A Case Study From Kirindi Oya in Sri Lanka. In: *Advancements in IIMI's Research 1989-1991*. A Selected Papers Presented at International Irrigation Management Institute in 1992, pp 208-232.

Sakthivadivel, R., Merrey, D.J. and Nihal, F. (1993) *Cumulative Relative Water supply: A Methodology for Assessing Irrigation Performance*. Irrigation and Drainage System 7, pp 208-232.

Sexton, R. (1990) *Perspective on The Middle East Water Crisis: Analyzing Water Scarcity Problems in Jordan and Israel*, ODI-IIMI, Irrigation Management Network Paper No. 90/3f, London, UK, pp 30.

Speelman, J. J. (1990) *Designs For Sustainable Farmer-Managed Irrigation Schemes in Sub-Saharan Africa*, ODI-IIMI, Irrigation Management Network Paper No. 90/1f, London, UK, pp 18.

Stern, R., Knock, J. and Hack, H. (1991) *INSTAT*. Climatic Guide, A Statistical Package for Micro Computers, Statistical Service centre, University of Reading, Whiteknights, Reading, U.K. pp C-R-64.

Vincent, L. (1990) *The Politics of Water Scarcity: Irrigation and Water Supply in The Mountains of The Yemen Republic*, ODI-IIMI, Irrigation Management Network Paper NO. 90/3e, London, UK, pp 28.

Wajayaratna, C.M. and Vermillion D. L. (1994) *Irrigation Turnover in The Philippines: Strategies of the National Irrigation Administration*, Short Series on Locally Managed Irrigation, IIMI, paper No. 4, Colombo, Sri Lanka, pp 23.

Wester, P., During, A. and Oorthuizen, J. (1995) *Locally Managed Irrigation in Senegal River Valley in The Aftermath of State Disengagement*, Short Series on Locally Managed Irrigation, IIMI, paper No. 9, Colombo, Sri Lanka, pp 21.

APPENDIX 1 DAILY CLIMATIC DATA

Table 1.1 Daily Rainfall (mm/day)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	0.0	0.0	1.1	15.1	9.5	3.5	3.1	0.0	1.4	0.0	0.0	5.9
2	1.6	1.2	4.2	4.9	6.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0
3	2.4	0.0	3.0	13.5	9.4	0.0	0.0	0.0	0.0	0.0	1.6	4.9
4	2.2	0.0	3.9	19.8	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1.2	1.7	2.1	12.9	10.1	1.2	0.0	0.0	0.0	0.0	0.0	2.5
6	3.2	0.0	0.0	16.2	2.6	0.0	1.1	1.2	0.0	0.0	2.7	2.4
7	0.0	1.7	0.0	6.9	6.2	1.0	1.8	0.0	0.0	1.5	2.2	1.4
8	0.0	0.0	1.3	8.7	4.7	0.0	0.0	0.0	0.0	1.6	2.8	1.7
9	2.0	0.0	2.3	8.8	9.2	0.0	0.0	0.0	0.0	1.8	1.6	1.4
10	0.0	1.9	0.0	23.5	6.1	0.0	0.0	2.2	1.4	0.0	0.0	0.0
11	3.2	1.3	0.0	6.9	5.6	0.0	0.0	1.5	1.7	0.0	2.1	2.3
12	1.1	0.0	5.6	9.1	2.9	0.0	0.0	0.0	0.0	0.0	4.5	1.9
13	0.0	2.2	1.2	6.6	3.7	1.3	0.0	0.0	0.0	1.3	3.6	1.3
14	1.5	0.0	6.9	4.5	5.5	2.0	0.0	1.8	0.0	1.3	1.8	1.8
15	1.0	0.0	1.8	10.9	3.9	1.2	0.0	0.0	0.0	1.2	6.8	2.0
16	1.8	1.1	10.4	10.2	3.4	1.4	0.0	0.0	0.0	0.0	0.0	3.4
17	3.2	3.2	4.0	15.7	6.5	0.0	1.0	0.0	0.0	0.0	4.2	1.7
18	1.3	2.5	3.1	23.8	4.6	0.0	2.3	0.0	0.0	2.4	8.8	2.2
19	3.3	1.4	3.6	26.1	6.8	0.0	0.0	0.0	0.0	0.0	3.3	2.3
20	0.0	0.0	7.9	9.3	7.4	0.0	0.0	0.0	0.0	0.0	1.4	0.0
21	0.0	2.6	1.2	7.8	3.0	0.0	0.0	0.0	0.0	1.1	1.2	0.0
22	0.0	3.1	1.8	17.5	9.1	0.0	0.0	0.0	1.2	0.0	0.0	0.0
23	0.0	0.0	8.1	15.6	5.4	0.0	0.0	0.0	0.0	1.8	3.2	0.0
24	1.6	0.0	5.5	27.3	5.4	3.1	1.3	0.0	0.0	0.0	3.2	0.0
25	1.8	2.5	6.0	14.0	3.0	0.0	1.1	0.0	0.0	0.0	3.6	2.6
26	0.0	0.0	5.0	5.0	4.7	0.0	0.0	0.0	0.0	2.3	2.8	1.2
27	1.3	0.0	5.4	6.6	2.7	1.6	1.4	0.0	0.0	0.0	2.9	6.5
28	0.0	0.0	5.5	7.1	1.6	0.0	0.0	0.0	0.0	1.1	2.4	0.0
29	2.9	5.3	13.4	9.5	5.7	0.0	1.5	0.0	0.0	2.1	1.2	2.5
30	5.8		4.9	15.6	3.0	0.0	0.0	0.0	0.0	2.7	3.0	1.9
31	2.4		2.9		0.0		0.0	0.0		1.9		1.4
Mean	1.4	1.1	3.9	12.6	5.5	0.6	0.5	0.2	0.2	0.6	2.4	1.8
Total	44.8	31.7	122.1	379.4	169.1	18.4	14.6	6.7	5.7	24.1	70.9	55.2
Min.	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max.	5.8	5.3	13.4	27.3	11.4	3.5	3.1	2.2	1.7	2.7	8.8	6.5

APPENDIX 1 Continued

Table 1.2 Daily Maximum Temperature (°C)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	31.9	32.4	32.9	31.0	27.7	26.0	25.4	25.7	27.5	30.0	31.3	31.1
2	31.8	33.0	32.8	31.0	27.7	25.6	25.2	25.3	27.7	30.0	31.3	31.2
3	31.7	32.9	33.4	31.1	27.8	26.2	25.4	26.2	27.5	29.3	31.5	31.2
4	31.7	32.7	33.2	30.5	27.4	25.9	24.9	26.1	27.4	30.0	31.7	31.6
5	31.9	32.7	33.2	30.2	26.9	26.1	25.4	25.5	28.2	30.1	31.6	31.6
6	32.2	33.3	33.1	30.4	27.5	26.0	25.0	26.0	27.7	30.2	31.8	31.2
7	31.2	33.0	32.9	30.1	27.8	26.2	25.3	25.7	27.6	30.6	31.2	30.9
8	32.0	33.1	33.0	29.9	27.2	26.1	25.4	25.8	27.9	29.9	30.9	31.1
9	32.2	32.9	32.9	30.1	27.5	26.0	25.7	25.9	27.8	29.9	31.5	30.8
10	31.8	33.5	32.7	29.8	27.1	25.8	26.0	25.7	27.8	30.2	31.4	31.1
11	31.9	33.3	32.6	29.3	26.8	26.2	25.8	26.5	28.6	30.3	31.4	31.1
12	32.1	32.8	33.3	29.6	27.4	25.9	25.4	25.8	28.5	30.1	31.0	30.9
13	31.8	33.1	32.8	29.7	26.9	26.2	25.5	25.7	28.2	30.6	31.1	31.1
14	31.7	32.5	33.1	29.7	26.9	26.0	24.8	25.5	28.4	30.9	31.6	30.8
15	31.9	32.6	31.8	28.9	27.1	25.5	24.8	26.1	28.6	31.0	31.3	30.9
16	31.8	33.1	32.7	28.8	26.3	25.6	25.0	26.0	28.5	30.6	31.8	31.1
17	31.9	33.0	32.2	28.9	27.2	25.6	25.2	25.9	28.6	30.8	31.3	31.0
18	32.2	32.6	32.3	28.8	26.8	25.3	25.8	26.4	29.0	31.0	31.0	31.0
19	32.1	33.0	32.2	28.9	26.0	25.3	26.1	26.8	28.7	31.0	30.9	31.4
20	32.1	33.1	32.2	28.5	26.5	25.4	25.6	26.1	29.0	30.8	30.9	30.9
21	32.8	33.2	31.6	28.4	26.1	25.0	25.2	26.9	28.8	31.5	31.1	31.4
22	32.5	32.6	32.2	28.6	26.3	25.4	25.1	26.6	28.6	31.1	31.7	31.3
23	32.7	33.0	32.4	28.8	26.4	25.2	25.6	26.4	29.1	31.1	31.6	31.2
24	32.2	33.0	31.7	28.6	26.4	25.1	25.1	26.6	29.1	31.2	31.4	31.7
25	32.5	32.7	31.6	27.8	26.8	24.8	25.3	26.6	29.0	31.6	31.4	31.6
26	32.5	33.2	31.3	28.4	26.2	25.6	25.5	25.7	29.2	31.6	31.2	31.8
27	32.6	33.3	31.5	28.1	26.5	25.3	25.7	26.7	29.4	31.7	30.8	31.3
28	32.9	33.4	30.9	28.1	26.3	25.7	25.4	27.1	29.4	31.5	31.0	31.2
29	33.0	32.4	31.3	27.8	25.8	25.4	25.5	27.6	30.2	31.4	31.2	31.8
30	32.7		30.7	27.9	25.9	25.1	25.5	27.4	30.5	31.2	31.4	32.2
31	32.4		30.9		26.5		25.8	27.1		31.5		31.7
Mean	32.1	33.0	32.3	29.2	26.8	25.7	25.4	26.2	28.5	30.7	31.3	31.3
Total	996.6	955.6	1001.4	877.5	831.8	769.5	787.5	813.3	856.5	952.7	939.3	969.2
Min.	31.2	32.4	30.7	27.8	25.8	24.8	24.8	25.3	27.4	29.3	30.8	30.8
Max.	33.0	33.5	33.4	31.1	27.8	26.2	26.1	27.6	30.5	31.7	31.8	32.2

