ASSESSMENT OF WATER DELIVERY PROBLEMS AND IMPROVEMENT STRATEGIES IN SMALLHOLDER IRRIGATION SCHEMES: CASE STUDIES OF NYANYADZI (ZIMBABWE) AND MATANYA (KENYA)

BY

GOTOSA J.

B.Sc. Agriculture Honours (Soil Science)
(University of Zimbabwe)
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DECLARATION

I declare that this thesis is may original work and has not been presented for a degree in any other University. All sources of information have been duly acknowledged.

17/10/97

J. GOTOSA

DATE

This thesis has been submitted to the University of Nairobi with my approval as University supervisor.

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Dr. F. N. GICHUKI

DATE

DEDICATION

I wish to dedicate this thesis to Tapiwa E. S. for her patience and unwavering support during my Post graduate studies at the University of Nairobi.

ABSTRACT

The potential benefits from smallholder irrigation schemes are rarely realised due to unsatisfactory performance of their water delivery systems. This study aims at evaluating and identifying strategies for improving the performance of water delivery systems of two contrasting smallholder irrigation schemes. At Nyanyadzi pump (and gravity) fed scheme in Zimbabwe with an integrated organisational structure and lined delivery system, the study entailed evaluating water delivery performance objectives of adequacy (A_d), reliability (D_p) and water distribution equity (E_q), using a close ended questionnaire survey and water requirement and problem analyses in block A. Poor adequacy, equity and reliability of water supply were perceived respectively by 57 %, 53 % and 77 % of the 30 irrigators interviewed in block A. At least 60 % of the respondents attributed this poor performance to illegal abstractions, weedy and silted conveyance canals. Solutions asserted by 90% of respondents were dam construction and increased pumping capacity at supply rivers.

Water delivery performance indicators (A_d, D_p and E_q) were quantified in block A, between October 1996 and January 1997 in two irrigation rotation turns. Good adequacy in the first turn and poor adequacy in the second were attained, but adequacy was negatively correlated (R^2 = 0.89) to the irrigation requirement on a particular irrigation date. Similar inferences were obtained for adequacy quantified as the weekly relative water supply (RWS).

In the same block, equity was quantified spatially and found to be poor during the period considered. On the other hand the reliability of water supply to this block was assessed temporally at 42 locations and 73 % had poor reliability. Furthermore, problem analysis revealed that the major causes of the unsatisfactory water delivery were inadequate water resource, inadequate flow regulation and deferred maintenance at the scheme.

At the Matanya gravity-fed segregated and unlined scheme in Kenya, the study involved the delineation of the water delivery system and assessment of irrigation water supply and demand. A questionnaire survey was employed to establish the irrigation water demand and to augment flow measurements in main canal for supply assessment. The results show that on average, 4.5 times the legalised amounts of water were diverted to the scheme 75 % of the time (in the wet seasons) compared to 0.64 proportion in the dry seasons. Water shortages resulted from inadequate regulation and losses through seepage, overtopping and consumptive use by the weeds. This was worsened by unscheduled abstraction from main canals through the use of channels with no design specifications.

It was concluded that the performance of the water delivery systems of smallholder schemes were related to their management (operation & maintenance) and inherent to design defects, regardless of the relative amounts conveyed, the irrigation infrastructure, organisational structure and the ownership of the irrigated land. The strategies for improving the performance of water delivery systems of these schemes identified were: maxmising use/storage of delivered irrigation water; installation of water control structures at strategic points along the delivery system network; adequate maintenance of the system; routine monitoring and evaluation of the delivery system; training of water users and water masters on aspects of irrigation operation and introduction of rules and staffing for improved performance of delivery system.

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LIST OF SYMBOLS AND ABBREVIATIONS

A_d	Adequacy of water supply
AGRITEX	Department of Agricultural, technical and extension services, Ministry of Agriculture, Government of Zimbabwe
AH	Abstraction height
CoV	coefficient of variation
CWR	Crop water requirements or consumptive water use
Dp	Dependability of water supply
Eq	Equity of water distribution
Et_c	Crop water requirements or consumptive use
Et_o	Reference crop evapotranspiration
FAO	Food and Agricultural Organisation of the United Nations
Fig	Figure
IMC	Irrigation Management Committee
IR	Irrigation requirement
K_c	Crop coefficient or crop factor
Ksh	Kenyan shilling
Mad	Mean adequacy
NSD	Night storage dam
NRM^3	Natural Resources Monitoring, Modelling and Management
Pers. Com.	Personal communication
Q	discharge (m^3/s)
R	Rainfall (mm)
r	correlation coefficient
R^2	Coefficient of determination
Re	effective rainfall
RWS	Relative water supply
S.Ad	standard deviation of adequacy
std. Dev	standard deviation
v	flow velocity (m/s)
Vr	required volume (m^3)
Va	actual or delivered volume (m^3)
UCA	Unit Command area
USD	United States Dollar
ZWD	Zimbabwean dollar

1. INTRODUCTION

1.1 BACKGROUND

The need for irrigation arises from the present food and agricultural crisis in the African continent. Over the years, there has been a widespread decline in per capita food production as the continent's population has been increasing rapidly and it is likely to double over the next 25 years (FAO, 1987). A failure to take the steps needed to halt this deterioration, could lead to a situation in which a large proportion of the population would be dependent on food aid and imports due to widespread famine. Such population increases in a finite world imply that the pressure to increase the productivity of both land and water is intensifying, since the demand for alternative water uses continue to increase.

Irrigation being the art and science of procuring, conveying and applying water to land with a view to sustaining or intensifying agricultural production, can substitute or supplement rainfall depending on prevailing climatic conditions. In arid areas, irrigation ascertains a reliable and suitable water supply. Farmers in these areas develop irrigation facilities to enhance their farm incomes and to safeguard themselves from the risks and uncertainties of the weather.

Irrigation not only achieves the national goal of food self-sufficiency, but it also raises agricultural incomes and generates employment. In Kenya, for instance, irrigation can generate up to two man-years of labour per hectare irrigated and about 70 percent of her exported horticultural produce receive some irrigation during its production (Achola, 1992).

It is quite evident that the ability to produce more food for the ever growing population will depend, largely, on extending the area under irrigation and improving the performance of the existing irrigation systems. However, increased on-farm water management is of paramount importance in irrigated agriculture, because of scarcity of good land for irrigation development and recent increases in the cost of civil works (Fairchild and Nobe, 1986). This is the main reason why Donor agencies emphasize on irrigation water management in their agricultural lending programs.

1.2 PROBLEM STATEMENT

The performance of smallholder irrigation schemes in Africa has been disappointing, with many failing, as indicated by low and declining yields per unit area. The low yields in such schemes can be attributed to low water use efficiencies resulting from high water losses, inequitable water distribution, inadequate and unreliable supplies associated with unsatisfactory water delivery systems. Usually, water has been treated as a free good by farmers and they spend little time to save it. Moreover, water charges seldom cover the operation and maintenance costs, resulting in water waste (Fairchild and Nobe, 1986). This situation in turn reduces the anticipated food production potential and directly drains the meagre financial resources of the developing countries.

Water losses in the water delivery systems can be excessive, such that only about 50 percent of the diverted supplies reach the crop (Fairchild and Nobe, 1986). It has been established from studies carried out in Pakistan that the overall irrigation efficiencies depend so much on the delivery efficiencies which decrease with distance from the intake points (Lowdermilk *et al*., 1978). It is therefore of importance to increase the delivery efficiencies. FAO (1994) also reports that there is a general realisation that the traditionally low efficiency of water use can no longer be accepted in irrigated agriculture. Current studies indicate that water for irrigation, rather than the land for cultivation, will become the critical natural resource in the agricultural development in future.

Low delivery efficiencies in smallholder irrigation schemes can create water conflicts in areas where water supplies are limited and good management practices are needed to meet the needs of all water users. The growth of alternative demands (such as industrial and urban) for water has placed a higher value on water resources, thereby calling for improvements in irrigation water use efficiencies.

Improvements of the performance of irrigation water delivery systems have the potential of increasing irrigated area, minimising conflicts among users, increasing reliability of water supply at the farm level and avoiding plant stress.

1.3 STUDY OBJECTIVES

This study hopes to shed some light on the performance of water delivery systems and identify strategies for improving the equity, adequacy, reliability and efficiency of the water delivery systems of smallholder irrigation projects.

The specific objectives were:

1. To assess opportunities and constraints of water delivery systems of Matanya and Nyanyadzi smallholder irrigation schemes
2. To quantify adequacy, dependability and equity of water supply at Nyanyadzi smallholder irrigation scheme.
3. To identify strategies for improving the performance of water delivery systems in smallholder irrigation schemes.

2.0 LITERATURE REVIEW

2.1 SMALLHOLDER IRRIGATION

2.1.1 General Background

The African continent is under pressure to increase food production to cater for the ever-growing population. The importance of the irrigation technology in alleviating food shortages in Africa cannot be overstated, as it has played a pivotal role in the success of the famous Asian Green Revolution. The development of irrigation in Africa has been disappointing and according to FAO (1987), only 1 in every 20 of Africa's cropped hectares is irrigated and less than half of the irrigated area is in Sub-Saharan Africa. In this region, irrigation is mainly informal, small-scale with simple technologies and partial control of irrigation water.

Smallholder irrigation is viewed by many as an answer to Africa's food crisis, since there is a lot of untapped potential in many countries. The continent has a total of 150 million hectares of irrigation potential, equivalent to about 16 times the currently irrigated land (FAO, 1986). Smallholder irrigation schemes were defined by Portch (1989) as projects which are farmed by a number of farmers operating either as individuals on small blocks of land or jointly as a cooperative. In reviewing the scope and potential of small-scale irrigation in Sub-Saharan Africa, Adams (1990) pointed out that:

> *There is nonetheless a lack of research on small-scale irrigation in Africa, whether on technical, economic, or social attributes, or on performance. Something called "small-scale irrigation" is often assumed to be an answer to the problem of the failure of large-scale projects,.. However, there is little hard evidence on the performance of small scale irrigation schemes, or explicit comparisons between large and small scale projects (emphasis in original).*

However, Peacock (1995), also argued that small-scale irrigation development has no distinct advantage over large-scale developments, because larger schemes attract better managers and large schemes achieve high efficiencies because of economies of scale.

2.1.2 Smallholder irrigation in Zimbabwe

2.1.2 1 Nature and extent

The irrigation potential of Zimbabwe was reported by FAO (1987) to be about 600,000 ha and a total of 150,000 ha are irrigated. Smallholder irrigation covers only 5% of the total irrigated area (Manzungu and Van Der Zaag, 1996). The plot sizes range from 0.5 to 2.0 ha/irrigator (Rukuni, 1988). Smallholder irrigation is mainly practised in the communal lands, which cover over some 40 % of the area of the country, supporting 57% of the total population (Central Statistical Office, 1984). Due to political reasons, communal lands are mainly situated on the poorest soils in areas of low and unreliable rainfall, natural regions III and IV Hungwe (1987).

2.1.2.2 Justification and need for smallholder irrigation

In Zimbabwe, smallholder irrigation is viewed as capable of alleviating rural poverty that is manifested by transitory and chronic hunger, malnutrition and unemployment (Jayne and Rukuni, 1994). It also offers the chance to modernise peasant agriculture, thereby contributing to the growth of local industries and foreign currency earnings (Manzungu and Van Der Zaag, 1996). Smallholder irrigation can also alleviate the increasing pressure on the scarce land resources through intensified agricultural production in the rural areas (Hungwe, 1987).