APPENDIX 1 Continued

Table 1.3 Daily Minimum Temperature (°C)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	18.0	17.9	18.5	19.2	19.1	17.8	16.5	15.8	16.3	17.3	17.8	18.4
2	17.9	17.7	18.1	19.2	18.9	17.9	16.4	16.0	15.7	17.1	17.8	18.2
3	17.8	17.6	18.2	19.4	19.1	17.6	16.4	15.7	16.5	17.0	18.6	18.3
4	17.8	17.6	18.3	19.5	19.1	17.9	16.6	16.1	16.0	17.4	18.1	18.4
5	17.7	17.9	18.2	19.5	19.1	17.4	16.0	15.7	15.9	17.2	17.9	18.1
6	18.0	17.8	18.5	19.8	19.0	17.1	16.2	16.2	15.9	17.8	18.4	18.3
7	18.2	18.1	18.5	19.7	18.9	17.5	16.4	15.9	15.9	17.4	18.6	18.6
8	18.1	18.2	18.3	19.6	18.8	17.6	16.4	16.0	16.2	17.6	18.2	18.3
9	18.0	18.1	19.0	19.8	18.8	17.5	16.0	15.9	16.4	17.4	18.1	18.4
10	17.7	18.1	18.6	19.5	18.9	17.1	16.0	16.6	16.6	17.1	18.3	18.3
11	18.1	18.6	18.8	19.8	19.0	17.5	16.0	16.6	16.8	16.7	18.4	18.6
12	17.8	18.6	19.0	19.6	18.8	17.4	16.1	16.4	16.2	16.7	18.5	18.6
13	18.1	18.4	19.2	19.7	18.8	16.8	16.7	16.3	16.5	17.0	18.7	18.5
14	17.5	18.3	19.4	19.6	18.9	17.2	16.6	15.7	15.7	16.9	18.7	18.4
15	17.7	18.5	19.3	19.5	18.9	17.3	16.7	16.2	16.6	17.2	18.6	18.7
16	17.7	18.6	19.0	19.4	18.6	17.4	16.3	16.4	16.1	17.5	18.1	18.3
17	18.0	18.4	19.4	19.8	18.1	17.4	15.7	16.4	16.2	17.0	18.4	18.0
18	17.7	18.4	19.0	19.7	18.2	16.8	16.1	16.1	16.1	17.6	19.2	18.1
19	18.0	18.4	19.2	19.4	18.1	16.8	16.2	16.4	16.1	17.7	18.6	18.6
20	17.8	18.2	19.1	19.1	18.3	17.1	15.9	15.9	16.7	17.5	18.5	18.1
21	17.8	18.2	19.4	19.4	18.3	17.0	16.1	15.3	16.8	18.3	18.4	17.6
22	18.1	18.3	19.7	19.3	18.4	16.8	16.3	15.6	16.2	18.2	18.1	17.7
23	18.0	18.1	19.8	19.7	18.3	16.5	16.3	16.2	16.3	17.6	17.8	17.8
24	18.1	18.2	19.3	19.4	18.1	17.1	16.3	16.0	16.4	17.3	18.2	18.0
25	17.9	18.2	19.4	19.5	18.3	17.0	16.5	15.4	16.7	17.8	18.1	18.3
26	17.8	18.2	19.3	19.4	18.4	16.8	16.1	15.7	16.6	17.7	18.1	18.2
27	18.1	18.6	19.3	19.4	18.1	16.1	16.1	16.3	16.5	17.8	18.3	18.1
28	17.8	18.4	19.4	19.3	17.8	16.1	15.8	15.8	16.3	17.6	18.0	17.4
29	17.7	18.8	19.4	19.2	18.1	16.4	16.0	15.8	16.3	17.9	18.0	18.0
30	17.7		19.4	19.1	18.1	16.2	15.8	15.7	16.9	17.8	18.3	17.9
31	17.9		19.0		17.8		16.4	16.1		18.0		17.7
Mean	17.9	18.2	19.0	19.5	18.5	17.1	16.2	16.0	16.3	17.4	18.3	18.2
Total	554.5	528.5	588.9	584.3	574.9	513.1	503.0	496.5	489.2	540.9	549.0	563.9
Min.	17.5	17.6	18.1	19.1	17.8	16.1	15.7	15.3	15.7	16.7	17.8	17.4
Max.	18.2	18.8	19.8	19.8	19.1	17.9	16.7	16.6	16.9	18.3	19.2	18.7

APPENDIX 1 Continued

Table 1.4 Daily Dew Point Temperature (°C)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	16.3	16.2	16.5	17.2	18.7	16.7	15.2	13.6	13.9	13.2	14.7	16.2
2	16.7	15.6	16.4	17.6	19.2	16.6	14.5	13.5	13.8	13.7	14.6	16.2
3	17.0	16.2	15.8	17.8	18.9	16.2	14.3	13.8	18.5	14.2	15.5	17.0
4	17.2	16.1	16.0	18.5	19.0	16.4	14.6	13.6	14.3	14.0	15.4	16.8
5	16.8	15.8	16.6	18.4	18.8	16.0	14.8	13.6	14.0	13.9	15.3	16.6
6	16.6	16.0	17.1	17.4	18.8	16.3	14.9	13.9	13.1	13.8	16.2	16.7
7	16.7	14.9	16.5	18.3	18.1	15.9	14.5	13.9	13.6	13.8	16.2	16.8
8	16.0	16.2	15.4	18.3	18.3	15.7	14.0	13.9	13.4	14.5	15.7	17.5
9	16.4	15.9	15.5	18.2	18.6	15.6	14.7	14.2	13.7	14.5	15.6	17.5
10	16.2	16.0	15.2	16.9	18.8	15.5	14.8	14.4	13.7	14.0	16.0	17.1
11	16.4	16.0	15.8	18.6	18.1	16.0	14.0	14.2	13.5	13.7	16.4	17.2
12	16.8	16.3	15.6	18.8	18.3	15.6	14.7	14.3	13.5	13.8	15.9	17.6
13	16.2	16.2	15.8	18.3	18.7	15.5	14.3	13.7	13.8	13.7	16.3	17.0
14	16.2	17.2	16.9	18.5	18.0	15.3	14.1	13.5	13.6	14.2	16.4	17.2
15	15.8	17.0	17.1	18.9	17.7	15.5	14.3	13.3	12.9	13.8	15.8	16.7
16	16.6	16.7	16.3	19.3	17.9	15.3	14.1	14.5	12.6	14.3	16.1	17.4
17	17.1	15.8	16.6	18.7	17.7	15.5	13.8	14.1	13.2	14.1	16.4	17.1
18	16.6	16.2	16.5	18.9	17.7	15.3	14.0	13.9	13.1	14.1	16.0	16.7
19	16.5	16.2	16.5	18.8	17.5	15.0	14.0	13.6	14.0	13.6	15.8	17.3
20	16.1	16.6	16.2	18.7	17.7	14.8	14.2	13.6	14.2	14.7	16.5	17.8
21	15.2	17.1	17.3	18.7	17.9	14.8	14.4	13.8	13.9	13.5	16.2	17.6
22	15.9	16.4	16.7	19.1	18.1	15.1	14.5	13.6	13.0	14.3	16.2	16.7
23	16.6	16.3	16.8	18.9	17.8	15.4	14.5	14.0	13.0	13.8	15.5	17.4
24	16.4	16.0	17.3	18.8	17.8	15.3	14.6	13.6	13.5	13.8	16.8	17.2
25	16.2	15.7	17.1	18.5	17.8	15.1	14.2	12.9	13.5	14.0	16.1	17.4
26	16.1	15.3	17.4	18.9	17.6	14.8	13.8	13.7	13.5	14.1	16.7	16.9
27	16.2	15.9	17.0	19.5	17.3	15.3	14.0	13.7	13.3	14.3	16.3	16.6
28	15.8	16.2	17.9	18.5	17.3	15.2	13.9	13.6	13.3	14.6	16.1	16.4
29	16.1	16.9	17.5	18.9	17.5	15.4	13.4	13.6	13.2	14.9	16.9	17.1
30	15.7		17.7	18.6	17.2	14.8	13.9	13.4	13.3	14.8	16.9	16.6
31	16.6		18.1		16.5		13.6	14.0		14.2		15.9
Mean	16.4	16.2	16.6	18.5	18.0	15.5	14.3	13.8	13.7	14.1	16.0	17.0
Total	507.0	469.1	515.1	554.6	558.9	466.0	442.4	427.2	409.8	435.7	480.3	526.3
Min.	15.2	14.9	15.2	16.9	16.5	14.8	13.4	12.9	12.6	13.2	14.6	15.9
Max.	17.2	17.2	18.1	19.5	19.2	16.7	15.2	14.5	18.5	14.9	16.9	17.8

APPENDIX 1 Continued

Table 1.5 Daily Maximum Relative Humidity (%)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	86	84	78	85	88	90	89	85	83	80	83	87
2	86	82	81	88	92	92	86	86	84	86	88	82
3	84	81	75	89	89	89	89	87	81	85	85	85
4	84	82	75	88	89	89	88	90	87	79	88	85
5	84	83	78	91	93	93	87	90	87	83	85	83
6	84	79	76	88	89	91	87	90	82	79	84	88
7	82	79	78	91	92	85	86	88	81	85	78	87
8	87	81	82	89	91	86	84	87	80	86	84	91
9	87	83	79	91	91	90	86	87	82	89	81	89
10	84	88	80	91	89	90	87	90	82	86	91	89
11	83	82	81	88	91	84	88	85	79	84	86	88
12	86	87	80	90	91	89	87	92	79	83	87	87
13	83	80	81	88	92	86	87	91	80	85	88	84
14	87	82	81	89	92	88	84	87	81	86	87	85
15	85	84	83	89	88	90	83	89	79	86	88	90
16	85	89	81	88	90	85	85	88	78	86	91	90
17	82	84	83	88	91	87	85	88	81	84	86	92
18	85	80	83	88	90	91	84	88	82	85	85	86
19	83	76	80	92	92	90	87	85	83	84	84	86
20	86	78	84	94	89	88	86	86	82	86	89	89
21	85	80	83	93	91	87	83	87	83	85	88	85
22	82	81	82	92	91	88	87	80	82	85	90	83
23	82	76	82	90	91	90	87	85	82	87	89	85
24	85	75	81	91	89	89	90	84	82	86	83	85
25	83	78	81	92	94	85	89	86	78	85	84	87
26	83	78	78	91	94	85	88	86	82	88	84	84
27	80	80	80	91	92	86	91	83	81	86	84	83
28	80	81	84	91	92	87	89	82	79	87	86	83
29	81	73	83	91	92	86	87	88	79	88	88	86
30	77		83	92	90	89	87	82	81	89	87	85
31	87		85		90		88	85		85		90
Mean	84	81	81	90	91	88	87	87	81	85	86	86
Total	2598	2347	2501	2698	2815	2646	2691	2687	2438	2638	2578	2680
Min.	77	73	75	85	88	84	83	80	78	79	78	82
Max.	87	89	85	94	94	93	91	92	87	89	91	92

APPENDIX 1 Continued

Table 1.6 Daily Minimum Relative Humidity (%)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	45	40	46	48	63	62	54	50	47	38	41	49
2	45	40	45	50	64	64	57	50	46	39	40	49
3	45	38	42	49	58	60	54	50	47	42	38	48
4	48	40	40	53	66	60	56	51	48	40	40	46
5	45	41	43	54	64	57	55	51	44	41	40	46
6	44	40	44	52	63	59	56	50	44	41	41	47
7	46	38	47	54	60	56	53	51	46	40	46	49
8	41	41	42	58	62	59	54	50	44	43	42	47
9	43	41	42	54	62	58	53	53	44	44	42	50
10	44	39	43	57	65	58	53	56	46	40	42	47
11	44	42	45	59	64	57	52	52	43	40	43	50
12	49	40	41	56	63	56	55	52	43	38	48	48
13	41	40	42	53	64	55	56	52	44	40	42	47
14	42	42	44	58	64	57	55	52	43	39	41	47
15	44	46	50	57	62	58	55	49	42	38	42	51
16	45	42	44	61	64	57	54	51	40	39	43	52
17	46	41	43	62	62	60	52	51	42	37	40	50
18	42	42	47	59	60	55	52	51	42	39	44	48
19	42	43	45	58	64	56	50	48	44	39	44	48
20	44	43	44	59	64	59	52	50	44	40	44	48
21	38	43	52	62	67	56	54	48	43	38	46	50
22	41	43	46	59	65	55	54	49	40	40	44	45
23	40	43	45	59	61	56	53	49	42	37	43	46
24	42	41	50	60	64	61	55	48	42	38	44	46
25	41	41	53	65	63	57	54	47	41	38	47	49
26	43	37	53	61	64	57	51	49	40	37	43	50
27	43	41	46	65	63	56	52	48	40	36	50	45
28	40	41	53	62	62	56	51	47	38	37	46	46
29	41	51	52	62	63	57	52	45	40	38	45	42
30	36		53	62	62	56	52	46	40	40	48	45
31	41		50		62		52	48		40		44
Mean	43	41	46	58	63	58	53	50	43	39	43	48
Total	1330	1198	1430	1730	1954	1728	1656	1544	1286	1216	1300	1473
Min.	36	37	40	48	58	55	50	45	38	36	38	42
Max.	49	51	53	65	67	64	57	56	48	44	50	52

APPENDIX 1 Continued

Table 1.7 Daily Sunshine Hours (h/day)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	9.1	8.8	7.9	7.1	4.5	5.1	4.9	4.7	6.3	7.6	8.8	8.0
2	8.6	9.9	8.2	7.9	5.3	3.9	5.6	4.8	6.7	7.4	8.4	8.2
3	9.1	8.5	8.5	7.5	5.8	4.6	4.8	5.4	5.4	6.7	8.6	7.9
4	8.8	8.9	8.8	7.4	4.8	4.8	4.6	5.7	6.2	7.5	8.2	8.4
5	8.7	9.3	8.3	6.2	4.2	5.4	3.8	5.0	6.6	7.4	8.8	8.7
6	8.7	9.1	9.1	7.0	5.1	4.5	4.2	5.1	5.6	7.6	8.6	8.2
7	8.0	8.6	7.9	6.1	4.7	5.0	4.7	3.8	6.0	7.7	7.2	7.9
8	9.0	8.8	8.9	6.4	4.4	4.3	5.3	4.8	6.7	7.0	7.6	8.2
9	9.3	9.1	8.8	6.4	5.5	4.5	5.2	4.3	6.5	7.6	8.3	7.8
10	8.6	9.1	8.2	5.9	4.9	4.8	5.0	5.2	5.9	7.7	8.0	8.7
11	9.0	9.0	7.6	5.4	4.4	4.8	5.3	5.3	7.6	8.4	8.5	7.4
12	9.1	8.6	8.9	6.6	5.9	5.2	3.6	4.5	7.3	8.5	7.7	7.6
13	8.9	9.0	7.5	6.7	5.4	5.7	4.2	4.6	7.1	7.7	8.5	8.4
14	9.4	8.6	7.6	6.6	4.8	4.9	3.0	4.7	7.1	8.3	8.7	6.9
15	8.3	8.0	6.7	7.1	4.7	4.8	4.2	4.2	7.3	8.0	8.5	8.5
16	8.3	8.5	8.1	5.3	3.7	4.5	3.8	4.6	7.2	7.2	8.7	8.7
17	8.7	8.3	8.1	6.3	4.9	3.7	4.7	4.6	7.6	8.9	8.1	8.1
18	9.1	8.7	7.5	6.3	5.2	3.5	5.3	5.4	7.6	8.2	7.8	7.8
19	8.9	9.1	7.6	6.2	3.9	3.9	6.2	6.0	6.8	8.4	8.4	8.5
20	9.3	9.1	8.0	6.1	3.8	4.4	4.9	5.1	7.4	8.1	7.2	9.1
21	9.3	8.8	6.8	6.5	3.8	4.5	4.3	6.6	7.0	8.8	8.7	8.3
22	9.1	8.8	7.3	6.3	4.0	4.7	3.9	6.2	8.1	8.7	8.8	8.6
23	9.1	9.1	7.5	6.7	4.3	4.5	4.0	4.9	7.8	8.6	9.0	7.8
24	8.3	8.6	7.1	6.0	4.1	3.5	3.2	5.3	7.0	9.0	8.4	8.9
25	9.0	9.2	7.3	5.7	4.3	3.5	4.3	6.2	6.7	9.0	8.5	8.6
26	9.2	9.1	6.5	5.6	4.0	5.0	4.6	5.3	7.5	8.8	7.9	8.4
27	8.7	9.0	7.7	5.0	4.6	5.3	5.0	5.5	8.0	9.3	7.5	8.1
28	9.4	8.7	6.3	5.6	5.1	5.1	3.7	6.3	8.3	8.3	8.1	8.8
29	9.8	8.4	7.4	5.3	3.4	4.1	4.2	6.7	8.0	8.7	9.1	9.5
30	9.8		7.0	5.3	4.3	3.8	6.1	7.1	7.6	8.1	8.8	9.8
31	8.8		7.3		4.8		5.4	5.3		8.7		8.9
Mean	9.0	8.9	7.7	6.3	4.6	4.5	4.6	5.3	7.0	8.1	8.3	8.3
Total	277.5	256.7	240.1	188.2	142.7	136.3	141.1	163.2	210.9	251.6	249.2	258.7
Min.	8.0	8.0	6.3	5.0	3.4	3.5	3.0	3.8	5.4	6.7	7.2	6.9
Max.	9.8	9.9	9.1	7.9	5.9	5.7	6.2	7.1	8.3	9.3	9.1	9.8

APPENDIX 1 Continued

Table 1.8 Daily Wind Run (km/day)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	150	139	165	146	86	63	57	73	127	185	173	151
2	134	149	154	161	85	58	58	86	123	193	178	159
3	117	149	154	164	73	56	63	82	115	175	185	152
4	131	143	156	142	68	61	72	80	113	170	194	157
5	137	134	154	118	73	59	73	92	117	178	197	155
6	135	144	163	127	66	61	69	83	115	176	212	132
7	133	146	161	119	73	66	71	81	132	198	206	132
8	134	136	188	120	71	61	71	86	179	185	186	146
9	146	142	182	124	79	59	66	90	152	171	184	142
10	139	152	189	122	70	57	67	82	139	166	181	131
11	132	139	187	108	72	65	71	79	153	199	186	141
12	148	133	194	114	67	68	61	84	145	196	176	137
13	143	148	168	104	70	69	65	87	142	199	192	136
14	139	136	159	120	62	60	73	89	142	205	176	141
15	123	139	155	101	67	64	59	87	143	186	197	126
16	122	153	197	112	66	64	61	86	158	185	194	141
17	132	126	177	111	66	62	66	90	151	199	184	120
18	124	134	161	100	77	63	71	88	139	207	180	124
19	133	130	268	105	72	56	70	95	157	187	181	124
20	138	140	180	98	80	54	67	96	161	189	185	138
21	143	142	156	101	70	59	73	91	163	199	170	132
22	124	148	161	87	70	63	69	84	162	203	173	132
23	140	144	162	88	70	65	76	99	161	186	169	129
24	138	159	168	99	70	64	75	95	165	195	157	127
25	143	152	154	95	62	66	76	103	152	213	172	116
26	147	150	142	85	63	71	74	112	157	220	148	119
27	143	151	167	78	62	65	75	105	168	203	144	116
28	147	180	140	85	64	57	74	106	168	194	165	118
29	148	236	138	92	67	65	73	117	188	199	168	137
30	156		139	88	66	66	71	101	199	211	135	141
31	145		133		66		73	116		194		128
Mean	138	147	167	110	70	62	69	92	150	192	178	135
Total	4263	4275	5173	3314	2171	1865	2139	2845	4485	5967	5350	4180
Min.	117	126	133	78	62	54	57	73	113	166	135	116
Max.	156	236	268	164	86	71	76	117	199	220	212	159

APPENDIX 1 Continued

Table 1.9 Daily Evaporation (mm/day)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	8.0	9.1	9.5	7.7	4.2	4.2	4.1	5.2	5.9	8.5	8.9	7.6
2	7.7	9.1	9.1	8.0	3.4	3.8	4.2	5.7	6.3	8.4	9.0	7.8
3	7.9	9.5	9.0	7.3	4.2	4.1	4.0	6.4	5.9	8.6	9.7	8.4
4	7.9	9.2	8.9	6.1	3.9	4.0	4.0	5.3	5.9	8.7	8.9	8.7
5	8.6	9.1	9.0	5.5	3.8	3.2	4.6	4.8	7.0	8.3	8.6	8.6
6	7.8	9.0	9.9	6.5	4.0	3.8	4.9	5.4	6.5	8.5	9.0	8.6
7	8.0	9.4	9.0	5.2	4.3	4.3	4.6	4.5	6.5	8.2	8.7	8.8
8	7.3	8.8	8.7	5.9	4.3	4.0	4.6	4.7	6.2	7.8	7.8	7.8
9	8.4	9.7	8.6	5.4	3.6	4.2	4.7	5.4	6.3	7.4	9.3	8.2
10	7.8	9.0	8.9	5.4	4.6	4.2	4.6	5.5	6.6	7.8	9.5	7.1
11	7.6	8.0	9.0	5.4	4.3	4.4	4.2	5.2	7.2	8.1	9.7	7.8
12	7.5	7.1	9.4	5.7	4.3	4.1	4.7	5.5	7.5	8.9	8.9	7.8
13	7.2	9.0	9.2	5.5	3.6	4.0	3.9	5.3	7.5	9.0	9.0	8.4
14	7.4	9.3	8.7	5.2	3.6	4.3	4.7	4.9	6.7	8.7	10.0	8.7
15	7.1	8.7	8.0	4.8	3.4	3.9	4.2	5.0	7.7	8.9	9.4	8.4
16	6.3	8.6	8.2	5.9	3.9	3.8	4.5	5.3	7.6	9.0	10.1	7.7
17	7.2	10.1	7.9	5.6	4.0	4.3	4.4	4.5	7.8	9.5	9.1	7.7
18	6.5	9.4	7.0	5.4	3.6	4.4	4.4	4.9	7.6	8.7	9.2	8.5
19	7.6	9.7	6.9	4.9	3.8	4.3	5.2	7.1	8.0	9.0	9.1	9.2
20	7.5	9.7	7.1	4.8	4.0	4.0	5.0	5.2	8.3	9.2	9.0	8.4
21	7.9	8.8	7.2	5.3	4.0	4.3	4.4	5.3	7.6	9.6	9.1	9.2
22	8.7	9.4	7.5	5.2	4.5	3.8	3.9	5.6	7.3	9.4	9.2	8.9
23	8.5	9.5	6.9	5.1	3.7	4.3	4.8	5.3	8.2	8.4	9.6	7.6
24	7.8	9.8	6.5	5.6	3.5	3.9	4.4	4.9	8.2	8.8	8.4	8.0
25	7.8	9.7	6.9	4.7	3.5	3.4	4.6	5.3	7.6	9.3	8.8	8.2
26	8.9	9.6	7.4	4.8	4.4	4.3	4.6	5.8	8.5	9.2	9.3	8.7
27	8.9	10.1	7.9	4.9	4.1	4.3	4.8	5.7	8.0	8.2	8.8	8.1
28	7.4	9.5	7.8	4.9	4.2	3.9	4.5	5.5	8.9	9.4	8.4	8.5
29	7.4	9.0	7.1	4.8	4.0	4.3	5.2	6.7	8.4	9.3	8.4	8.9
30	9.0		7.1	4.3	3.7	4.1	5.1	6.0	8.1	8.3	8.5	8.9
31	9.0		6.7		3.8		5.0	6.0		8.9		7.6
Total	1242.6	266.9	250.9	165.9	122.0	122.1	140.7	168.0	219.7	269.8	271.3	256.7
Mean	7.8	9.2	8.1	5.5	3.9	4.1	4.5	5.4	7.3	8.7	9.0	8.3
Min.	6.3	7.1	6.5	4.3	3.4	3.2	3.9	4.5	5.9	7.4	7.8	7.1
Max.	9.0	10.1	9.9	8.0	4.6	4.4	5.2	7.1	8.9	9.6	10.1	9.2

APPENDIX 1 Continued

Table 1.10 Climatic Data for Musa Mwinjanga Irrigation Scheme Adopted During Rehabilitation.

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chekeroni Station (Lat. 03°23'S, Long. 37°22' E; Altitude 725 m; Recording Period 1982-1989)													
P (mm)	548	37	33	51	150	86	18	20	12	7	26	43	65
T (°C)	25.0	26.4	27.2	27.8	26.2	23.7	22.6	22.1	22.5	23.8	25.5	26.0	26.0
RH (%)	71	68	65	69	75	78	76	73	74	68	66	67	69
WS (km/h)	5.8	0.7	9.1	12.5	6.8	3.7	2.6	2.0	2.8	5.3	7.3	5.7	3.2
SH (h/day)	6.9	10.1	9.8	9.2	6.5	3.7	5.3	0.9	5.3	5.5	7.1	7.9	8.8
SR (cal/cm^2/day)	4.7	5.9	5.9	5.9	4.6	3.4	3.6	3.3	4.0	4.3	5.1	5.3	5.5
Eo (mm)	1911	206	213	242	165	112	110	106	120	151	169	161	156
Station 93.37/029 (Representative for Musa Mwinjanga Scheme According to FAO (1986a))													
P (mm)	694	36	45	88	237	129	17	7	11	14	27	35	48