2.1.2.3 Water supply situation in smallholder schemes

Water supply is a problem in Zimbabwean smallholder irrigation schemes. Most rivers flow for six to eight months a year and those which are perennial have low flows at the time of peak irrigation water demand. For example, Pearce (1983) reported dwindling water supply at the Nyanyadzi smallholder irrigation scheme from the Nyanyadzi river due to drought and irrigation development upstream (Table 1).

Table 1 Trends of water shortage at Nyanyadzi irrigation scheme

Decade	Year of water shortage	Year Nyanyadzi river dried up
1940 - 1949	1947, 1949	nil
1950 - 1959	1952, 1954, 1957	nil
1960 - 1969	1960, 1961, 1964, 1968	nil
1970 - 1979	1970, 1971, 1973	nil
1980 - 1989	1983, 1984, 1987	nil
1990 - 1995	1991, 1992, 1994, 1995	1992, 1994, 1995

Source: Bolding (1996)

The prospects for groundwater supply in the Zimbabwean communal areas are poor as the underlying aquifers are low yielding (Hungwe, 1987). In the high yielding aquifers, the water is deep and are therefore a costly source of irrigation water.

2.1.2.4 Performance of smallholder schemes

In Zimbabwean smallholder systems, Pazvakavambwa (1984) reported the prevalence of the head/tail end problem due to inequitable water distribution. Water scarcity in the lower parts of schemes leads to farmer dissatisfaction and dissent, causing them to break or vandalise control structures, which have been very difficult to replace at times. A case in point is the Nyanyadzi irrigation scheme in Manicaland province, where most of the gauge boards of measurement structures were destroyed by farmers who suspected that the structures were responsible for their water crisis (Manzungu, 1996).

The performance of smallholder irrigation with regard to productivity, depends on the holding size. Rukuni (1988) found that large plots (>1.4 ha) realise larger farm income, but on small plots (<0.8), farmers are more efficient users of the resources available to them.

2.1.2.5 Constraints of smallholder irrigation

Unsuitable Soils

Most soils in communal areas, according to Hungwe (1987), are derived from granitic rocks and are generally shallow (<30 cm), light textured, of poor fertility and low water holding capacities. Irrigation scheduling is a problem in schemes where the soils have low available water capacities and evaporation rates are as high as 11 mm/day.

Improper scheme designs

According to Pazvakavambwa (1984), there is no proper link between how smallholder scheme designs were made and how the schemes were subsequently used and this was attributed to low performances, as farmers took up "unauthorized practices which they have now adopted as the norm."

Risk avoidance by farmers

Smallholder irrigation is generally earmarked for small farmers. But its expansion has been arrested by the characteristic risk avoidance by small farmers (Makadho,1994). The author also reported that irrigated crop production involves the use of expensive machinery, expensive inputs and dependence on a single cash crop, which imply great risks. Even though irrigated crop production in itself is less risky than dryland farming.

2.1.3 Smallholder irrigation in Kenya

2.1.3.1 Nature and extent

In Kenya, smallholder irrigation refers to an irrigation system where farmers have considerable control of critical irrigation resources (water, land and labour). Smallholder irrigation accounts for 16,700 ha or 33% of all irrigated land.

The bulk of smallholder schemes consist of a group of farmers sharing a common water source and operating fairly individual plots. The irrigation schemes are small (less than 500 ha) and associated with already settled communities (Osoro, 1992; Chancellor and Hide, 1996). The projects are privately owned; group based pump fed or group based gravity fed projects with varying land holding sizes. However, most are gravity fed and land holdings average less than two hectares (Chancellor and Hide, 1996).

2.1.3.2 Justification and need for smallholder irrigation

The average irrigation potential of Kenya is 390,000 ha which is equivalent to about 18% of the area presently under irrigation (Osoro, 1992). Out of this, the Ministry of Agriculture estimates the potential of smallholder irrigation development between the six project groups to be 49,500 ha, hence its importance in boosting agricultural productivity.

Smallholder irrigation offer quite a number of benefits including food increases from increased cropping intensity, expansion of cropped area and increase in yield/unit area. In a study of smallholder irrigated projects in Kenya's Kiambu District, Kamau (1990) reported increased annual cropping intensities from 200% under rainfed conditions to 250% under irrigation. Smallholder irrigation can also increase income and employment in the country, especially, where the potential coincides densely populated areas.

2.1.3.3 Water supply situation in Smallholder irrigation

Approximately 80% of Kenya is arid or semi-arid and the main determinant of availability of water resources is rainfall (Achola, 1992). Compared to other uses, irrigation makes the highest demand on water resources (surface and groundwater) and Achola (1992) also reported that the use of water for irrigation in Kenya is largely consumptive with limited return flow (<30%). Therefore the water supply for irrigation can not meet the demand for irrigation and other uses. Conflicts between irrigation and livestock in arid and semi-arid areas are common, e.g. in the Loitoktok area. This testifies the seriousness of the water supply situation in these areas, where small holder irrigation could be useful in assuring food security.

2.1.3.4 Performance of smallholder schemes

The performance of smallholder irrigation schemes with regard to irrigation water management has not been encouraging in group based irrigation schemes. The problem of tail-enders who are hydraulically disadvantaged, is proverbial. In the Matanya group based scheme, about 72% of the farmers interviewed perceive, in the 1994/95 season, that there was tail-ender problem as a result of improper management of the water received (NRM[3], 1996).

2.1.3.5 Constraints of smallholder irrigation schemes

a) Inadequate development funds and working capital

Undertaking smallholder irrigation is quite costly and a cost range of Ksh 40,000 - 100,000/ha has been reported by the Ministry of Agriculture in such schemes (Osoro, 1992). This is likely to exceed resources possessed by an individual farmer. Moreover, the existing loan arrangements are unsuitable (collateral, bureaucracy, etc.) for individual smallholders.

b) Low yields

Crop yields in smallholder developments tend to be low compared to the potential created by irrigation in general. This is due to limited farmer knowledge about inputs (fertilizers, protectants, etc.) and on proper use of irrigation water (Osoro, 1992).

(c) Unstable Agricultural Markets

The market of irrigated produce in Kenya is characterised by fluctuation between glut, with associated low prices, and periods of scarcity when prices are high. This makes the financial viability of irrigated agriculture lower than anticipated.

2.2 IRRIGATION WATER DELIVERY SYSTEM

The irrigation water delivery system is an irrigation sub-system which delivers water to the root zone at farm level or the 'heart' of any irrigation system (Skogerboe, 1986). It is complemented by the water removal sub-system in supporting the growth of plants that provide food for humans and animals. The water delivery system or the main system connects the main water source (reservoir, canal, tank or river) or the intake structure to the various outlets providing water to a group of farmers in a unit command area. A water delivery system can further be sub-divided into the following sub-systems:

- Hydraulic sub-system
- Organization sub-system.
- Operation and maintenance sub-system

2.2.1 Hydraulic sub-system

The hydraulic delivery sub-system is made up of canals (conveyance, secondary/distributary & tertiary/feeder) and all ancillary structures and equipment.

2.2.1.1 Irrigation canals

The main canal connects the water source to secondary or tertiary canals. The secondary canal connects the main canal with tertiary canals. Direct supply of irrigation water from main and distribution canals to the farms is not recommended. The tertiary canal is connected to a secondary or main and delivers water to the farms. The farm outlet is an outlet on the distribution system serving one farm. It is usually equipped with an isolation valve or with a water meter.

Sizing of irrigation canals

The sizing of the irrigation canals involves determining the delivery rate, delivery duration, peak water requirements and the area commanded (Campbell,1986; Clemmens, 1987).

(a) Delivery flow rate (Q_t)

A delivery flow rate, Q_t, is usually specified as being the 'normal' flow rate for all deliveries within a district (Clemmens, 1987). This rate could be the maximum that will be delivered or the guaranteed minimum available. Delivery rates of up to 10 l/s for small-scale irrigation and 1000 l/s for large-scale level basin irrigation systems were reported by Clemmens (1987).

(b) Delivery duration, P

The daily delivery period, P, is defined as the number of hours in a day that deliveries take place. Canal capacities should be adjusted accordingly to supply sufficient amounts of water in the given duration.

(c) Peak water requirements, Wp

The system capacity is usually related to the requirements during the peak demand period. The peak period refers to a period of weeks or months over which the average water use is greatest. Canal capacity restrictions during this part of the growing season usually result in yield reductions. Clemmens (1987) reported that canal capacities at the lower end of the system need to consider the largest peak use rate, whilst those at the upper end of system need only consider the average peak use rate. The average gross peak irrigation requirement is computed from the net average peak irrigation requirements and annual application efficiency of the farm as:

$$W_u = \frac{W_p}{e_f} \tag{2.1}$$

Where: W_u = average gross peak irrigation requirement (m/day)

W_p = average net peak irrigation requirement (m/day)

e_f = average farm application efficiency.

The canal discharge is computed by converting the gross irrigation requirements to a volume and dividing it by the number of hours in which the water is to be delivered to the farm and by the efficiency of the conveyance system.

In general terms, Campbell (1986) reported that, the peak capacities of canals should allow safe passage of peak flow rate or maximum steady state flow through the delivery system.

d) Area relationships

The area (A_t) that can be irrigated with the given delivery flow rate (Q_t,) the given average gross peak requirement (W_u) and the given daily delivery period (P), can be found from the following expression:

$$Q_t P = 24 A_t W_u \qquad (2.2)$$

Where: Q_t = delivery flow rate (m^3/day)

P = daily delivery period (hours/day)

A_t = Area irrigated or rotation area (m^2)

w_u = average gross peak water requirement (m/day)

For a broken up rotation area into N farm areas, A_f, the rotation area would be defined as:

$$A_t = N A_f \qquad (2.3)$$

If F is the average frequency of irrigation in reciprocal days for farm area, A_f, and D is the duration of irrigation in hours, then,

$$P = NFD \qquad (2.4)$$

If the equations 2.2, 2,3 & 2.4 are combined then

$$Q_t FD = 24 A_f W_u \qquad (2.5)$$

e) Capacity requirements at any point in system

The capacity requirements at any point in the system are determined through normalizing the flow rate at any given point in the system, Q, and its corresponding area serviced, A. The equations used are:

(i) Discharge:

$$Q_n = \frac{Q}{Q_t} \qquad (2.6)$$

In which: Q_n = relative flow rate (normalized flow rate)

Q = flow rate at any given point in system

Q_t = standard delivery flow rate

(ii) Area

$$A_n = \frac{A}{A_t} \qquad (2.7)$$

In which: A_n = relative area (normalized)

A = area serviced at any given point in system

A_t = rotation area

Plots of relative discharge against relative area can be done for different irrigation schedules and they are useful in canal sizing (Clemmens, 1987).

Flow measurement in open channels

In general, the water flow rate can be measured using the velocity-area methods and the direct discharge measurement methods.

Velocity -Area methods require the determination of discharge by measurement of the mean flow velocity. The velocity is obtained from standard formulae, which expresses it as a function of the hydraulic roughness of the channel, the hydraulic radius and the hydraulic slope. The formulae commonly used to compute the mean velocity are the Manning's and Chezy's. The discharge is then computed as the product of the mean velocity and the cross sectional area of wetted section of the channel.

The current meter technique is the most commonly used velocity-area method. If no other method is feasible, the velocities in a channel can be approximated, by timing of a floating object over a known distance. The mean velocity in the vertical is obtained by applying a coefficient of 0.85 to the velocity recorded from the float (Dare, 1972; Michael, 1978).

Direct discharge methods do not involve velocity measurement. Volumetric measurements fall into this group and they entail determination of volume of flow in a certain time. They are used for measuring comparatively small flows. For large flows, rated measurement structures are used, which include flumes, weirs and orifices.

2.2.1.2 Flow regulation and hydraulic structures

In canals, hydraulic structures are mainly used for the following reasons:

- To measure and control the distribution of water
- To maintain water levels for command
- To dissipate unwanted energy
- To control sedimentation

Water movement control and regulation structures

The pre-requisites for water control in an irrigation system are proper: (i) planning (ii) designing and, (iii) operation and maintenance. These factors singly or jointly affect the reliability, adequacy, equity, delivery efficiency and crop yield.

Kay (1986) broadly grouped water control structures into head regulators and cross regulators.

a) ***Head regulators***: This group of structures is used to control and sometimes measure the flow of water into canals. The head regulators are usually located at the head of the canals. The size of the head regulators depend on the size of discharge being controlled. Gates are the most common structures used as head regulators. The types of gates commonly used are: sluice (sliding), lift and shutter. Division boxes also fall into this group and they are used to divide canal water into two or more channels.

b) ***Cross regulators:*** These structures are built across the canals to maintain the water level at the command required to irrigate the fields. According to Kay (1986), when a canal is operated below its normal discharge, water levels are usually lower, so the command is reduced. The location of cross regulators depends on scheme size. On large schemes, they are located close to head regulators to control the water levels at canal junctions. Checks fall into this group of structures. They are placed across channels to stop and redirect the flow or to control the channel flow depth. Checks are permanent in sections where water is collectively used by farmers and temporary where water is diverted into individual fields. Temporary check structures include earthen dikes or canvas or rigid dams.

Water movement control structures should have the following attributes: (i) minimal leakage when closed; (ii) nil obstruction to flow when open; (iii) easy to operate; and (iv) cheap to construct and install.

Channel degradation control structures

These structures are required to reduce deterioration of the channel cross-section from sedimentation or erosion. *Sediment traps* are designed to collect sediment in one place which would otherwise collect along the delivery channels. *Drop structures* on the other hand, reduce the channel slopes and thus flow velocities (dissipate excess energy) in order to prevent channel erosion.

Culverts

Culverts are built where irrigation channels intersect established paths or travel routes. They reduce the deterioration of channel banks by concentrating the passage of traffic. Culverts may be lined depending on the volume of traffic.

Water measurement structures

These structures are used to measure large flows and are needed for equitable distribution of irrigation water amongst farmers. Open channel constrictions are normally used for measuring water flows and they are preferably permanently installed in situations where water measurements are part of a comprehensive water management program. In an irrigation system, water is measured at the storage reservoir outlet, the canal head works, and at lateral and farm turnouts. The type of measuring structure selected for these locations depends on availability of head, adaptability to site, economy of installation and ease of operation (US Department of interior Bureau of Reclamation, 1989; Trout and Kemper, 1980).

Flumes, weirs and gates are the commonly used measurement structures in smallholder irrigation schemes. Measurement of flow is achieved through the use of head/discharge rate equations, usually developed from the Bernoulli equation for both submerged and free flow conditions.

2.2.2 Organisational sub-system

2.2.2.1 Organisational structures

The success of an irrigation organisation depends on its structure (the way in which tasks and responsibilities are formally allocated among its members) and on its management process (the way in which decisions are taken within the existing structures). The main development activities of an irrigation organisation are:

- Water management
- Agricultural extension
- Applied research
- Supply of inputs
- Marketing
- Basic infrastructure service
- Social services.

The main criterion chosen to classify the organisations is whether their organisational structures cover all the development activities or a few of these activities or only those related to water management (Trout and Kemper, 1980; Sagardoy *et al.*, 1986). Based on this criterion, two main irrigation organisational structures are identified namely: integrated and segregated organisational structures.

Organisations with an integrated management structure

In a centralised or integrated structure, the primary responsibility and authority is in the hands of the government. For each irrigation entity of this management structure, there is usually a manager who coordinates, directs and controls various aspects of irrigation (water distribution, irrigation maintenance, crop production, processing and marketing). The farmers' role in decision making is minimal. For instance, the government decides on which crops to grow or which irrigation channels will be improved and how they will be improved and reconstructed or it may carry out or contract the reconstruction work.

Organisations with a segregated management structure

In an irrigation project, the organisation is regarded as having a segregated or decentralised management structure if a number of project related activities, such as extension support, production inputs and marketing services are rendered to the farmer by separate agencies (Sagardoy *et al.*, 1986). Farmers take the primary responsibility and the government may wholly control the water management, but in relative terms, they will have a large amount of responsibility and authority in improvement and management of their portion of the irrigation system. Group based smallholder schemes in Kenya have this management structure, where individual irrigated plots average 0.5 ha/family (Gitonga,1992).

2.2.2.2 irrigation organisations

According to Sagardoy *et al.*(1986), the main criterion used to classify the irrigation organisations is whether the *organisational structure* covers all the development activities (section 2.2.2.1) or a few of these or only those related to water management. In this regard, the main types of irrigation organisations are:

- Integrated management organisations
- Specialised water management organisations
- Multipurpose water management organisations

A. Integrated management organisations

This class of irrigation organisations are characterised by an *integrated* organisational structure, where all development activities are undertaken by Specialised units which are all connected by a clear line of command and finally responsible to a single person (project manager). Integrated organisations can further be classified, depending on the degree of government intervention in scheme management. State farms, irrigation settlement projects and service cooperatives are the organisational subclasses identified.

State farms

State farms are large production units fully controlled by government officials. These are established for maximising agricultural production of nationalised land or where land reform processes have occurred (Sagardoy *et al.*; 1986). For instance, Gitonga (1992) reported that state farms in Kenya are operated by the Agricultural Development Cooperation. In these farms, organisational structure is characterised by a number of units covering the main development and production activities directly under the manager or executive director. State farms experience bureaucracy related problems and lack of staff continuity due transfers.

Irrigation settlement projects

These are small production projects whose aim is to improve the economic life and social welfare of landless farmers by providing them with irrigated land and agricultural production means. Management of the projects is in the hands of government officials.

The projects were regarded by Sagardoy *et al.*(1986) as the most complex of all integrated management organisations as the targeted farmers have little irrigation experience and low educational and financial status.

The main organisational structural units are "The manager's Office" and "The executive unit". The manager's office being the highest executive body of the project is run by the manager who is directly under the national institution running irrigation schemes in the country. The executive units under the manager include: operation, maintenance, finance, marketing, training, production, administration and social assistance.

Irrigation settlement schemes go through a development cycle. The main stages involved are: planning, implementation, transition and the full development stages.

In Kenya, the irrigation settlement schemes are managed by the National Irrigation Board of Kenya (NIB) and plot sizes vary between 1.3 and 1.6 ha per family (Gitonga, 1992). The 5,840 hectare Mwea scheme run by the NIB is a typical example of a settlement scheme with an integrated organisational structure and the details of development activities are shown in Table 2.

Table 2 Standard National Irrigation Board /farmer cooperation model (structure)

FARMERS OBLIGATIONS	NIB OBLIGATIONS
-Infield water control -Nursery establishment -Field leveling -Provision of all labour for cultivation, weeding and harvesting	-Guarantee of irrigation water supply -Provision of mechanised land preparation at cost -Supply of crop inputs (fertilizers, pesticides, etc.) -Crop marketing -Overall management and extension services

Source: Gitonga (1992)

Service cooperatives

The shape of a service cooperative is adopted where the irrigation organisation is run by relatively wealthy farmers (with strong payment capacity). An irrigation cooperative is established by the free will of its members and it is only binding on them. The organisation of an irrigation cooperative depends on the kind of contributions made and the services needed by the farmers. Its organisational structure is similar to that of irrigation associations.

B. Specialised water management organisations

These organisations were defined by Sagardoy *et al.*(1986), as social organisations aiming at an appropriate (timely & equitable) use of water for irrigation purposes among the farmers of a community. They are usually part of a *segregated* organisational structure (defined in section 2.2.2.1).

The functions of Specialised water management organisations are:

- Operation and maintenance of the irrigation and drainage systems
- Assessment and collection of water charges.

On executing their functions, they are supported by general management services (finance, personnel, planning and monitoring). The degree of intervention by government and the farmers in undertaking the functions above is the basis for classifying the specialised water management organisations. The classes identified are:

- Irrigation associations
- Public Irrigation schemes
- Mixed control schemes

Irrigation Associations

Irrigation associations(IAs) are organisations of and for the benefit of the people (Sagardoy *et al.*,1986). Although the participation of the government is excluded, its support and encouragement are necessary. The size of IAs range from 2000 to 4000 members or scheme sizes of up to 10 000 hectares.

The organisational structure comprise the farmers themselves. The executive body of an IA consists of (in descending order): The general Assembly, The board of Directors, The Manager's Office and The Executive units. Traditional IAs have their own juries to punish faults against the set rules and regulations. The juries are selected from distinguished members of the board.

The existence of a water management organisation implies an adoption of a segregated organisational structure. The other necessary services are provided by other institutions. To ensure coordination with the agricultural services and to engage them actively in the affairs of the irrigation scheme, representatives (board members)of such institutions are included as special members on the Board of Directors of the association.

The IAs are non-political and democratic when it comes to decision making. There is effective administration, communication (two way) and water fee recovery. Because of good respect for the jury, rules and regulations, the relations between the farmers and water masters are friendly. Consequently, water conflicts could be kept to a bare minimum.

Despite the above advantages, the main weakness lies in the fact that, long periods of considerable effort are required to get an IA established and working properly. There are also considerable operational water losses associated with the semi-demand water distribution system usually adopted by the IAs.

Public Irrigation Schemes

In Public Irrigation Schemes (PIS), government officials have the largest stake of their control, unlike IAs controlled by farmers. There is strong institutional support at the national level for such schemes. The schemes are not bound by obsolete water rights and there are good possibilities to rationalise water distribution.

The management structure consists of "The Manager's Office" and "The Executive Bodies". The management is in charge of the implementation of the irrigation plan approved by the responsible Ministry. The Executive bodies report to the Manager and deal with operation, maintenance and administration responsibilities.

The main weakness of PISs is that the project staff are not accountable to the farmers and there is lack of staff continuity as the public officials transfer, thereby prejudicing job performance. However, technical data archiving is done and is important for future operation and maintenance of the scheme.

Mixed control irrigation schemes

This designation is applied to schemes where the main irrigation system is controlled by government officials while the tertiary canals are controlled by the farmers' associations. The establishment of the irrigation associations based on the water course is for all practical purposes similar to small irrigation system management. The mixed control management system is popular where acute water distribution problems in the water courses exist, e.g. in the Far East and Asian irrigation schemes (Murray-Rust and Vandervelde, 1994).

Establishment of Specialised Water Management Organisations

The establishment of PIS is relatively simple as it only requires some qualified personnel, equipment and finance. These elements are generally present during the construction of the irrigation system. Establishment of IAs is a major problem, since it involves transfer of management of scheme to framers. It is difficult to explain to the future members of the association what an IA is and then convincing them the convenience of its establishment. The model and training approaches are followed in order to overcome establishment problems.

In the *model approach*, farmers learn by seeing. In the initial year of operation of the irrigation scheme, a PIS is set up, which then serves as a model to show how the system should be managed. During these early years (10 to 15 years), a proposal is made that an IA should be established and later transferred. The approach is practical and other advantages are: immediate utilisation of the water distribution and "on-the-job" training.

The *training approach* is carried out, where farmers already have some notion about irrigation practices and a good cooperation exists. It is then possible to give farmers and their leaders short training that permits early establishment of an IA. The Philippines has successfully adopted this approach through its Farm System Development Cooperation (FSDC) (Sagardoy *et al.*,1986). This approach requires strong support from the government. Furthermore, specially trained groups of people capable of training of the farmers' leaders is required.