APPENDIX 2 SOILS OF MUSA MWINJANGA IRRIGATION SCHEME

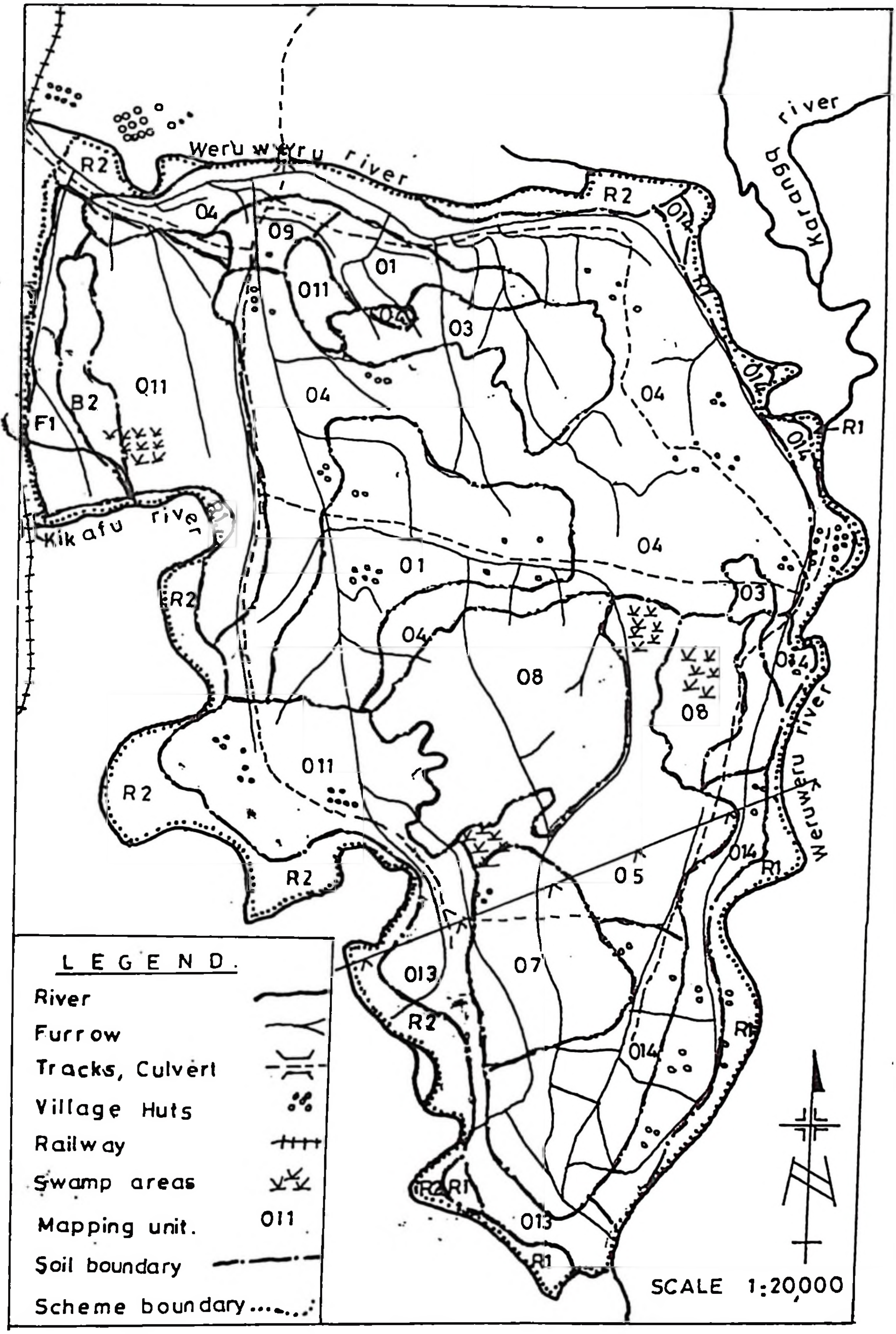


Fig. 2.1 Soils of Musa Mwinjanga Irrigation Scheme

SOURCE: Kips and Ndondi (1990)

APPENDIX 2 Continued

Table 2.1 Soil Fertility Data of Musa Mwinjanga Soils

Mapping Unit	Texture Class	pH H_2O	ECe	Org. C	Total N	Avail. P	CEC and Exchangeable Bases					BS	ESP
							CEC	Ca	Mg	K	Na		
			mS/cm	%	%	mg/kg	me/100 g					%	%
Volcanic Outwash Plain (O-soils)													
O1, O2	SCL-grSCL	7.5	0.13	1.1	0.10	>37	15.8	10.3	4.0	1.89	0.18	>100	1
O3	CL-C	7.4	0.15	0.9	0.09	>40	24.1	8.8	3.4	1.76	0.61	75	3
O4	CL-C	7.5	0.08	0.9	0.09	>35	20.2	10.2	3.7	1.84	0.15	79	1
O5	CL-SCL	7.6	0.09	1.1	0.12	23	19.4	8.8	4.0	1.70	0.28	78	2
O7	L	7.7	0.06	1.0	0.10	32	19.6	10.9	3.8	3.25	0.12	92	1
O8	CL-C	9.0	0.29	1.1	0.12	>35	28.3	13.7	6.6	3.17	3.30	95	11
O9	SCL	7.3	0.07	1.3	0.11	>32	17.4	12.0	4.2	2.20	0.29	>100	2
O11	CL-C	7.2	0.09	1.1	0.11	>38	19.9	11.2	4.7	2.29	0.26	93	1
O13	SiL-L	7.4	0.13	2.0	0.19	31	37.0	20.5	6.6	3.44	0.48	84	1
O14	fSL	7.6	0.06	2.0	0.20	28	28.8	16.5	5.6	4.03	0.58	93	2
Mbuga (B-soils)													
B2	C	8.6	0.47	2.8	0.24	36	29.1	22.4	6.5	3.00	3.10	>100	11
River Flood Plain (R-soils)													
R1	fSL-SiCL	7.5	0.12	1.6	0.16	23	21.0	13.3	3.9	2.54	0.26	95	1
R2	fSL-L-SiCL	7.3	0.17	1.8	0.17	>30	32.1	19.4	6.4	3.37	0.41	92	1
Foot of Minor Scarp (F-soils)													
F1	C	6.9	0.11	0.7	0.08	26	24.1	10.5	4.0	2.31	0.04	70	0

SOURCE: Kips and Ndondi (1990)

APPENDIX 3 QUALITY OF IRRIGATION WATER

Table 3.1 Results of Surface Water Samples for Musa Mwinjanga Irrigation Scheme

Location	Sample number	pH	Ecw	Ca	Mg	Na	HCO3	CO3	Cl	SAR	AdjRNa
			mS/cm	me/l							
- Primary furrow close to intake	MW1	7.3	0.17	0.25	0.16	1.48	0.2	0.0	0.9	3	1
- Mzee Kondo Secondary furrow	MW2	7.3	0.18	0.25	0.25	1.35	0.1	0.0	0.9	3	1
- Musa Mwinjanga Secondary furrow	MW3	7.4	0.18	0.25	0.16	1.39	0.2	0.0	1.0	3	1

Samples were taken in march, 1989, before the start of the rainy season.

SOURCE: Kips and Ndondi (1990)

APPENDIX 4

KEY PROBES FOR DIAGNOSTIC ANALYSIS OF THE STUDY AREA

1. What are the nature, extent and effects of upstream, middle and tail end deprivation?
2. Which farmers do not irrigate fully, when, and why?
3. What do farmers, especially in the tails, know about what water they will receive and when it will come?
4. Could some farmers do as well or better with less water?
5. How and by whom are water allocation, scheduling and delivery decisions made and implemented?
6. How does individual farmer liaise and interact with water committee members?
7. What incentives do the water committee members have to manage badly or well?
8. What happens at night?
9. Who is responsible in maintaining/cleaning the canals?
10. What does the water committee know and not know, and how accurately, about water movement and delivery, crops, cropping calendar, cropped areas, and crop stages on the system?
11. What software changes could improve performance using existing hardware?
12. What happens when and where water is scarce?
13. What is the average irrigation intervals for paddy and upland crops respectively?

14. How much does the individual farmers pay to cover for the running costs of operation and maintenance of the system?
15. What is the control capacity of the system; how much is used?
16. Do the leaders given priority in receive water for irrigation?
17. How much water is available?
18. How could farmers gain more from the way the system is managed?
19. How does conflicts arising from water allocation and distribution resolved?
20. Are the by-laws against Irrigation mall-practices being enforced?
21. How does land preparation being implemented?
22. What is the physical condition of the system irrigation infrastructures?

APPENDIX 5 IRRIGATION EFFICIENCIES

Table 5.1 Conveyance Efficiency of Musa Mwinjanga Main Canal (MMC)

Date	Intake (l/s)	Offtake MMC/TC1 (l/s)	Offtake MMC/TC2 (l/s)	Offtake MMC/TC3 (l/s)	Offtake MMC/MKSC (l/s)	MMC/MMSC (l/s)	Losses (l/s)	Losses (l/s/km)	Ec (%/km)
15.11.95	497	115	-	-	214	120	48	52.2	89.5
20.11.95	495	82	-	-	218	146	49	53.3	89.2
25.11.95	492	102	-	-	210	134	46	50.0	89.8
30.11.95	490	98	-	-	189	156	47	51.1	89.6
05.12.95	490	85	-	-	188	170	47	51.1	89.6
10.12.95	486	95	-	-	223	124	44	47.8	90.2
15.12.95	484	86	-	-	214	138	46	50.0	89.7
20.12.95	484	92	-	-	228	120	44	47.8	90.1
26.12.95	480	90	35	-	198	106	51	55.4	88.5
30.12.95	478	104	-	-	218	115	41	44.6	90.7
05.01.96	478	100	-	-	210	128	40	43.5	90.9
10.01.96	474	98	-	-	203	132	41	44.6	90.6
15.01.96	474	89	-	-	216	128	41	44.6	90.6
20.01.96	470	95	-	-	245	88	42	45.7	90.3
25.01.96	465	85	-	-	182	160	38	41.3	91.1
30.01.96	458	14	-	-	249	155	40	43.5	90.5
06.02.96	458	46	-	32	259	78	43	46.7	89.8
10.02.96	475	86	-	-	240	108	41	44.6	90.6
15.02.96	474	91	-	-	244	100	39	42.4	91.1
20.02.96	474	88	-	-	223	122	41	44.6	90.6
25.02.96	473	89	-	-	221	122	41	44.6	90.6
05.03.96	473	92	-	-	221	120	40	43.5	90.8
10.03.96	470	94	-	-	241	95	40	43.5	90.7
15.03.96	470	98	-	-	234	100	38	41.3	91.2
20.03.96	469	91	-	-	223	115	40	43.5	90.7
25.03.96	487	95	-	42	195	105	50	54.3	88.8
30.03.96	486	106	-	-	182	146	52	56.5	88.4
AVERAGE	477.9	89.1	35.0	37.0	218.1	123.4	43.3	47.1	90.2
STD	10.3	19.1	7.1	20.7	22.6	4.1	4.5	4.4	0.783
CV	0.022	0.214	0.191	0.095	0.183	0.095	0.095	0.080	0.009

The average Conveyance Efficiency (Ec) for Musa Mwinjanga Main Canal is 90.2% per km.

APPENDIX 5 Continued

Table 5.2 Conveyance Efficiency of Secondary Canals

(a) Conveyance Efficiency of Musa Mwinjanga Secondary Canal

Date	Offtake MMC/MMSC (l/s)	Offtake MMSC/TC1 (l/s)	Offtake MMSC/TC2 (l/s)	Offtake MMSC/TC3 (l/s)	Offtake MMSC/TC4 (l/s)	MMSC (l/s)	Losses (l/s)	Losses (l/s/km)	Ec (%/km)
02.12.95	165	-	-	80	-	68	17	17.3	89.5
03.12.95	158	34	-	55	-	54	15	15.3	90.3
04.12.95	143	-	-	42	45	42	14	14.3	90.0
07.12.95	130	-	25	54	-	39	12	12.2	90.6
08.12.95	115	-	-	67	-	38	10	10.2	91.1
AVERAGE	142.2	34.0	25.0	59.6	45.0	48.2	13.6	13.9	90.3
STD	20.4			14.4		12.8	2.7	2.8	0.6
CV	0.143			0.242		0.265	0.199	0.199	0.007

The average conveyance efficiency (Ec) for Musa Mwinjanga Secondary Canal is 90.3% per km.

(b) Conveyance Efficiency of Mzee Kondo Secondary Canal

Date	Offtake MMC/MKSC (l/s)	Offtake MKSC/TC1 (l/s)	Offtake MKSC/TC2 (l/s)	Offtake MKSC/TC3 (l/s)	Offtake MKSC/TC4 (l/s)	MKSC (l/s)	Losses (l/s)	Losses (l/s/km)	Ec (%/km)
22.11.95	168	48	-	-	101	-	19	19.4	88.5
06.12.95	218	46	28	38	79	-	27	27.6	87.4
20.12.95	234	50	-	-	153	-	31	31.6	86.5
03.01.96	184	50	32	36	44	-	22	22.4	87.8
17.01.96	245	47	30	-	135	-	33	33.7	86.3
AVERAGE	209.8	48.2	30.0	37.0	102.4		26.4	26.9	87.3
STD	32.8	1.8	2.0	1.4	43.5		5.9	6.0	0.914
CV	0.156	0.037	0.067	0.038	0.425		0.223	0.223	0.010

The average conveyance efficiency (Ec) for Mzee Kondo Secondary Canal is 87.3% per km.