C. Multipurpose water management organisations

These organisations have responsibilities directly related to water management and some others such as: irrigation extension, research, water quality management, marketing etc. The latter group of responsibilities is not effectively provided by the existing institutions.

Multipurpose organisations take the structure of a PIS and they can be designated MPIS. The MPIS have a clear advantage of providing some supporting services which are nearly indispensable in the early stages of development of an irrigation scheme. This service provision is arguably, the key to achieve proper water management at the farm level.

2.2.3 Operation and maintenance sub-system

2.2.3.1 Operation of the delivery system

Operation refers to manipulating the structures that convey, distribute, and apply irrigation water according to the designs specifications. Unreliable and inequitable water supply usually result when communication and travel times are not considered in the operation of the irrigation system. The principal goal of the operation service is therefore, to satisfy crop water requirements by delivering water to the root zone. According to Sagardoy *et al.* (1986), this goal is achieved by the following activities:

- Preparation of an irrigation plan
- Implementation of the plan
- Monitoring of the operation service through collection of data on water abstraction, its use as well as waste discharges and preparation of corresponding reports.

2.2.3.1.1 Preparation of the irrigation plan

The preparation of the irrigation plan involves (i) estimating the future water supply (ii) estimating projected water demand and (iii) matching available water supply and projected demand.

1. Estimation of irrigation water supply

The future water supply estimation from a water source depends on climatic parameters and hydrological features at the water source and availability of water storage. Where the source of irrigation water is large compared to designed diversion/abstraction or where there is provision for storage reservoir, the available water supply can be determined with a considerable degree of accuracy for the future irrigation season (Hazlewood and Livingstone, 1982). In instances where availability of the irrigation water is uncertain, projections are made on the basis of conservative estimates using mathematical models (Sagardoy *et al.*, 1986).

2. Estimation of irrigation water demand

Irrigation water demand is determined on the basis of expected cropping pattern, cultivation practice, timing and amount of rainfall and irrigation efficiencies. Under segregated organisational structure, there are difficulties in foreseeing cropping patterns as farmers have the freedom of choosing the nature and type of cropping patterns. In this instance, cropping information from previous years coupled with analysis of historical trends is useful in determining future water demands. However, the cropping pattern is easily picked in schemes with an integrated management structure, where the government through the operating agency controls the pattern.

Depending on the crop growth stage, climate and the area, the monthly crop water needs can be computed following standard procedures (FAO,1977). The computations begin with estimation of reference crop evapotranspiration (Et_o) from climatic and crop data. The "modified" Penman and Pan evaporation methods are normally adopted for estimating Et_o. The next step involves the computation of daily and monthly crop water needs, which is the product of the crop factor (K_c) and Et_o. The crop factor (K_c) is a function of crop type, stage of growth and soil surface moisture conditions. The final step is the calculation of irrigation water requirements (IR) for the period in question and it is the difference between crop water needs (Et_c) and the effective rainfall, as shown in Equation 2.8

$$IR = Et_c - R_e - Os + On \quad (2.8)$$

In which: IR = irrigation requirement

Etc = crop water needs

R_e = effective rainfall

Os =other sources (ground water recharge)

On = Other needs (e.g. leaching requirements)

Effective rainfall can be approximated from actual rainfall on a weekly, monthly and annual basis. The weekly effective rainfall can be computed using the formula in FAO (1994):

$$Re = C_1(R - C_2) \quad (2.9)$$

Where R_e is the effective rainfall in mm/week, R is the average total rainfall in mm/week and C_1 and C_2 are empirical coefficients that must be locally calibrated.

The monthly R_e can be approximated using the following formulae in FAO (1974):

$R_e = 0.8R - 25$ if $R > 75$ mm/month

$R_e = 0.6R - 10$ for $17 < R < 75$ mm/month

$R_e = 0$ for $R < 17$ mm/month

where R = monthly rainfall total (mm)

The IR (mm) computed from Equations 2.8 and 2.9 is then multiplied by the area grown to a crop to get the corresponding volume of IR (demand) to be compared with water supply. The gross water demand is obtained by dividing the net irrigation demand with the irrigation efficiency. The summation of water demand of portions grown to different crops gives the demand of each farm. A summation of all the farm demand gives the unit command area (UCA) demand. Similarly, a summation of UCA demand gives the system demand.

3. Matching available water supply and projected demand

a) Operational situations

The area irrigable from a given supply will depend on the level of demand in relation to supply and on how closely the seasonal pattern of demand follows the seasonal pattern of supply. Matching supply with demand attempts to ensure that the water requirement for crop and for other field activities are fully met without wastage. In every irrigation scheme, deficit occurs when the demand for water is greater than the available supply. With regard to this, three operational situations exist:

(i) Schemes where water supply is greater than or equal to the demand: No deficit

Water operation under this situation is easy to manage, but, such schemes tend to have low returns per unit of water distributed (inefficient), leading to waterlogging at times. Farmers in such schemes tend to adopt wasteful water use habits which are difficult to discard in future when the project users grow in number (Sagardoy *et al.*, 1986).

(ii) Irrigation scheme with a moderate water deficit (10-20%)

Irrigation schemes in this situation provide an incentive to maximise crop yield returns from the available water. Farmers and operational staff normally work out coping mechanisms that include reduction of distribution and application water losses as well as modification of cropping patterns.

(iii) Irrigation schemes with a large water deficit (> 50%)

Schemes in such a situation come about as a result of pursuing the objective of maximising the number of households to be served, under evaluation of crop water requirements or in pursuit of maximum government revenue per unit area commanded. Such schemes produce lower crop yields than expected due to water stress and salinity problems.

b) Measures to match irrigation water supply and demand

Measures taken by irrigation management to match with demand can be broadly grouped into restrictive and storage measures (Sagardoy *et al.*, 1986; Livingstone and Hazlewood, 1982).

(i) Restrictive measures to match supply and demand

In order to reduce the gap between supply and demand, restrictive measures which could be employed by the irrigation management relate to:

- the cropping pattern
- the water distribution practices
- the water fees

According to Sagardoy *et al.* (1986), these measures should preferably be utilised in combinations as they are not mutually exclusive.

Measures related to the cropping pattern.

Cropping pattern related measures may be effected by:

- changing the planting time
- substituting existing crops with those having lower water requirements; or
- reducing the irrigation area.

The above measures are difficult to effect and the responsible management organization will need to have authority and considerable diplomacy with a view to convincing the farmers to make necessary changes.

Regulation of the planting time and other cultivation activities can lead to large reductions in water requirements during the peak demand of an irrigation scheme. For example, Taiwanese farmers are capable of obtaining adequate water at periods of peak requirements by keeping the pre-planned planting time-tables aimed at matching supply and demand (Sagardoy *et al.*, 1986).

Substituting existing crops with those having lower water requirements effectively reduces water demand, e.g. sorghum for maize, but there is a risk of introducing crops which may have low water requirements but not financially attractive to the farmers.

Water demand can be reduced by reducing the irrigated area. This is usually achieved by reducing water allocation which in turn lead to a reduction in area irrigated by the farmer. However, farmers can take the risk of irrigating a larger area than technically feasible, though it is very rare to get high yield returns under such circumstances.

Measures related to water distribution practices

The measures available for reducing water deficit related to distribution practices are:

- Allocating water to high value crops such as fruit and vegetables
- Reducing irrigation depth
- Extending the interval between irrigations

Introducing a charge for water

This measure is effected by increasing water fees in order to decrease the amount of water used and the irrigators will use the water more carefully. An increase of water fees is always a sensitive matter, one to be handled with care owing to its political repercussions. It will also be undesirable to schemes where farmers are poor and unable to pay for their water (Kay, 1986).

(ii) Storage measures to match supply and demand

Storage of water is one way in which a closer fit of the demand and supply of water can be achieved. By storing water, it is possible to transfer it through time from surplus months to relieve the shortage in constraining months so that the area irrigated would not be limited. However, storage water is lost in transit from one month to the other through evaporation and seepage.

Storage measures during short term shortages

Short term irrigation water shortages imply a short period (few days) of below normal supply In schemes where water distribution is on a continuous basis, short-term water shortages are avoided by building night storage reservoirs along the distributary canals. Alternatively, productivity per unit of water can be maximised by deficit irrigation or irrigation at critical crop growth stages during short dry spells (Tembo and Senzanje, 1988; English and Stoutjesdijk,1995).

Storage measures during short seasonal shortages

These shortages occur when there is inadequate water throughout the season. Such shortages reduce the irrigated area. Through storage at stream level, Livingstone and

Hazlewood (1982) argue that water can be transferred from surplus months to deficit months and permit an increase in the irrigated area.

Small reservoirs (tanks) to tackle seasonal water shortages in the arid areas are usually associated with low water use efficiencies due to mainly design related problems. This was observed by Sharma and Helweg (1984), in a study they conducted at the Aurepalle and Dokur reservoirs (India) where monsoon precipitation was collected in small reservoirs (tanks) to supply irrigation water for the dry season. The authors reported 3 to 5 times lower overall system water use efficiencies, when compared to the potential water use efficiency due to poor system design, improper system maintenance and inefficient irrigation practices.

Storage measures during long term shortages

This type of shortage occurs in schemes with a very large water deficit. Water supply is improved by inter-year storage which is directed towards reducing the risk of failing to provide water for the target irrigated area in bad years. Hazlewood and Livingstone (1982) reported that without inter-year water storage, the frequency distribution of river flows from year to year has a characteristic positive skew. Storage increases the probability of water availability just above the target level and the converse is true. This also reduces very high uncontrolled river flow rates, which could inundate irrigable area.

2.2.3.1.2 Water Distribution: Implementation of operation

The water distribution methods are delimited by the way in which the flow rate, frequency and duration of water supply are defined. These parameters determine the flexibility of a particular method. The water distribution methods commonly used in smallholder irrigation schemes are: continuous flow, rotation and on demand. The actual distribution of water has different characteristics depending on the water distribution method employed.

a) Rotational supply

Rotational system is restrictive, as the flow rate, frequency and duration are fixed by policy of the central water authority and remain fixed for the entire irrigation season. Such systems were reported by Clemmens (1987), to be common in the third world irrigation schemes, where farmers lack adequate knowledge of irrigation methods and high equity levels are attainable.

The supply schedules can be rigid (fixed supply with fixed duration and fixed interval) or flexible and adjusted to changes in cropping patterns and field irrigation requirements. Rotational supply is well adapted to schemes with a single crop or simple cropping pattern. In schemes where water availability is supply-oriented, such as the Chibuwe scheme in Zimbabwe, flexible rotational system is adopted by this block smallholder scheme (Manzungu, 1996). Water distribution is a consequence of negotiations between farmer and operators (water bailiffs) and the farmer is required to arrange his activities in accordance with the availability of water supply.

When in operation, each canal section carries the maximum and constant discharge. As a result, high conveyance efficiencies are achieved since there is little seepage from limited pore formation (Trout and Kemper 1980). Sedimentation problems are also reduced, as large discharge variations are avoided.

The main weakness is that water supply to the diversified cropping pattern with distinct, different irrigation requirements over an area and time is a problem. This is a common scenario in most smallholder schemes, especially those with a segregated management structure.

b) Continuous supply systems

Continuous systems are a special case of the rotation systems, where duration is the entire season and the frequency is once per year (Clemmens, 1987). A continuous supply system is therefore constantly in operation and the discharge in the canals is adjusted to the daily irrigation requirements. The supply is distributed within the irrigation system in proportion to the area served and it is regulated by simple diversion structures.

The continuos flow is the simplest water distribution system adopted, but it is the least efficient because delivery is from field to field resulting in large evaporation, deep percolation and run off losses, as water moves from top to bottom in a thin, but extensive layer. Because of these losses, the scheme water use efficiencies are low. It is also difficult to handle small stream sizes and to accurately adjust the supply in proportion to actual field requirements.

Where water is scarce, the continuos flow usually result in inequitable water distribution. In schemes where water is not limiting, the continuos method of water distribution is associated with flooding, rise in water table, reducing their sustainability and usually call for expensive drainage installations (Bos *et al.*, 1994).

c) Demand systems

Demand systems are the most flexible of all the irrigation distribution methods, as they allow an unlimited amount of water to be taken from the system at the user's convenience. The user decides when and how much water to take. Such ideal systems are not practical and would be prohibitively expensive (Clemmens, 1987).

In an on-demand system, farmers request irrigation water according to their felt needs. An advance scheduling is common in this system and requests for water are made 2 or 3 days in advance and the distribution of water is programmed accordingly.

A free demand supply is difficult to achieve in the open canal systems. For efficient water use, the irrigators should be acquainted with proper irrigation scheduling as farmers do not necessarily irrigate according to theoretically determined crop water demands (Manzungu, 1996). A well trained staff must be available to operate the system, which requires full control of water level and discharge of each part of the distribution system.

d) Water allocation

(i) Methods of water allocation

The main objective of water allocation is to attain equity and high delivery efficiencies. Two methods of water allocation in smallholder irrigation schemes were reported by Campbell (1986) and these are:

Area based water allocation method

This method of water allocation is purely based upon area of holding. It is usually practised on land with uniform soils and near flat topography. The irrigator is free to use his allocation of water as he pleases: choice of crop, amount (depth) of water applied and area irrigated being left to his judgment. The main advantage of this method lies in the simplicity in water distribution and canal operations as flow required at any point is at the same rate per unit area served throughout the season (Campbell, 1986).

Request based water allocation method

Water allocation is determined through advance requests by the irrigator each season, and agreement by the irrigation management for supply of sufficient water for a particular area of a particular crop. The irrigation management exercises discretion in sharing the available supply between applicants. This allocation method is practised under conditions of more variable soils and topography, where circumstances dictate growing different types of crop with differing water requirements, on neighbouring areas. Its main weakness is complexity in water supply and operation.

(ii) Water allocation procedure

The water allocation procedure is usually carried out in three steps: The procedure followed is similar to the one used in the operation and simulation module of OMIS model (Van der Krogt, 1994):

Demand inventory step: The demands in each command area are computed and traced upwards through the irrigation system network. At each node or branch, the relevant demands or losses are added. This upward tracing establishes the target diversions at the different gates.

Balancing demand and supply: The demand at the main intake is compared with a "dependable" or expected available flow for the coming operation time step. If the available flow is insufficient, the water allocation to unauthorized cropping is first cut off, followed, if necessary, by a proportional reduction of water allocation to unauthorized crops. Reductions in allocation are implemented via an adjustment of target diversions established in the demand inventory step.

Allocation step: The flow of water is traced downwards through the network, joining (splicing) diverted water and losses at each relevant branch (or node). At each diversion, it is attempted to divert the target diversion flow established in the previous steps.

2.2.3.2 Maintenance of the water delivery system

1. Problems in water delivery canals and solutions

The main problems in earth canals are: silting, weed growth and bank erosion.

a) Silting

The accumulation of sediment is a common problem affecting the performance of open channels and is mainly caused by silty water being taken from a river. The silt accumulates on the bed of a canal and reduces the hydraulic radius, hence the flow capacity. Silted canals are also susceptible to seepage losses. Some canals can become completely blocked when the silt content is very high. Silt can be removed by hand, but the productivity of labour was reported by Sagardoy *et al*. (1986), to be low due to muddy conditions.

b) Weed infestation

The growth of weed can seriously impede the flow of canal water due to increased hydraulic roughness. Weeds also increase wetting up water losses due to consumptive water use. Silting encourages and precedes weed growth in lined canals. The main groups of weeds found in canals are:

Earth weeds: These weeds root in the soil and their habitat is not the water, but they proliferate on canal slopes and in banks, benefiting from favourable soil moisture conditions (Trout and Kemper, 1980).

Aquatic weeds: These weeds can either root in the water or the earth, but their habitat is the water.

Water weeds are removed by cutting or excavation when desilting.

c) Erosion of banks

The erosion of canal banks can be due to heavy rainfall, wave action, stock grazing or passage by drinking animals or transit of vehicles using them as roads. Kay (1986) argues that the worst damage is caused by weather, and gullying from rainfall being the most common. Erosion of canal banks can be reduced by growing grass in banks and damage by animals can be reduced by fencing and confining animals to specific watering points.

2. The need for maintenance

Maintenance of the delivery system is aimed at combating the effects of siltation, weed growth and other canal problems and it is therefore, a pre-requisite for sustained performance of an irrigation project. In the delivery channels, Murray-Rust and Vandervelde (1994) reported that maintenance of the delivery system is required for:

- minimizing conveyance losses
- prevention of failure of control structures; and
- sustaining the hydraulic conditions required by the design for effective water distribution

A balance for these reasons should be struck at the design stage so that a dependable supply can be delivered to every farmer (Skogerboe, 1986). The maintenance of irrigation canals was viewed as a key to restructuring irrigation management. According to Sijbrandij and Van Der Zaag (1993), the need for canal maintenance can bring water users together in cooperation which may help to forestall conflicts over water supply. This may help reduce competition among water users along the same canal, which often results from inequitable water distribution.

3. Types of maintenance activities

- Annual routine maintenance: for keeping the irrigation system function at an acceptable level.
- Special maintenance: For repairs of damage caused by disasters like floods
- Deferred maintenance: This includes any work necessary to regain the lost flow capacity in canals, reservoirs and structures when compared to the original design. This type of maintenance involve modifications to canals and structures as a result of changes in the cropping patterns and drainage problems.

2.2.3.3 Water losses in open channels

a) Causes of conveyance losses

Irrigation water losses during conveyance are caused by the following factors:

- Highly permeable soils
- Insect or rodent holes in banks
- Dirty canals

- Lengthy canal network
- Rigid delivery methods

Wasted irrigation water often result in drainage, salinity or waterlogging problems which reduce the environmental sustainability of irrigation schemes (Bos *et al.*, 1994).

b) Classification of conveyance losses

Water losses in conveyance system were classified by Trout and Kemper (1980) as steady state or transient losses. *Steady state losses* occur in the conveyance system as a result of seepage into the bed and banks, visible leakage through and over the banks and evaporation from the water surface.

Seepage losses occur in the form of normal infiltration into bed and bank soils and excess seepage into bank holes and cracks. This is significant in channels underlain by coarse soils and channels with large wetted perimeters.

Leakages occur as over topping bank leaks and leakage through closed outlets. Overtopping can be caused by combinations of inadequate bank free boards, extensive vegetation in the channel and/or obstructions to the flow. They also indicate deferred maintenance of conveyance system by the users

Transient losses occur while the system is not flowing under steady state conditions and are further classified into dead storage losses and wetting up losses in dry channels. Dead storage losses result from channel beds lying below the field levels and from undulations in the bed. Channel drying is caused by direct evaporation from the soil and evapotranspiration by plants living on the banks. Tortuous conveyance and on demand scheduling are associated with high wetting up losses (Trout and Kemper,1980;Sagardoy *et al.*,1986).

c) Quantification of water losses

Water conveyance losses are quantified (total volume or %) through actual physical loss measurements or approximations using hydraulic computer model simulations (FAO,1994).

In economics terms, the value of irrigation water can be quantified in terms of its *marginal value to crop production*. It was defined by Trout and Kemper (1980) as the value of additional output which can be produced with an additional water to the farmer. The marginal value of water to crop production is the main criterion used to determine which channel improvement strategy to use for reducing the water conveyance losses. If channel improvements can provide water to the farmer at less cost than the marginal value, then they should be carried out.

d) Techniques to reduce water losses

There are basically three renovation techniques employed to reduce water losses from the conveyance systems and they include cleaning of vegetation from banks, earthen renovation and channel lining. The selection of technique depend on:

- Amount and types of losses diagnosed
- The cost of the program and the benefits derivable from the saved water or the marginal value to crop production
- The resources (personnel and financial) available
- The priorities set
- Time available

(i) Channel cleaning and repair

This renovation strategy involves stopping the easiest to control forms of channel losses. Activities include: bank raising, channel smoothening, compaction, hole plugging, weeding and desilting. The benefits of cleaning and repair are of limited duration and prolonged benefits require regular cleaning. This strategy is undertaken by farmers, so that they can note the changes in water delivery as a result of their effort and become more aware of the importance of maintenance and of their ability to improve their water supply (Trout and Kemper, 1980). In addition, delivery efficiencies are high when the owner irrigated and maintained his part of the water course (Lowdermilk *et al.*,1978).

(ii) Earthen renovation

This technique entails complete destruction of old channel banks and reconstruction to specifications based upon hydraulic design and the installation of permanent structures at junctions and major outlets. Maintenance is also essential for the lasting of benefits.

Permanently installed flow measurement devices are essential for monitoring conveyance losses in the channels under this renovation strategy.

(iii) Channel lining

The lining of channels is a high cost improvement technique and it can achieve high delivery efficiency. This technique is justified mainly, when high value cash crops are grown in schemes where water is a limiting input and losses are excessive. In order to extend the life and extract maximum benefits, maintenance of lined channels is essential. Maintenance include, patching of holes, maintaining earth in support banks, raising the bank height in settled sections, replacing damaged structures, cleaning silt from inside the channel and preventing vegetation growth in the channel or through the lining.

The equity of water distribution was reported by Murray-Rust and Vandervelde (1994) to be improved by lining, as designed flows were easily maintained. The authors also reported that inequity in unlined channels result from over-excavation during desilting. Over-excavation reduces the working head for upstream outlets and allows more water than designed to pass towards the tail, thereby distorting the equity of water distribution.

2.2.3.4 Water and maintenance rates

These are the sums paid by the farmer as his contribution to government investment in the engineering works for the storage and distribution of water and to cover the expenses related to operation, maintenance and administration of the scheme. Water rates are calculated using the following methods suggested by Sagardoy *et al.* (1986):

- payment per unit water used
- payment per unit area of irrigated land
- payment by fixed share (%) of harvested crops

In countries like France, Spain, USA, water rates actually correspond to the theoretical calculation, but in others, they bear little or no relation to the calculated fees, where they are more of a political issue than a technical one (Clemmens, 1987).

In Zimbabwean smallholder irrigation, the water rate is also referred to as the irrigation rate or maintenance rate. Manzungu and Van Der Zaag (1996) reported a consistent reluctance by farmers to pay for any amount of water rates for various reasons. The main reason, according to Makadho (1994), is that the money farmers pay for maintenance charges goes to the government's treasury and they feel that it should be ploughed back into their respective schemes, by way of purchasing tangible materials and equipment, hence the reluctance. Rukuni (1988) also pleaded that scheme-specific rates, reflecting real running costs should be used for distinguishing schemes which need subsidies from those which do not.

2.2.4 Modelling water delivery

Computer models can act as a focus for improved irrigation management, as they demand a quantified approach to tackling water delivery problems. They are information systems believed by FAO to be of importance in the decision making process. However, like any other computer software, irrigation water delivery models offer a valuable aid to, but are not a substitute for, sound management and knowledge of irrigation practice.

The irrigation water delivery models can be broadly classified as:

- Irrigation management models
- Models to optimize irrigated crop production and
- Hydraulic models to simulate open channel systems.

The functions of these models are explained in Table 3.