The average conveyance efficiency for Secondary Canals, Ec $= 1/2*(87.3 + 90.3)$
$= 88.8\%$ per km.

APPENDIX 5 Continued

Table 5.3 Conveyance Efficiency of Tertiary Canals

(a) Conveyance Efficiency of Kaurwa Tertiary Canals (MMC/KTC)

	MMC/TC1	MMC/DTC	KTC/LQC	KTC/AQC	MMC/KTCd	LOSSES		Ec
						(1/s)	(1/s/km)	(%/km)
	105	68	-	10	21	6	9.6	90.9
	88	45	-	-	38	5	8.0	90.9
	75	35	20	-	15	5	8.0	89.3
	85	53	-	18	9	5	8.0	90.6
	98	56	-	-	36	6	9.6	90.2
AVER	90.2	51.4	20	14	23.8	5.4	8.6	90.4
STD	11.65	12.34		5.66	12.80	0.55	0.88	0.67
CV	0.129	0.240		0.404	0.538	0.101	0.101	0.007

NOTE:
MMC/TC1 = Tertiary Canal Offtake
MMC/DTC = Dutu Tertiary Canal
KTC/LQC = Alfani Quaternary Canal
KTC/ATC = Abdallah Quaternary Canal
MMC/KTCd = Kaurwa Tertiary Canal downstream

(b) Conveyance Efficiency of Joseph Tertiary Canal (MKSC/JTC)

	MKSC/JTCu	JTC/QC1	JTC/QC2	JTC/QC3	MKSC/JTCd	LOSSES		Ec
						(1/s)	(1/s/km)	(%/km)
	30.0	-	-	13.0	16.0	1.0	2.0	93.2
	28.0	16.0	-	-	11.0	1.0	2.0	92.7
	32.0	-	20.0	-	11.0	1.0	2.0	93.6
	32.0	-	-	15.0	16.0	1.0	2.0	93.6
	25.0	24.0	-	-	-	1.0	2.0	91.8
AVER	29.4	20.0	20.0	14.0	13.5	1.0	2.0	93.0
STD	2.97	5.66		1.41	2.89	0.00	0.00	0.756
CV	0.101	0.283		0.101	0.214	0.000	0.000	0.008

NOTE:
MKSC/JTCu = Joseph Tertiary Canal Offtake
JTC/QC1 = Quaternary Canal
JTC/QC2 = Quaternary Canal
JTC/QC3 = Rashidi Quaternary Canal
MKSC/JTCd = Joseph Tertiary Canal downstream

APPENDIX 5 Continued

(c) Conveyance Efficiency for Miembeni Tertiary Canal

	MMSC/TC13u	TC13/QC1	TC13/QC2	TC13/QC3	TC13/QC4	MMSC/TC13d	LOSSES (l/s)	LOSSES (l/s/km)	Ec (%/km)
	23.0	-	-	21.0	-	-	2.0	2.6	88.7
	25.0	-	23.0	-	-	-	2.0	2.6	89.6
	22.0	20.0	-	-	-	-	2.0	2.6	88.2
	28.0	-	-	-	25.0	-	3.0	3.9	86.1
	29.0	-	-	-	-	27.0	2.0	2.6	91.0
AVER	25.4	20.0	23.0	21.0	25.0	27.0	2.2	2.9	88.7
STD	3.0						0.4	0.6	1.81
CV	0.1						0.2	0.2	0.02

NOTE:
MMSC/TC13u = Tertiary Canal Offtake
TC13/QC1 = Quaternary Canal TC13/QC1
TC13/QC2 = Quaternary Canal TC13/QC2
TC13/QC3 = Shabani Kisavuli Quaternary Canal
TC13/QC4 = Mzee Makopo Quaternary Canal
MMSC/TC13d = Mwembeni Tertiary Canal downstream

The average conveyance efficiency for tertiary canals is:

$$Ec = \Sigma(Li*Ecimean)/\Sigma(Li)$$

$$= (0.625*90.4+0.49*93+0.77*88.7)/(0.625+0.49+0.77)$$

$$= 90.4\% \text{ per Km.}$$

APPENDIX 5 Continued

Table 5.4 Determination of Field Application Efficiency

(a) Plot No.: **PL1** Crop: Maize Plot Size: 0.81 ha

Planted Date: 22.11.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	27	16.9	0.4	16.6	38.7	22.1	42.8
December	7	27.0	2.9	24.2	56.9	32.7	42.5
	21	48.0	0.4	47.6	74.7	27.1	63.7
January	4	74.5	0.0	74.5	96.1	21.6	77.5
	19	32.2	0.0	32.2	93.4	61.2	34.5
	25	39.2	0.0	39.2	85.4	46.2	45.9
February	1	56.6	0.0	56.6	69.4	12.8	81.5
	11	38.7	0.0	38.7	74.7	36.0	51.9
	18	54.1	0.0	54.1	69.4	15.3	78.0
	28	92.4	1.2	91.2	80.1	-11.1	113.9
TOTAL		479.8	4.9	474.9	738.8	263.9	
AVERAGE		48.0	0.5	47.5	73.9	26.4	63.2
STD		22.6	0.9	22.7	17.0	19.7	24.6
CV		0.5	1.9	0.5	0.2	0.7	0.4

(b) Plot No.: **PL2** Crop: Paddy Plot Size: 0.51 ha

Nursery Date: 06.09.1995 Transplanting Date: 22.10.1995

Month	Date	ET_c	P_e	S&P	I_n	WD	Al	Ea
November	18	42.2	0.1	23.8	65.9	175.1	109.2	37.6
	25	58.3	0.1	34.0	92.2	149.4	57.2	61.7
	5	39.5	1.2	23.8	62.1	162.3	100.2	38.2
December	12	27.6	1.1	17.0	43.5	145.2	101.7	29.9
	17	85.3	0.9	51.0	135.4	175.1	39.7	77.3
January	1	23.5	0.0	13.6	37.1	121.0	83.9	30.7
	5	29.0	0.0	17.0	46.0	153.7	107.7	29.9
	10	28.2	0.0	17.0	45.2	162.3	117.1	27.9
	15	16.1	0.0	10.2	26.3	93.9	67.6	28.0
	18	16.2	0.0	10.2	26.4	83.3	56.9	31.7
	21	26.9	0.0	17.0	43.9	149.4	105.5	29.4
	26	47.4	0.0	30.6	78.0	132.4	54.4	58.9
TOTAL		440.3	3.5	265.2	702.0	1703.1	1001.1	
AVERAGE		36.7	0.3	22.1	58.5	141.9	83.4	40.1
STD		19.8	0.5	11.7	31.3	29.5	26.8	16.5
CV		0.5	1.6	0.5	0.5	0.2	0.3	0.4

APPENDIX 5 Continued

(c) Plot No.: PL3 Crop: Maize Plot Size: 0.61 ha

Planted Date: 25.11.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	26	15.2	0.1	15.1	42.7	27.6	35.3
December	5	23.4	2.8	20.7	59.3	38.6	34.8
	19	20.2	0.2	19.9	54.6	34.7	36.5
	27	58.4	0.0	58.4	68.8	10.4	84.8
January	11	30.5	0.0	30.5	80.7	50.2	37.8
	17	53.7	0.0	53.7	83.0	29.3	64.6
	27	28.1	0.0	28.1	94.9	66.8	29.7
February	1	28.0	0.0	28.0	90.1	62.1	31.1
	6	78.3	0.0	78.3	80.7	2.4	97.1
	20	94.1	0.2	93.9	83.0	-10.9	113.1
March	9	57.9	1.5	56.3	80.7	24.4	69.8
TOTAL		487.8	4.9	482.9	818.5	335.6	
AVERAGE		44.3	0.4	43.9	74.4	30.5	57.7
STD		25.9	0.9	26.0	16.1	24.0	29.9
CV		0.6	2.0	0.6	0.2	0.8	0.5

(d) Plot No.: PL4 Crop: Paddy Plot Size: 0.4 ha

Nursery Date: 15.09.1995 Transplanting Date: 20.10.1995

Month	Date	ET_c	P_e	S&P	I_n	WD	Al	Ea
November	20	76.9	0.3	44.2	120.8	135.2	14.4	89.4
December	3	56.5	1.7	34.0	88.8	113.9	25.1	78.0
	13	44.5	1.5	27.2	70.3	128.1	57.8	54.9
	21	39.4	0.4	23.8	62.7	117.4	54.7	53.4
	28	47.2	0.0	27.2	74.4	149.4	75.0	49.8
January	5	29.6	0.0	17.0	46.6	142.3	95.7	32.8
	10	29.8	0.0	17.0	46.8	138.8	92.0	33.7
	15	40.5	0.0	23.8	64.3	142.3	78.0	45.2
	22	45.9	0.0	27.2	73.1	128.1	55.0	57.1
	30	38.6	0.0	23.8	62.4	124.5	62.1	50.2
February	6	36.9	0.0	23.8	60.7	113.9	53.2	53.3
TOTAL		485.9	3.9	289.0	771.0	1433.9	662.9	
AVERAGE		44.2	0.4	26.3	70.1	130.4	60.3	54.3
STD		13.3	0.6	7.6	20.7	12.2	25.0	16.8
CV		0.3	1.8	0.3	0.3	0.1	0.4	0.3

APPENDIX 5 Continued

(e) Plot No.: **PL5** Crop: Maize Plot Size: 0.61 ha

Planted Date: 01.10.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	10	52.5	0.4	52.1	78.3	26.2	66.5
	21	46.9	0.1	46.9	78.3	31.4	59.9
	30	45.4	0.6	44.7	80.7	36.0	55.4
December	9	43.6	1.9	41.6	66.4	24.8	62.7
	18	34.4	0.8	33.6	73.5	39.9	45.7
	25	50.1	0.1	50.0	68.8	18.8	72.6
January	4	44.0	0.0	44.0	78.1	34.1	56.4
	14	55.1	0.0	55.1	71.2	16.1	77.4
TOTAL		372.0	4.0	368.0	595.3	227.3	
AVERAGE		46.5	0.5	46.0	74.4	28.4	62.1
STD		6.4	0.7	6.7	5.2	8.4	10.1
CV		0.1	1.3	0.1	0.1	0.3	0.2

(f) Plot No.: **PL6** Crop: Paddy Plot Size: 0.4 ha

Nursery Date: 10.09.1995 Transplanting Date: 15.10.1995

Month	Date	ET_c	P_e	S&P	I_n	WD	Al	Ea
November	10	30.7	0.3	17.0	47.5	99.6	52.1	47.6
	15	55.3	0.2	30.6	85.7	85.4	-0.3	100.4
	24	35.2	0.0	20.4	55.5	92.5	37.0	60.0
	30	57.4	0.9	34.0	90.4	103.2	12.8	87.6
December	10	61.1	2.3	37.4	96.2	99.6	3.4	96.6
	21	57.1	0.4	34.0	90.7	113.9	23.2	79.6
	31	59.0	0.0	34.0	93.0	121.0	28.0	76.9
January	10	79.2	0.0	47.6	126.8	121.0	-5.8	104.8
	24	38.6	0.0	23.8	62.4	103.2	40.8	60.5
	31	41.9	0.0	27.2	69.1	113.9	44.8	60.7
TOTAL		515.5	4.1	306.0	817.4	1053.3	235.9	
AVERAGE		51.6	0.4	30.6	81.7	105.3	23.6	77.5
STD		124.7	0.7	8.9	23.4	11.9	20.3	19.7
CV		0.3	1.7	0.3	0.3	0.1	0.9	0.3