Table 3 Functions and types of irrigation water delivery models

Function	Model type							
	Irrigation management models: Basin level	Main level	Tertiary level	Management information systems	Soil water balance	Water ordering	Hydraulic simulation models	Optimisation models
Water allocation (planning/simulation/evaluation)								
-basin level	•	X		X	X	X	X	X
-Main system	X	•	X	X	•	•	X	X
Tertiary system								
On-farm activity & irrigation scheduling		X	X	X	•	X		X
Cropping pattern selection		X	X	X	X			•
Support to general mgnt. Function O & M				•				
Hydraulic analysis/operation strategies/design							•	

• Primary function X Possible secondary function **Source**: FAO (1994)

1. Irrigation management models

These models are developed to assist in the integrated management of tasks facing irrigation managers. Irrigation management models are further classified into basin, main system and tertiary levels models depending on directed level of simulation (Table 3).

Modelling using the INCA software

Model description

The Irrigation Network, Control and Analysis (INCA) software was developed by Makin and Skustch (1994), for the management of irrigation systems. The model is applied in: pre-season planning, water allocation, performance monitoring and evaluation and the general management of irrigation data. It is suited to gravity, lift canal networks and reservoir supplies.

The principal modules in the database deal with:

- system geometry and characteristics
- agriculture
- hydrology
- planning
- water allocation
- water monitoring
- monitoring-general management (operation and maintenance)

When used for planning, the module combines a resource operations model (reservoir) with results from a pre-season run of water allocation model, analysing seven probability levels for rainfall in the process. If the model is used for water allocation, it calculates soil water balances for upland and basin crops. Water requirements are aggregated through the system to specified locations, checked against capacity and if necessary, automatically modified.

The input data required is on: historical performance, meteorology, crops and cropped area, soils, scheme layout and flows. The model output include schedules, graphs, data summaries and reports on water distribution, performance and general management information.

Kraseio irrigation scheme's experience with INCA modelling

In the Kraseio irrigation scheme, Thailand, adequacy and equity indicators of irrigation water delivery were assessed in two dry seasons, before and after implementation of the INCA software. Adequacy was assessed in terms of relative water supply (RWS) which is the ratio of water supply to demand and the equity parameter was assessed in terms of the inter-quartile ratio. Values close to unity for both parameters, indicated near perfect water delivery.

The software assisted in matching water releases with water needs and stabilising the depth of water supply. As a result of software introduction the following improvements in performance were obtained:

- the inter quartile-ratio and RWS approached unit (perfection)
- Reduction in water use:7-9% reduction in water releases and 7 -23% reduction in overall use.

2. Models to optimize irrigated crop production

This group of models use linear programming techniques to optimize water use and allocation with cropping pattern, agricultural output and canal system demands.

Optimisation of water allocation in canal systems of ChenGai irrigation area

The SGI software developed by Zhou Zhenmin (1994), was used to optimise canal water allocation of the ChenGai irrigation scheme, China.

Model description

The model determines the optimum cropping patterns and water allocation with minimum rotation times. Linear programming is applied at each distributary of a multi-branched system to (a) optimise returns within a total water restraint and (b) minimise water use by devising an optimal canal rotation pattern. Restraints being total area, upper and lower bounds of areas planted to each crop, total water supply, upper and lower bounds on discharges in the main canal.

The output from the optimization model are: summary tables showing returns for optimal crop pattern on each distributary canal discharges under optimal rotation pattern.

Application of the model

At the ChenGai irrigation scheme were the optimisation model was implemented, the utilisation of water resources was *ad hoc* with serious waste of water and prolonged rotations and the potential benefits have not been realised (Zhou Zhenmin, 1994). As a result of introduction the SGI software, the following improvements in operation were noted:

- Improvement s in flows, such that maximum flow (Q_m) was attained in the first 8 days of the rotation and more than half of maximum flow rate in the last two days of the rotation, preventing siltation in the branch canals.
- By use of the optimisation model, irrigation rotation was reduced from 14 days in the traditional irrigation system to 10 days. This saved time and water.

The weaknesses of the optimisation models are:

(i) The value of the model depend on the quality of information entered

(ii) Difficulties in entering the variables and constraints that adequately represent the irrigation system or the whole irrigation system

(iii) The linear programming equations are difficult to solve.

3. Hydraulic models to simulate open channel systems

Hydraulic models are helpful in identifying problems caused by inadequate management and their main objectives are:

- to provide understanding of canal system hydraulic characteristics
- to identify appropriate operational practices
- to identify constraints, evaluate the effect of possible design modifications on the performance and target maintenance resources most effectively

Hydraulic modelling using the MISTRAL software

Model description

The MISTRAL model was developed by Bhutta (1988) for hydraulic analysis targeting options for operation and maintenance. It handles both steady and unsteady state flow conditions. The model is based on the continuity and momentum equations and it also solves the St. Venant equation.

The input data required for the model include: topography, canal cross-sections, head/discharge relationships for canals and structures, structural parameters, canal seepage loss and roughness. Tabulated water levels and discharges are the outputs from the simulations.

Operational simulations are based on varying head and discharges on a given time step and comparing downstream performance under alternative rotational patterns. When applied for maintenance purposes, simulations are based on changing canal cross sections and canal parameters.

Model application in the Lagar distribution canal (Pakistan)

The rule at the irrigation department is that canals should run at least 70 % of their design discharge for the equity objective to be met. However, this rule is not followed and inequitable water distribution is reported along the canal.

The MISTRAL hydraulic model was used to establish the potential for improving the operational management for the Lagar distributary canal under current physical conditions. The simulation was carried out in 1988 and the following results were obtained:

- the equity of water distribution became poor when the discharge at the head of the Lagar canal was less than 100 % of the design.
- by assessing the IQR (an equity indictor), it was observed that the introduction of a rotational schedule at the heads of distributaries under existing physical conditions can improve water supplies to outlets along the entire length of distributaries, especially in the tail reaches.

2.5 PERFORMANCE INDICATORS OF IRRIGATION SCHEMES

Irrigation performance indicators translate irrigation goals into quantifiable measures applicable for comparison of actual and potential performance. Performance indicators of irrigation schemes identified by Hoecht (1990) and Bos *et al.* (1994) include productivity, profitability, financial viability, quality of water delivery and maintenance; and environmental sustainability.

2.5.1 Productivity of irrigation schemes

Productivity refers to production (or yield) per unit resource use. The productivity of smallholder irrigation can be assessed in terms of productivity per unit of land, labour, water and capital (Meinzen-Dick *et al.*,1994). Generally, productivity is assessed in terms of yield per unit water or land resource. In schemes where there is no water scarcity, productivity per unit of land is the gauge to use.

Productivity in relation to land can be expressed as (i) gross margin per unit area (ii) gross margin per hectare actually cropped and (iii) gross margin per hectare of total holding. The productivity at farm level depends on the size of the holding. In smallholder schemes Rukuni (1988) reported that the optimal holding size should be between 1 and 1.2 ha for maximum productivity to be obtained. But, Chancellor and Hide (1996) reported that farmers with the largest irrigated holdings of 1.6 hectares in Nyanyadzi scheme were able to put more of their land into high value crops (such as tomatoes, summer vegetables and cotton) and experience the desired return to labour (minimum of two units of labour per farm). These crops require large amounts of working capital which farmers with large holdings could more easily afford (Tiffen, 1990; Meinzein-Dick *et al.*, 1994).

In schemes where water is in short supply, the maximisation of water resource (productivity per unit of water) is more appropriate. This is achievable through deficit irrigation and irrigation at critical crop growth stages (Tembo and Senzanje, 1988; English and Stoutjesdijk,1995). The productivity per unit of water, expressed as gross margin per unit of water, gives an indication of the efficiency of water use in terms of financial returns to the input.

2.5.2. Profitability of irrigation schemes

Profitability refers to the net income to farm inputs in monetary terms after deducting the production costs from gross income as indicated by the enterprise gross margins. Indicators of profitability can be assessed in terms of water delivered or land, depending on which resource is scarcer (Mao Zhi, 1989):

$$\text{i) } Area \quad based \quad profitabilty = \frac{Increamental \quad benefit \quad per \quad unit \quad Area}{Total \quad irrigation \quad \text{expences} \quad per \quad unit \quad Area} \qquad (2.10)$$

$$\text{(ii) } Water \quad based \quad profitabilty = \frac{Increamental \quad benefit \quad per \quad unit \quad water}{Total \quad irrigation \quad \text{expences} \quad per \quad unit \quad water} \qquad (2.11)$$

2.5.3. Financial and economic viability of irrigation systems

2.5.3.1 Financial viability

Bos *et al.*(1994) reported that, there has been an increase in recurrent costs required to keep irrigation systems function and as a result, there has been moves towards the privatisation of irrigation agencies to make them more financially self-supporting. These moves are geared towards enhancing the financial viability of the systems. Indicators of financial viability can be expressed as total financial viability, financial self-sufficiency and fee collection performance.

$$\text{(i) } Total \quad financial \quad viability = \frac{Actual \quad O \quad \& \quad M \quad Allocation}{Total \quad O \quad \& \quad M \quad \text{Re}quirements} \qquad (2.12)$$

$$\text{(ii) } Financial \quad self \quad sufficiency = \frac{Irrigation \quad Agency \quad income}{Total \quad O \quad \& M \quad \text{Re}quirements} \qquad (2.13)$$

$$\text{(iii) } Fee \quad collection \quad performance = \frac{Irrigation \quad Fees \quad collected}{Irrigation \quad fees \quad due} \qquad (2.14)$$

Where O & M = operation and maintenance costs

The financial indicators give an indication of the extent to which the irrigation agency is expected to be self-financing. The fee collection performance indicator was reported by Bos *et al.*(1994), to have been successfully used by National Irrigation Administration in the Philippines, where the agents collect the money from the farmers.

2.5.3.2 Economic viability

Irrigation planners and policy makers are primarily concerned with the economic performance of investments, or the return to capital employed, which is an aspiration of the irrigation management. The indicators used are: *economic internal rate of return* or *financial internal rate of return*. The internal rate of return of an irrigation project can be treated as a single measure of performance and it is particularly adopted as the supreme criterion of whether or not an irrigation project is worthwhile (Chambers, 1986). Hence its use in appraisals and assessing proposed projects.

2.5.4 Quality of water delivery

The quality of water delivery can be assessed in terms of the following parameters: adequacy (volume balance), reliability (temporal parameter) and equity of water distribution (spatial parameter). These performance indicators were described by Murray-Rust and Snellen (1993), as the primary objectives for an irrigation water delivery system and are interrelated, but usually treated separately. Assessment of all the three fully describes the performance in respect of water delivery.

2.5.4.1 Adequacy of water supply

Adequacy is a measure of the degree to which water deliveries meet soil-plant-water requirements or irrigation requirement. A system that has adequacy objectives aims at delivering water in sufficient volume at appropriate times to avoid potential yield reductions caused by periods of water shortages that cause plant stress.

Many systems do not have adequacy as a water delivery objective because there is insufficient water in relation to land resources to permit all farmers to cultivate their plots to full extent. Adequacy can be managed in the following ways: (i) by either matching cropping plans and calendars with estimated seasonal water availability before the start of the season; and (ii) by adjusting operational targets in response to actual demand during the season (Murray-Rust and Snellen, 1993). Supply-based systems do not attempt to make short-term adjustments in discharge even though demand is varying when managing adequacy, whilst demand-based systems do.

The adequacy parameter measures the variation of the flow rate or duration around the design specifications at a given point in the system. Mathematically, adequacy was defined by Reddy (1986) as:

$$A_d = \frac{Va}{Vr} \tag{2.15}$$

Where: A_d = adequacy of water supply; V_a = delivered volume; and V_r = required volume. Other parameters of interest to adequacy are: flow rate, duration and the total volume of water received at/from a given point in the system.