APPENDIX 5 Continued

(g) Plot No.: **PL7** Crop: Maize Plot Size: 0.51 ha

Planted Date: 15.10.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	14	51.8	0.1	51.7	59.8	8.1	86.5
	28	48.4	0.6	47.9	55.5	7.6	86.2
December	8	68.1	2.7	65.4	51.2	-14.2	127.7
	22	70.8	0.4	70.4	55.5	-14.9	126.9
January	5	71.4	0.0	71.4	59.8	-11.6	119.4
	19	45.3	0.0	45.3	59.8	14.5	75.7
	29	27.6	0.0	27.6	64.0	36.4	43.1
February	5	26.2	0.0	26.2	59.8	33.6	43.9
TOTAL		409.6	3.7	405.9	465.4	59.5	
AVERAGE		51.2	0.5	50.7	58.2	7.4	88.7
STD		18.1	0.9	17.8	3.9	20.4	34.2
CV		0.4	2.0	0.4	0.1	2.7	0.4

(h) Plot No.: **PL8** Crop: Paddy Plot Size: 0.81 ha

Nursery Date: 06.11.1995 Transplanting Date: 10.12.1995

Month	Date	ET_c	P_e	S&P	I_n	WD	Al	Ea
November	17	27.5	0.2	17.0	44.3	62.1	17.8	71.4
	22	54.2	0.1	34.0	88.2	75.3	-12.9	117.1
December	2	42.2	0.9	27.2	68.5	72.8	4.3	94.1
	10	36.7	1.5	23.8	59.0	50.0	-9.0	117.9
	17	55.1	1.2	34.0	87.9	66.2	-21.7	132.8
	27	41.2	0.0	23.8	65.0	65.7	0.7	98.9
January	3	41.2	0.0	23.8	65.0	78.9	13.9	82.3
	10	59.4	0.0	34.0	93.4	74.3	-19.1	125.7
	20	62.8	0.0	34.0	96.8	68.5	-28.3	141.3
	30	44.9	0.0	23.8	68.7	54.0	-14.7	127.2
February	6	45.4	0.0	23.8	69.2	56.7	-12.5	122.0
	13	63.4	0.0	34.0	97.4	55.2	-42.2	176.4
	23	33.0	0.0	17.0	50.0	48.8	-1.2	102.5
	28	66.1	0.0	34.0	100.1	73.4	-26.7	136.3
March	9	32.4	0.3	17.0	49.2	49.8	0.6	98.7
	14	29.0	0.3	17.0	45.7	57.5	11.8	79.5
	19	37.8	1.1	23.8	60.5	52.5	-8.0	115.2
	26	45.4	5.8	34.0	73.6	62.0	-11.6	118.7
TOTAL		817.5	11.4	476.0	1282.2	1123.7	-158.5	
AVERAGE		45.4	0.6	26.4	71.2	62.4	-8.8	114.3
STD		12.2	1.4	6.9	18.6	9.8	15.7	25.3
CV		0.3	2.2	0.3	0.3	0.2	-1.8	0.2

APPENDIX 5 Continued

(i) Plot No.: **PL9** Crop: Paddy Plot Size: 0.51 ha

Nursery Date: 15.09.1995 Transplanting Date: 25.10.1995

Month	Date	ET_c	P_e	S&P	I_n	WD	Al	Ea
November	15	42.8	0.2	23.8	66.4	78.0	11.6	85.2
	22	41.6	0.0	23.8	65.4	72.1	6.7	90.7
	29	57.8	0.7	34.0	91.1	76.0	-15.1	119.9
December	9	66.6	2.5	40.8	104.9	80.6	-24.3	130.2
	21	39.4	0.4	23.8	62.7	59.8	-2.9	104.9
	28	59.0	0.0	34.0	93.0	80.6	-12.4	115.4
January	7	41.6	0.0	23.8	65.4	68.3	2.9	95.8
	14	40.5	0.0	23.8	64.3	75.6	11.3	85.0
	21	40.2	0.0	23.8	64.0	75.9	11.9	84.4
	28	87.2	0.0	54.4	141.6	78.5	-63.1	180.4
TOTAL		516.9	3.9	306.0	819.0	745.4	-73.6	
AVERAGE		51.7	0.4	30.6	81.9	74.5	-7.4	109.2
STD		15.9	0.8	10.4	26.0	6.4	23.3	29.8
CV		0.3	2.0	0.3	0.3	0.1	-3.2	0.3

(j) Plot No.: **PL10** Crop: Maize Plot Size: 0.4 ha

Planted Date: 01.11.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	14	29.6	0.3	29.4	58.7	29.3	50.1
	29	46.2	1.5	44.6	61.4	16.8	72.7
December	13	44.9	1.8	43.1	64.0	20.9	67.4
	23	50.6	0.3	50.3	53.4	3.1	94.2
January	2	51.5	0.0	51.5	58.7	7.3	87.6
	12	63.4	0.0	63.4	58.7	-4.7	108.0
	24	70.6	0.0	70.6	64.0	-6.6	110.3
February	6	61.6	0.0	61.6	53.4	-8.2	115.4
	20	34.3	0.0	34.3	64.0	29.7	53.6
TOTAL		452.7	3.9	448.8	536.3	87.5	
AVERAGE		50.3	0.4	49.9	59.6	9.7	84.4
STD		13.4	0.7	13.6	4.2	15.0	24.6
CV		0.3	1.7	0.3	0.1	1.5	0.3

APPENDIX 5 Continued

(k) Plot No.: **PL11** Crop: Maize Plot Size: 0.81 ha

Planted Date: 25.10.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	20	44.1	0.3	43.8	41.0	-2.8	106.8
December	4	62.6	2.5	60.0	76.0	16.0	79.0
	18	49.1	0.5	48.7	68.0	19.3	71.6
	28	31.2	0.0	31.2	56.0	24.8	55.7
January	3	72.3	0.0	72.3	74.0	1.7	97.8
	17	73.8	0.0	73.8	84.0	10.2	87.9
	31	40.9	0.0	40.9	69.0	28.1	59.2
February	9	49.0	0.0	49.0	57.0	8.0	86.0
TOTAL		423.1	3.3	419.7	525.0	105.3	
AVERAGE		52.9	0.4	52.5	65.6	13.2	80.5
STD		15.3	0.9	15.1	13.7	10.9	17.8
CV		0.3	2.18	0.3	0.2	0.8	0.2

(l) Plot No.: **PL12** Crop: Maize Plot Size: 0.4 ha

Planted Date: 25.10.1995

Month	Date	ET_c (mm)	P_e (mm)	I_n (mm)	Water Delivered to Plot	Application Losses (mm)	Ea (%)
November	22	32.0	0.1	32.0	76.0	44.0	42.1
December	2	60.4	2.2	58.2	83.5	25.3	69.7
	16	69.1	1.4	67.7	68.6	0.9	98.6
	30	57.0	0.0	57.0	66.0	9.0	86.4
January	10	73.7	0.0	73.7	71.4	-2.3	103.2
	24	68.8	0.0	68.8	65.5	-3.3	105.1
February	7	57.5	0.0	57.5	72.4	14.9	79.4
TOTAL		418.6	3.7	414.9	503.4	88.5	
AVERAGE		59.8	0.5	59.3	71.9	12.6	83.5
STD		13.8	0.9	13.7	6.3	17.2	22.4
CV		0.2	1.7	0.2	0.1	1.4	0.3

APPENDIX 5 Continued

Table 5.5 Determination of Scheme Overall Irrigation Efficiency

Block		I			II			III	
Plot	PL2	PL4	PL6	PL8	PL9				
Crop 1: PADDY									
Main canal									
- length (m)	310	920	920	920	920	-	-	-	-
- loss per km (%)	9.8	9.8	9.8	9.8	9.8	-	-	-	-
- total loss (%)	3.0	9.0	9.0	9.0	9.0	-	-	-	-
- conv. effi. (%)	97.0	91.0	91.0	91.0	91.0	-	-	-	-
Secondary canal									
- length (m)	-	650	1680	2980	1295	-	-	-	-
- loss per km (%)	-	11.2	11.2	11.2	11.2	-	-	-	-
- total loss (%)	-	7.3	18.8	33.4	14.5	-	-	-	-
- conv. effi. (%)	-	92.7	81.2	66.6	85.5	-	-	-	-
Tertiary canal									
- length (m)	300	380	775	155	1275	-	-	-	-
- loss per km (%)	9.6	9.6	9.6	9.6	9.6	-	-	-	-
- total loss (%)	2.9	3.6	7.4	1.5	12.2	-	-	-	-
- conv. effi. (%)	97.1	96.4	92.6	98.5	87.8	-	-	-	-
Ovr. conv eff (%)	94.2	81.3	68.4	59.7	68.3	-	-	-	-
quaternary canal									
- length (m)	195	80	85	20	315	-	-	-	-
- loss per km (%)	9.6	9.6	9.6	9.6	9.6	-	-	-	-
- total loss (%)	1.9	0.8	0.8	0.2	3.0	-	-	-	-
- ditch. effi. (%)	98.1	99.2	99.2	99.8	97.0	-	-	-	-
Distrib. effi. (%)	92.4	80.7	67.8	59.6	66.2	-	-	-	-
Field/Plot									
- Appl. effi. (%)	40.1	54.3	77.5	114.3	109.2	-	-	-	-

Block		I			II			III	
Plot	PL1	PL3	PL5	PL7		PL10	PL11	PL12	
Crop 2: MAIZE									
Main canal									
- length (m)	310	920	920	920	-	920	920	920	-
- loss per km (%)	9.8	9.8	9.8	9.8	-	9.8	9.8	9.8	-
- total loss (%)	3.0	9.0	9.0	9.0	-	9.0	9.0	9.0	-
- conv. effi. (%)	97.0	91.0	91.0	91.0	-	91.0	91.0	91.0	-

APPENDIX 5 Continued

Secondary canal									
- length (m)	-	940	1680	2980	-	305	3900	3185	-
- loss per km (%)	-	11.2	11.2	11.2	-	11.2	11.2	11.2	-
- total loss (%)	-	10.5	18.8	33.4	-	3.4	43.7	35.7	-
- conv. effi. (%)	-	89.5	81.2	66.6	-	96.6	56.3	64.3	-
Tertiary canal									
- length (m)	185	225	700	60	-	1900	60	-	-
- loss per km (%)	9.6	9.6	9.6	9.6	-	9.6	9.6	-	-
- total loss (%)	1.8	2.2	6.7	0.6	-	18.2	0.6	-	-
- conv. effi. (%)	98.2	97.8	93.3	99.4	-	81.8	99.4	-	-
Ovr. conv eff (%)	95.2	79.6	68.9	60.3	-	71.8	50.9	58.5	-
quaternary canal									
- length (m)	125	45	125	30	-	115	25	115	-
- loss per km (%)	9.6	9.6	9.6	9.6	-	9.6	9.6	9.6	-
- total loss (%)	1.2	0.4	1.2	0.3	-	1.1	0.2	1.1	-
- ditch. effi. (%)	98.8	99.6	98.8	99.7	-	98.9	99.8	98.9	-
Distrib. effi. (%)	94.1	79.3	68.1	60.1	-	71.1	50.8	57.9	-
Field/Plot									
- Appl. effi. (%)	63.2	57.7	62.1	88.7	-	84.4	80.5	83.5	-

CONVEYANCE EFF (%)	94.7	80.5	68.6	60.0	34.1	35.9	25.5	29.3	-
- Block Avg.		81.3			43.3			27.4	
- Scheme Overall		53.6							
FIELD CANAL EFF (%)	98.5	99.4	99.0	99.8	97.0	98.9	99.8	98.9	-
- Block Avg.		99.0			98.5			99.3	
- Scheme Overall		98.9							
DISTRIBUTION EF (%)	93.3	80.0	67.9	59.8	33.1	35.5	25.4	28.9	-
- Block Avg.		80.4			42.8			27.2	
- Scheme Overall		53.0							
APPLICATION EFF (%)	51.7	56.0	69.8	101.5	109.2	84.4	80.5	83.5	-
- Block Avg.		59.2			98.4			82.0	
- Scheme Overall		73.6							
OVERALL EFF (%)	48.2	44.8	47.4	60.7	36.1	30.0	20.5	24.2	-
- Block Avg.		46.8			42.3			22.3	
- Scheme Overall		39.0							
SCHEME IRR. EFF (%)	39.0								

APPENDIX 6

Table 6.1 Weruweru River Discharges (at 80% probability of exceedance)

Location: Close to the Scheme Intake Site
Catchment Area: 172 km2
Period: 1978-1988
Unit: (m3/s)