The adequacy parameter is determined per rotation or weekly (i.e. in a short time frame).

An adequacy value of 1.0 is desirable, a value less than 1.0 indicates water deficiency and a value greater than 1.0 indicates that an amount of water is wasted. The adequacy parameter (A_d) can be classified as good, fair or poor according to the scale developed by Molden and Gates (1990) as shown in Table 4.

Table 4 Assessment ranges of performance indicators

Indicator	"Good"	"Fair"	"Poor"
Adequacy, A_d	> 0.9	0.8 - 0.9	< 0.8
Equity, E_q	< 0.1	0.1 - 0.25	> 0.25
Dependability, D_p	< 0.1	0.1 - 0.2	> 0.2

Source: Molden and Gates (1990)

Over a long time frame (monthly or over three or four rotational time periods), the adequacy parameter was referred to as the water delivery performance by Clemmens and Bos (1990) and the computation is as follows:

$$Water \quad delivery \quad performance = \frac{actual \quad volume}{target \quad volume} \tag{2.16}$$

This performance indicator is used to assess the effectiveness of the management inputs. A value of 1.0 for the water delivery performance parameter imply that the management inputs are effective.

Relative water supply (RWS) can also be used to indicate adequacy of water supply. RWS was mathematically defined by Levine (1982) as:

$$RWS = \frac{Irrigation \quad + \quad Effective \quad rainfall}{Evapotranspiration \quad + \quad Seepage \quad + \quad Percolation} \tag{2.17}$$

Where: RWS = relative water supply; the numerator is total supply and the denominator is the total demand.

When interpreting RWS values, it is necessary to establish the critical value below which water supply becomes inadequate. The value of RWS is an indication of the relative abundance with respect to adequacy, although it is sensitive to the scale of the irrigated area because of conveyance losses (Murray-Rust and Snellen, 1993). A RWS value less than 1.0 implies water deficit, such that supply is less than demand and the crop does not get its full requirement. A RWS value greater or equal to 1.0, implies that water supply is adequate to meet the theoretical minimum irrigation requirement (Makadho, 1994). However, at scheme level, Makadho (1994) suggested that it may be economically more efficient to operate at RWS values less than 1.0. This is because some small levels of water stress may produce the highest output per unit volume of water, although crops react differently to sub-optimal water supply (Doorenbos and Kassam, 1979). In order to attain economic efficiency, Keller (1986) also recommended that irrigation of grain crops and fruit crops should be done at RWS values of not less 0.75 and 1.0 respectively.

The RWS values can be used as guidelines for management inputs. According to Murray-Rust and Shellen (1993), a RWS value greater than 1.5 at tertiary level suggests water is sufficiently abundant that management inputs need not be very intensive. Values at or close to 1.0, management inputs themselves will not necessarily compensate for the relative water scarcity. However, the RWS index has been used in Zimbabwean smallholder irrigation schemes by Makadho (1994), to compare scheme types and seasonal water supply adequacy.

At field level, the Water Availability Index (WAI) is a simple method of quantifying water adequacy. The indicator, WAI, was developed by Wijayaratna (1986) and it is based on a qualitative scale of observations of water conditions in rice fields as explained in Table 5.

Table 5 Water Availability Indices of rice paddies under different soil moisture situations

Soil moisture situation	WAI
Water flowing from paddy to paddy	4.0
Standing water in rice field	3.0
Soil is moist, with water in depressions	2.0
Soil is dry and surface cracks are appearing	1.0

Source: Wijayaratna (1986)

2.5.4.2 Reliability of water supply

Reliability or dependability is an expression of confidence in the irrigation water system to deliver water as promised. Without a reliable system, farmers view irrigation more or less the same as rainfall and act accordingly. The water which is delivered has limited value to them and they spend little effort in utilising it efficiently.

Under continuous flow conditions, reliability is primarily, the expectation that a particular water level/discharge will be met or exceeded (Murray-Rust and Snellen, 1993) and *variability* is the main concern. On the contrary, under intermittent (rotational) flow conditions, the *predictability* of the time when flow will start and stop (length of run or turn) is of importance. The predictability of water deliveries significantly affects the overall adequacy of water delivered and have direct impact on crop production. According to Bos *et al.*(1994), the rationale for this is that, water users may be less efficient in water use if there is an unpredictable variation in volume or timing and they may not use other inputs such as fertilisers in optimal quantities if they are more concerned with crop survival than crop production.

In canals, flow rate *consistency* is of concern for all water distribution methods as reported by Clemmens and Bos (1990).

Reliability is indicative of the notion "timeliness of deliveries"with respect to flow rate, the time of arrival and duration of supply (Rey *et al.*, 1993). In statistical terms, reliability or dependability (Dp) was defined by Chancellor and Hide (1996) as the coefficient of variation (CoV) of adequacy for individual locations over different time periods (see Equation 2.18).

$$D_p = \frac{S_{Ad}}{M_{Ad}} \qquad (2.18)$$

Where: S_{ad} = standard deviation of adequacy; and M_{ad} = mean of adequacy.

Reliability was similarly defined as the standard deviation of adequacy for individual locations over different time periods (Molden and Gates, 1990; Clemmens and Bos , 1990) as explained in Appendix 1. Bos *et al.*(1994), recommended that monthly or bi-weekly coefficient of variation of the Ad or flow rate or flow level, give a good indication of predictability of each of these variables.

The interpretation of the Dp parameter can be carried out using the Molden and Gates (1990) assessment ranges for performance indicators (see Table 3).

If reliability has been low, then the psychological incentives are to use all opportunities and all mechanical adjustments (authorised and unauthorised) to "hoard" the water as if it were the last irrigation (Replogle, 1986). As a result, an otherwise adequate irrigation supply does not meet system demands. Shortages are particularly borne by farmers farther away from the supply source. Replogle (1986) also reported that the reliability becomes lower and the hoarding pressures become higher as a function of distance from the supply source. A vicious circle is created where hoarding causes low reliability which then increases hoarding.

Besides hoarding, farmers can vandalise structures in response to a system which is not dependable, in the process the equity is affected. When there is a crisis (high unreliability), farmers can opt for very expensive water. For example, farmers in the Gunjurat-Mahi project (Sri-Lanka) were reportedly willing to pay over six times the cost of canal water for private tube well water, because the canal water was not dependable nor could not provide water control (Lowdermilk, 1985).

2.5.4.3 Equity of water distribution

Equity is an expression of the share for each individual or group that is considered fair by all system members. It also refers to the *spatial* distribution of reliability and adequacy parameters. The mechanism for determining equity comes through the water allocation process and the system design has to be compatible with the allocation principle (Murray-Rust and Snellen, 1993; Replogle, 1986). Equity is technically indicative of the notion "equitable distribution among a set of structures". The goal is to provide each user with a volume of water in proportion to the land holding. Equity, Eq, is statistically defined as a coefficient of variation (CoV) or standard deviation of the adequacy values between different locations (Chancellor and Hide, 1996; Molden and Gates, 1990; Clemens and Bos , 1990) and is expressed as:

$$E_q = \frac{S_{ad}}{M_{ad}} \qquad (2.19)$$

In which S_{ad} = standard deviation of adequacy and M_{ad} = mean of adequacy.

An equity value of zero (Eq = 0) indicates perfect equity and a value of 1.0, indicates serious inequity in the water distribution (Table 4). A perfectly equitable distribution will result if all locations receive an adequate supply or if each location receives the same water supply.

The inter-quartile ratio is another indicator of equity and it was defined by Abernethy (1986), as the ratio of supply received by the most favoured 25% of the locations to the supply received by the least well supplied 25%. A value of unity for this ratio indicates perfect equity.

Inequity can also result in social tension (conflicts) and the criterion for delineating social tension due to inequity in water distribution is RWS or water density (Keller, 1986). If RWS is low, a very "high water tension" system results, requiring very strong system management to distribute water equitably to all land area within and between UCAs. But, Sampath (1988) argued that, the consequences of inequity in irrigation in terms of malnutrition and poverty will be much more severe in a water scarce environment than in a water abundant environment.

2.5.4.5. Efficiency of the delivery system

Efficiency is indicative of the notion of "No waste" and it is mathematically defined as:

$$E = \frac{V_s}{V_c} \qquad (2.20)$$

Where: E = efficiency of water use; Vc = volume of water required by the crop and Vs = volume supplied at any given level in the system.

The inverse of adequacy can be considered as an efficiency term according to Clemens and Bos (1990), and the statistics associated with this parameter provide information about overall irrigation performance.

An oversupply of the water causes problems in two main respects. Firstly, water is wasted and is therefore unavailable for other users resulting in inequity. Secondly, excess water can reduce crop yields due to waterlogging and salinity.

2.5.4.6 Farmer perception on the quality of water delivery

The monitoring of the perception of farmers and managers on adequacy, dependability and equity of water distribution was reported by Makadho (1994), to be a practical approach to assessing the quality of water delivery service. The proportion of farmers satisfied with the service can give an indication of the water supply performance and their needs, which could help in improving the irrigation system. This active involvement of farmers in irrigation planning was also supported by Lowdermilk (1985), as a way of improving the efficiency and cost effectiveness of irrigation schemes.

Farmer perception is monitored by way of questionnaire surveys (formal and informal) and the representativeness of the results mostly depends on the sampling methodology used. For Zimbabwean small holder irrigation schemes, the sampling methodology employed during formal questionnaire surveys was developed by Meinzein-Dick *et al.*, (1994) as shown in Table 6.

Table 6 Sampling criteria for Agritex, Community and ADA schemes

Total of No of farmers	Sampling criteria
0 - 20	all
21 - 80	20 (randomly selected)
81 - 120*	every fourth
121-200*	every fifth
>200*	every seventh

* stratified schemes.
Source: Meinzein-Dick *et al.* (1994)

The methodology was reported to produce acceptable results for all types of smallholder schemes, blocks or section of large schemes studied.

2.5.4.7 Maintenance indicators

Performance assessment in respect of maintenance of irrigation infrastructure has been normally neglected, despite the fact that it is the most costly item in irrigation development.

1. Conveyance efficiency

Delivery systems require maintenance to control conveyance losses as this directly affects objectives of adequacy and equity. These losses are measured between two water measurement structures using the inflow-outflow principle. From such determinations, the conveyance efficiency can be computed. If changes in this efficiency over time are tracked, then criteria for timing maintenance activities (such as channel cleaning or shaping) can be established (Bos *et al.*, 1994).

Maintenance is also required for sustaining the hydraulic integrity of the conveyance system and the conveyance efficiencies can be used for this purpose. If the system relies on open channel hydraulic relationships to achieve water distribution objectives, then maintenance will be a critical management input. Failure to maintain the canal cross-sections at or close to design specifications in most systems, means that the head-discharge relationships at the off-takes will be different from those intended, resulting in lower than expected performance of water distribution (Murray-Rust and Snellen, 1993).

2. Infrastructure effectiveness

The Infrastructure effectiveness indicates the extent to which the management retains control over the delivered water. It is defined mathematically as:

$$Effectiveness \quad of \quad infrastructure = \frac{No. \quad of \quad functioning \quad structures}{Total \quad no. \quad of \quad structures} \qquad (2.21)$$

The values associated with this indicator give a quantification of the maintenance intensities of control structures required (Clemens and Bos,1990; Murray-Rust and Snellen, 1993; Mao Zhi, 1989). For effective analysis, Mao Zhi (1989) suggested that it must divide structures up into their hierarchical importance (main, secondary and tertiary level) and the analysis done at each level. Maintenance is particularly critical for automatic systems and instantaneous demand systems where frequent and thorough maintenance of gates is necessary for accurate response to changes in water levels.