Date	Jan	Feb	Mar	Apr	Sep	Oct	Nov	Dec
1	1.90	1.52	1.51	1.92	1.48	1.42	1.50	1.9
2	1.88	1.50	1.55	1.82	1.44	1.43	1.52	2.1
3	1.86	1.47	1.52	1.89	1.48	1.45	1.55	2.1
4	1.77	1.51	1.37	2.23	1.47	1.46	1.53	2.1
5	1.53	1.60	1.44	2.19	1.45	1.44	1.51	2.1
6	1.49	1.64	1.53	1.92	1.45	1.44	1.73	2.0
7	1.48	1.67	1.52	2.35	1.46	1.39	1.57	2.0
8	1.39	1.67	1.60	2.39	1.49	1.34	1.53	2.0
9	1.46	1.69	1.62	2.61	1.46	1.34	1.46	2.0
10	1.39	1.68	1.63	2.40	1.45	1.34	1.37	1.9
11	1.39	1.80	1.67	2.59	1.39	1.34	1.42	1.9
12	1.30	1.71	1.66	1.86	1.37	1.35	1.49	2.0
13	1.48	1.64	1.67	1.99	1.36	1.31	1.51	1.8
14	1.41	1.63	1.85	1.66	1.38	1.19	1.67	1.8
15	1.47	1.66	1.95	1.78	1.36	1.23	1.65	1.9
16	1.37	1.64	2.37	1.25	1.34	1.39	1.58	1.9
17	1.57	1.59	2.16	0.76	1.31	1.30	1.62	2.0
18	1.56	1.56	2.12	1.58	1.43	1.35	1.63	1.9
19	1.58	1.54	1.74	1.79	1.44	1.33	1.65	1.5
20	1.61	1.52	1.74	2.21	1.46	1.46	1.80	1.6
21	1.73	1.58	1.80	2.62	1.46	1.43	1.81	1.7
22	1.77	1.54	1.83	2.48	1.46	1.44	1.89	2.2
23	1.65	1.64	1.72	2.47	1.41	1.44	1.93	2.3
24	1.63	1.59	1.78	2.54	1.39	1.41	2.06	2.4
25	1.70	1.58	1.84	2.77	1.39	1.49	2.11	2.1
26	1.71	1.53	1.75	2.57	1.33	1.33	1.92	2.2
27	1.66	1.44	1.65	3.19	1.36	1.32	2.06	2.2
28	1.57	1.42	1.66	3.58	1.36	1.25	2.14	2.2
29	1.68	1.23	1.87	3.48	1.35	1.29	1.93	2.1
30	1.52		2.03	3.40	1.35	1.45	1.95	2.1
31	1.53		2.02			1.58		2.0
Mean	1.58	1.58	1.75	2.28	1.41	1.38	1.71	2.0
Min.	1.30	1.23	1.37	0.76	1.31	1.19	1.37	1.5
Max.	1.90	1.80	2.37	3.58	1.49	1.58	2.14	2.4

APPENDIX 7

Table 7.1 Reference Crop Evapotranspiration (mm/day)

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day.												
1	5.1	5.2	5.4	4.6	3.3	3.0	2.9	3.1	3.9	5.1	5.3	4.8
2	4.9	5.6	5.3	4.7	3.4	2.9	2.9	3.2	4.0	5.1	5.3	4.9
3	4.8	5.3	5.5	4.7	3.4	3.0	2.9	3.3	3.4	4.7	5.3	4.8
4	4.8	5.3	5.5	4.4	3.3	3.0	2.9	3.3	3.8	4.9	5.4	4.9
5	4.9	5.3	5.4	4.2	3.2	3.0	2.9	3.3	4.0	5.0	5.4	5.0
6	5.0	5.5	5.5	4.4	3.3	2.9	2.9	3.3	3.9	5.0	5.5	4.7
7	4.7	5.4	5.4	4.2	3.3	3.0	3.0	3.2	4.0	5.2	5.1	4.6
8	5.0	5.3	5.8	4.2	3.2	3.0	3.0	3.3	4.3	4.9	5.0	4.7
9	5.1	5.4	5.7	4.2	3.3	3.0	3.0	3.2	4.2	4.9	5.3	4.6
10	4.9	5.6	5.7	4.2	3.2	2.9	3.0	3.3	4.1	4.9	5.1	4.7
11	5.0	5.4	5.5	3.9	3.2	3.0	3.0	3.4	4.4	5.3	5.2	4.6
12	5.1	5.2	5.9	4.1	3.3	3.0	2.8	3.3	4.4	5.2	5.0	4.6
13	5.0	5.5	5.4	4.1	3.2	3.0	3.0	3.3	4.3	5.3	5.1	4.7
14	5.0	5.1	5.3	4.1	3.2	3.0	2.9	3.3	4.3	5.4	5.2	4.5
15	4.9	5.1	4.9	4.0	3.2	2.9	2.9	3.4	4.4	5.3	5.3	4.6
16	4.8	5.4	5.6	3.7	3.0	2.9	2.9	3.3	4.5	5.1	5.4	4.7
17	4.9	5.2	5.3	3.9	3.1	2.9	3.0	3.4	4.5	5.4	5.[illegible]	4.6
18	5.0	5.2	5.1	3.9	3.2	2.8	3.1	3.5	4.5	5.4	5.0	4.6
19	5.0	5.3	5.8	3.9	3.0	2.8	3.2	3.6	4.4	5.3	5.0	4.7
20	5.1	5.4	5.3	3.7	3.0	2.9	3.0	3.5	4.6	5.2	4.9	4.7
21	5.3	5.3	4.8	3.8	2.9	2.9	3.0	3.6	4.5	5.6	5.0	4.7
22	5.1	5.3	5.0	3.7	3.0	2.9	3.0	3.5	4.6	5.5	5.2	4.7
23	5.2	5.4	5.1	3.8	3.0	2.8	3.0	3.5	4.7	5.4	5.2	4.6
24	5.0	5.5	4.9	3.7	3.0	2.8	2.9	3.6	4.6	5.5	4.9	4.8
25	5.2	5.5	4.8	3.6	3.0	2.8	3.1	3.7	4.5	5.7	5.1	4.7
26	5.3	5.6	4.6	3.6	2.9	3.0	3.1	3.5	4.7	5.8	4.8	4.7
27	5.2	5.5	4.9	3.4	3.0	2.9	3.1	3.7	4.8	5.7	4.6	4.6
28	5.4	5.7	4.4	3.6	3.0	2.9	3.0	3.7	4.9	5.4	4.9	4.7
29	5.5	5.8	4.7	3.5	2.8	2.8	3.1	3.9	5.2	5.4	5.0	5.0
30	5.5		4.5	3.5	2.9	2.8	3.1	3.8	5.3	5.4	4.8	5.1
31	5.2		4.5		3.0		3.2	3.7		5.5		4.9
Mean	5.1	5.4	5.2	4.0	3.1	2.9	3.0	3.4	4.4	5.3	5.1	4.7
Total	157.0	156.4	161.5	119.2	96.8	87.4	92.8	106.5	131.8	163.5	153.2	146.3
Min.	4.7	5.1	4.4	3.4	2.8	2.8	2.8	3.1	3.4	4.7	4.6	4.5
Max.	5.5	5.8	5.9	4.7	3.4	3.0	3.2	3.9	5.3	5.8	5.5	5.1

APPENDIX 8 IRRIGATION SCHEDULING OF UPLAND CROPS

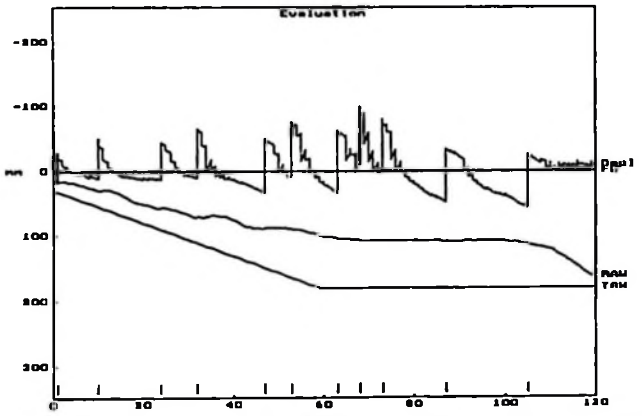


Fig. 8(a) Evaluation Scheduling of Upland Crop (PL3)

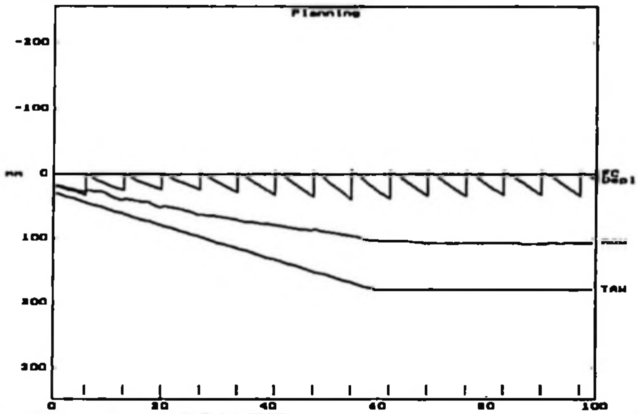


Fig. 8(b) Planning Scheduling of upland Crops (PL3)

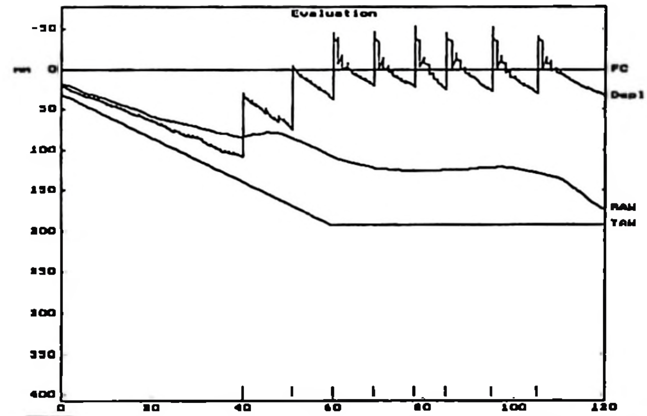


Fig. 8(c) Evaluation Scheduling of Upland Crops (PL5)

APPENDIX 8 Continued

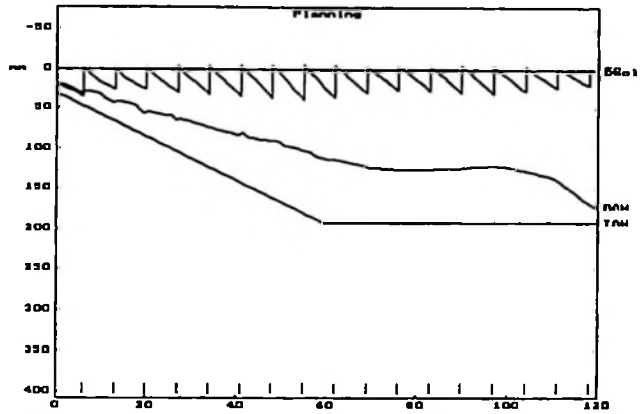


Fig. 8(d) Planning Scheduling of Upland crop (PL5)

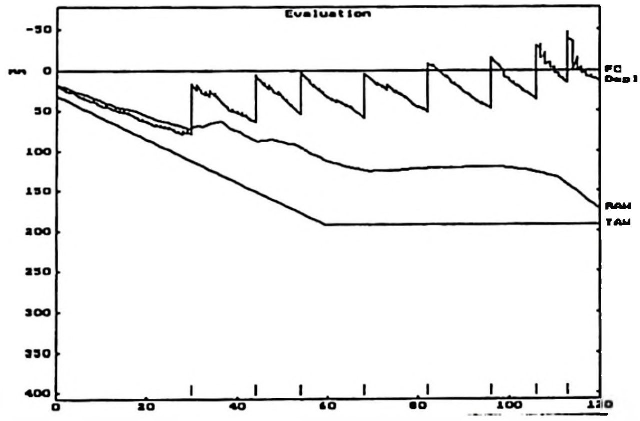


Fig. 8(e) Evaluation Scheduling of Upland Crops (PL7)

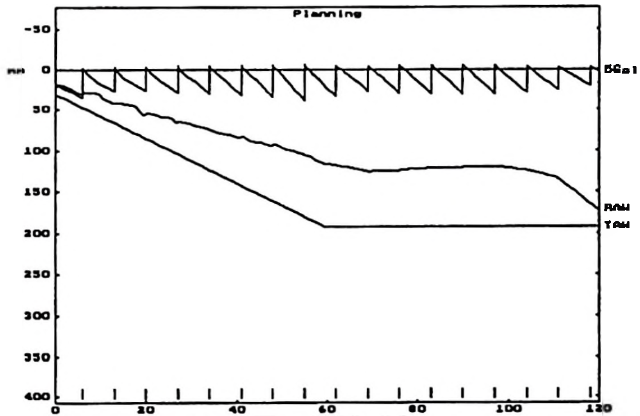


Fig. 8(f) Planning Scheduling of Upland Crops (PL7)

APPENDIX 8 Continued

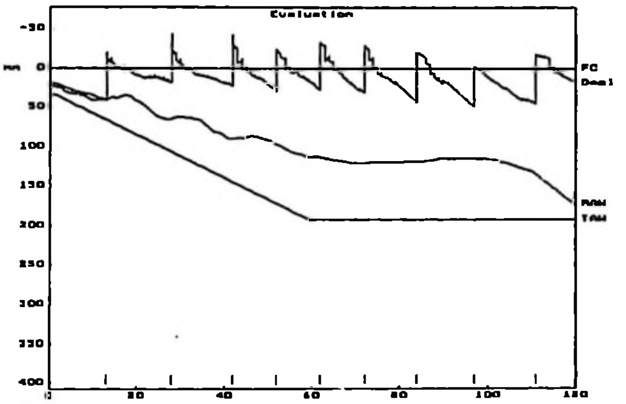


Fig. 8(g) Evaluation Scheduling of Upland Crops (PL10)

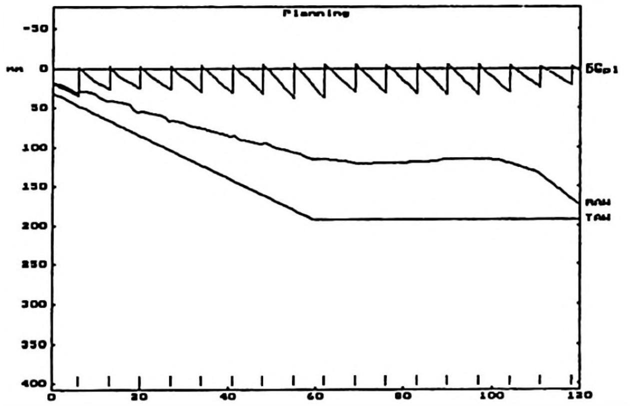


Fig. 8(h) Planning Scheduling of Upland Crops (PL10)

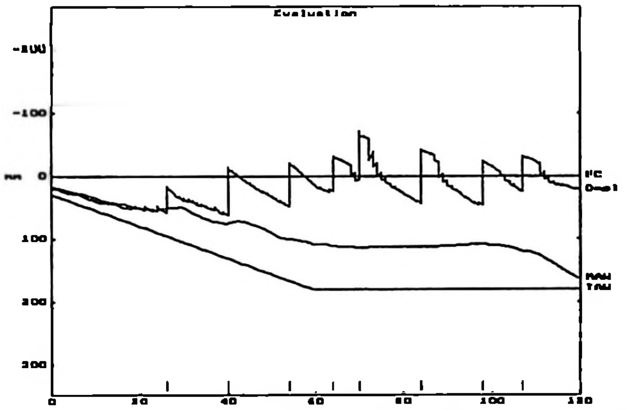


Fig. 8(i) Evaluation scheduling of Upland Crops (PL11)

APPENIDX 8 Continued

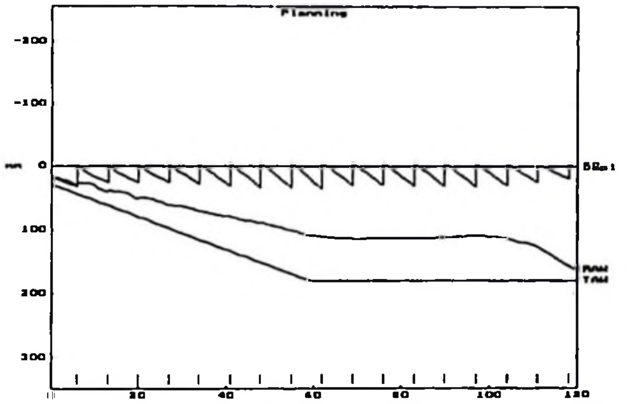


Fig. 8(j) Planning Scheduling of Upland Crops (PL11)

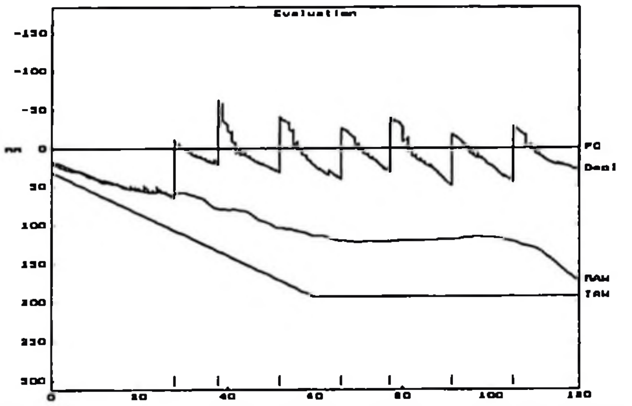


Fig. 8(k) Evaluation Scheduling of Upland Crops (PL12)

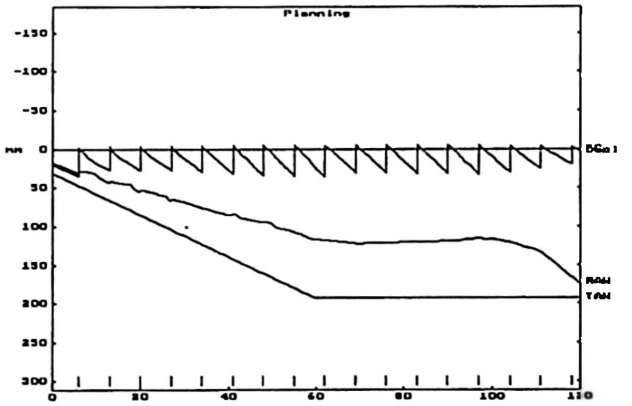


Fig. 8(l) Planning Scheduling of Upland crops (PL12)

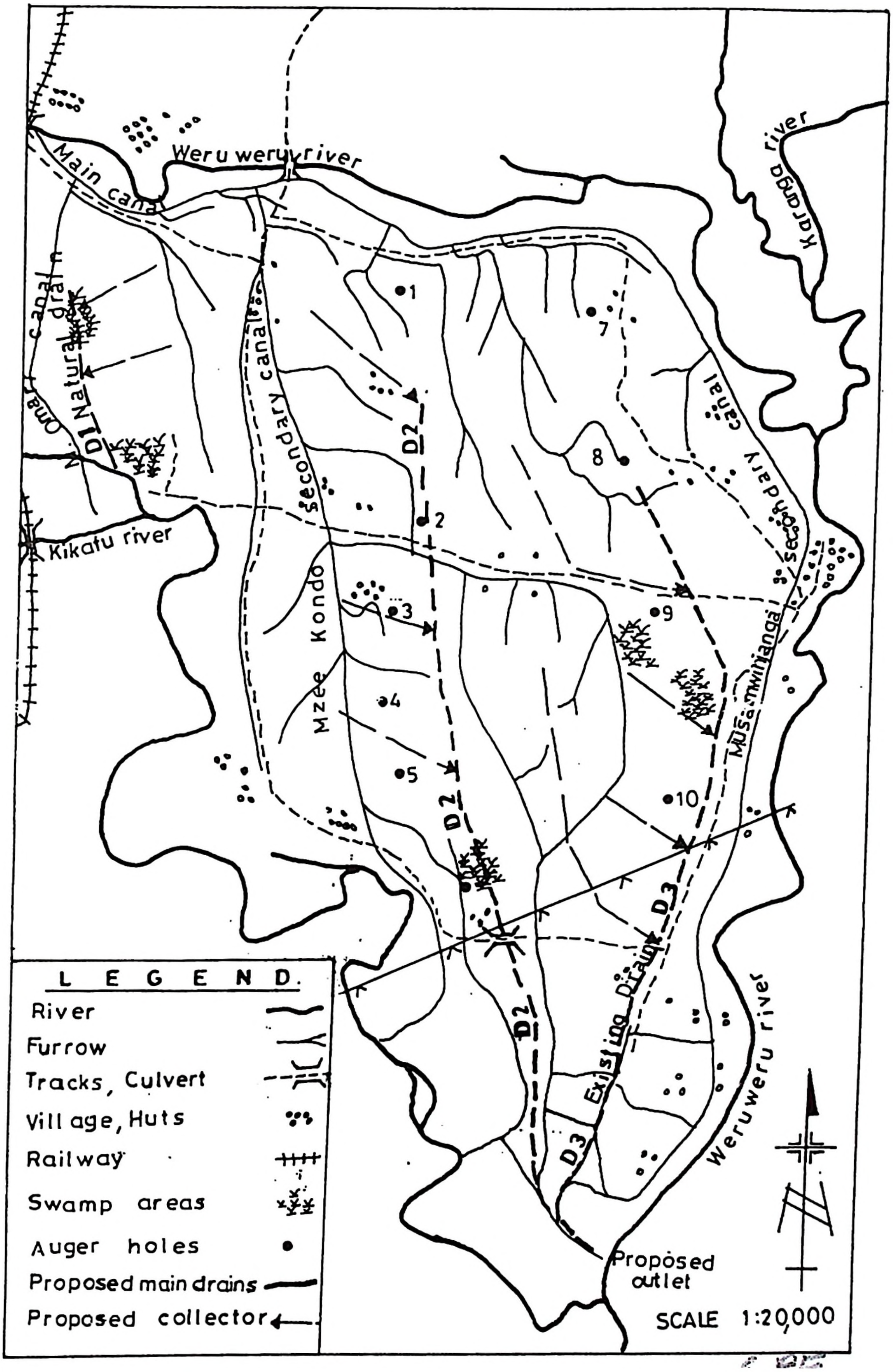
APPENDIX 9

Table 9.1 Water Distribution Plan for Musa Mwinjanga Scheme

OFFTAKE	AREA	MODULE	DISCHARGE THROUGH THE OFFTAKES							FLOW IN MUSA MWINJANGA MAIN CANAL						
	(ha)	(l/s/ha)	MON	TUE	WED	THU	FRI	SAT	SUN	MON	TUE	WED	THU	FRI	SAT	SUN
INTAKE	600	1.42	850	850	850	850	850	850	850	850	850	850	850	850	850	850
MMC/TC1	52	1.16	60	60	60	60	60	60	60	790	790	790	790	790	790	790
MMC/TC2	8	1.05	29	29	-	-	-	-	-	761	161	790	790	790	790	790
MMC/TC3	5	1.05	-	-	37	-	-	-	-	761	761	753	790	790	790	790
MMC/MKSC	320	1.26	404	404	404	404	404	404	404	357	357	349	386	386	386	386
MMSC/TC1	4	1.05	-	-	-	29	-	-	-	357	357	349	357	386	386	386
MMSC/TC2	1.5	1.05	-	-	-	11	-	-	-	357	357	349	346	386	386	386
MMSC/TC3	16.5	1.05	-	-	-	-	40	40	40	357	357	349	346	346	346	346
MMSC/TC4	69	1.16	80	80	80	80	80	80	80	277	277	269	266	266	266	266
MMSC/TC5	13	1.05	32	32	32	-	-	-	-	245	245	237	234	234	234	234
LOSS										127	127	127	127	127	127	127
NET										118	118	110	107	107	107	107
MMSC/DS/TC5	111	1.16								136	136	136	136	136	136	136

SOURCE: **KZIU** - Musa Mwinjanga Scheme Design Note

APPENDIX 10


Weru weru river
Main canal
N. Omari canal
D1 Natural drain
Kikafu river
Secondary canal
Mzee Kondo
D2
1
2
3
4
5
6
7
8
9
10
Karanga river
Secondary canal
Musa mwijanga
D3
Existing Drain
Proposed outlet
Weruweru river
LEGEND
River
Furrow
Tracks, Culvert
Village, Huts
Railway
Swamp areas
Auger holes
Proposed main drains
Proposed collector
N
SCALE 1:20,000