3. Equipment effectiveness

The equipment effectiveness is an indicator of maintenance which describes the extent to which equipment provided for use in maintenance is in good working condition. This indicator was mathematically defined by Mao Zhi (1989) as:

$$Equipment \quad Effectiveness = \frac{Actually \quad functioning \quad equipment}{Total \quad equipment \quad provided} \tag{2.22}$$

Although the equipment effectiveness and infrastructure effectiveness maintenance indicators are subjective, they give an indicative measure of the extent to which capital investment for maintenance is being properly looked after.

2.5.5 Environmental sustainability and drainage

Over or under supply of irrigation water resulting in water-logging or salinity problems are the aspects of physical sustainability of irrigated agriculture that can be affected by managers. The indicator of sustainability of irrigated land was defined by Bos *et al.* (1994) as:

$$Sustainablity \quad of \quad irrigated \quad area = \frac{Current \quad irrigable \quad area}{Initial \quad irrigable \quad area} \tag{2.23}$$

Sustainability can be determined in relation to depth to groundwater by the following relationship:

$$Rate \quad of \quad change \quad of \quad dept \quad to \quad groundwater = \frac{New \quad depth \ - \ old depth}{Old \quad depth} \tag{2.24}$$

Where irrigated area is prone to flooding, sustainability is assessed in terms of impact to flooding as follows:

$$Impact \quad of \quad flooding = \frac{Area \quad subject \quad to \quad floodng}{Total \quad irrigable \quad area} \tag{2.25}$$

Bos *et al.* (1994) reported that in countries threatened by deterioration of the physical environment, standards are usually available for the following factors:

- depth to water table
- permissible quality of drainage water
- soil salinity levels
- Sodium adsorption ratios
- Measures of toxins associated with agricultural input use

3.0 MATERIALS AND METHODS

3.1 DESCRIPTION OF STUDY AREAS

3.1.1 Site selection

The study aims to identify strategies for improving the performance of water delivery systems in smallholder irrigation schemes.

The Nyanyadzi smallholder scheme in Zimbabwe was selected for this study because it is equipped with background information and historical hydro-meteorological data collected for previous studies. It is also situated in an area where irrigation is essential for improved agricultural productivity.

The Matanya smallholder scheme in Kenya was selected for similar reasons. Background information about the scheme is available and hydro-meteorological data has been routinely collected by the Laikipia Research Programme (LRP) since 1985.

Although there has been some research work carried out at both schemes, little attention was paid to the assessment of performance of the water delivery systems within them. The main reason for selecting these *two* schemes is their complimentarity with respect to: scheme management & organisational structure, operation and infrastructure development. The results about the scheme performances could be used by irrigators, irrigation managers and planners for improving the quality of water delivery in similar smallholder schemes.

In order to improve the selection of the schemes, reconnaissance visits were made to Matanya and Nyanyadzi in August 1996 and October 1996 respectively. The purposes were (i) scheme familiarisation (ii) research introduction to the scheme management and irrigators and (iii) to get general background information about the schemes which include infrastructure, size, management, holdings, operation and maintenance.

3.1.2 Nyanyadzi smallholder irrigation scheme: Zimbabwe

3.1.2.1 General description

Location and accessibility

Nyanyadzi irrigation scheme is located (see Figure 1) about 100 kilometres south of Mutare, along Mutare/Birchenough bridge road in Manicaland province, Zimbabwe. It is situated at the confluence of the Nyanyadzi and Odzi rivers.

The scheme is gravity and pump-fed, benefiting 509 plot holders. It comprises four blocks (**A** to **D**) covering 414 hectares, with Blocks **A** and **C** at the head reaches of the Odzi and Nyanyadzi river water sources (see Fig. 1and Table 7)

Table 7 Nyanyadzi blocks, command area, registered plot holders and water sources

BLOCK	COMMAND AREA	PLOTS HOLDERS	WATER SOURCE
	Ha	No.	River
A	136.55	144	Odzi & Nyanyadzi
B	143.57	222	Odzi & Nyanyadzi
C	65.02	68	Nyanyadzi
D	69.00	75	Odzi & Nyanyadzi
Total	414.14	509	

Source: AGRITEX (1996)

Climate

The scheme has a unimodal rainfall pattern and it receives heavy and isolated storms from October to March (see Fig. 2). The mean annual rainfall is about 490 mm and evaporation (class A) is 1900 mm with peak rates of up to 11 mm per day. The scheme falls in agroecological zone V of low agricultural potential (Pearce, 1983).

Soils

The soils at the scheme are deep, well drained loams (Chromic luvisols and Chromic cambisols) derived from mainly alluvium with colluvial influence of the Umkondo formations (Thompson and Purves, 1981). The soils in the scheme are fast draining and easy to traffic and work on. They have available water capacities of 190 mm/m and variable fertility.

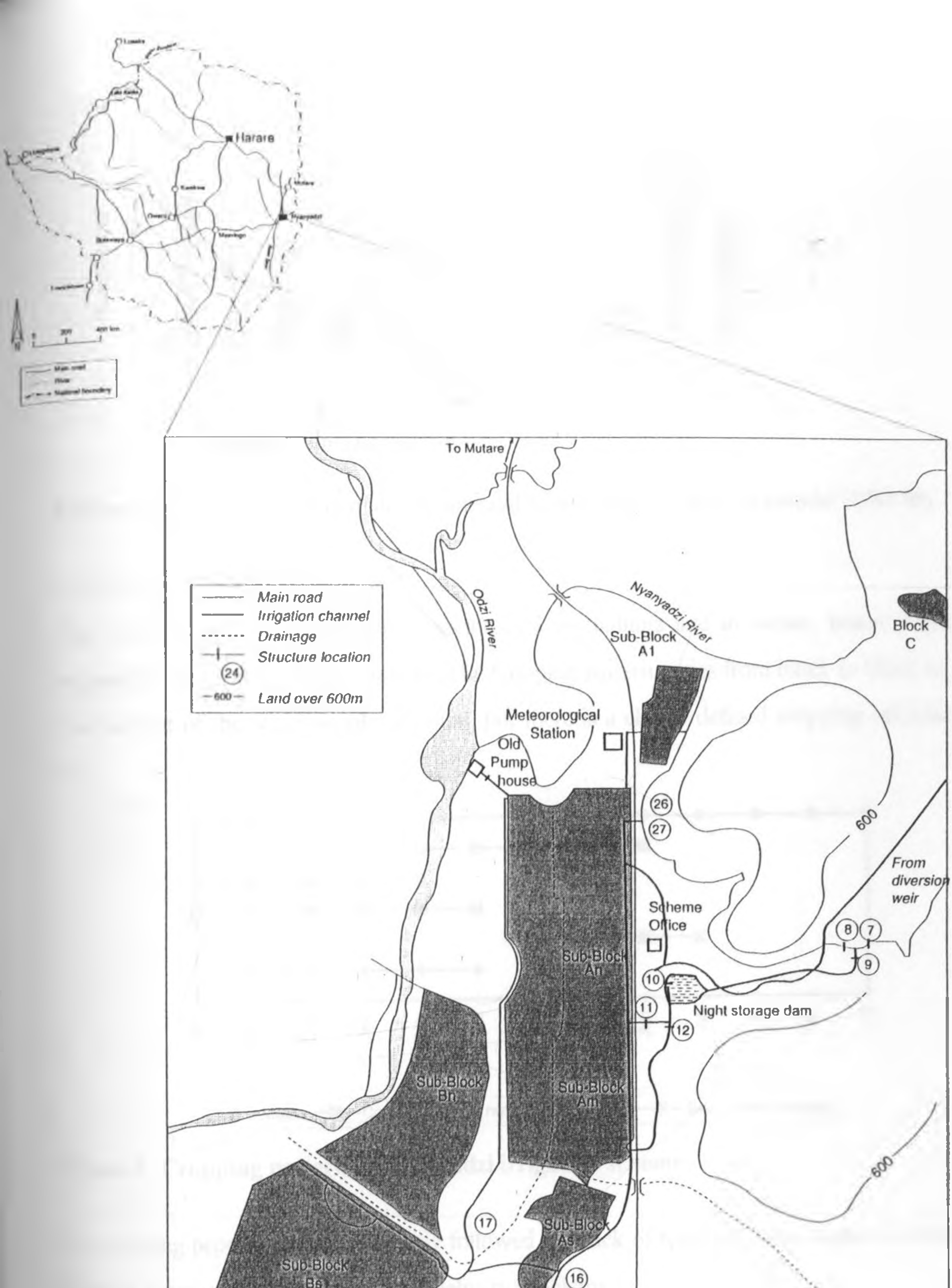


Figure 1 Location map of Nyanyadzi and scheme layout

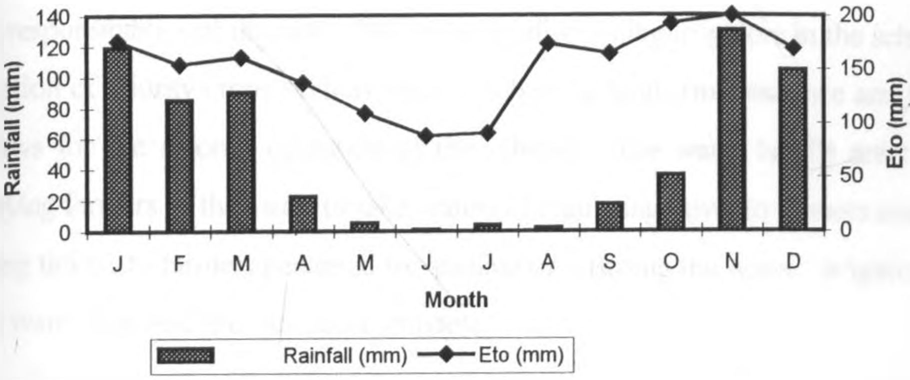


Figure 2 Average monthly rainfall and potential evapotranspiration at Nyanyadzi (1983-88)

Land use and crop production

The main summer crops are maize, cotton and groundnuts and in winter, beans, wheat and vegetables are grown under irrigation. The cropping pattern varies from block to block to make the best out of the water supply situation, but there is a clearly defined cropping calendar (Fig. 3):

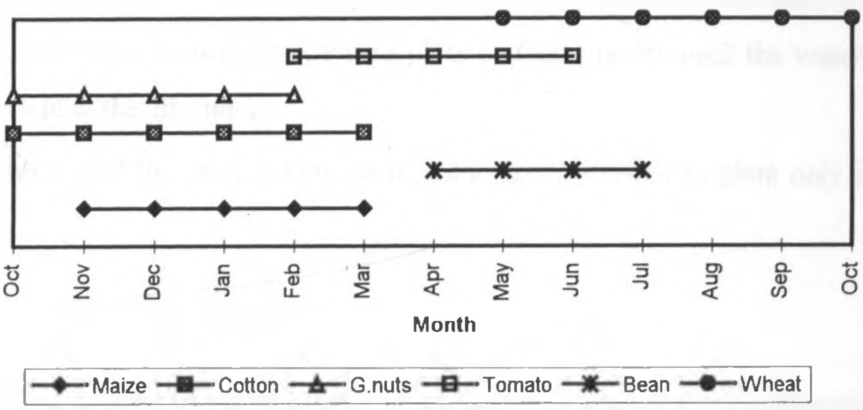


Figure 3 Cropping pattern of Nyanyadzi irrigation scheme

The planting programme is not strictly followed and lack of feedback from farmers on the exact planting dates usually results in water delivery problems.

3.1.2.2 Scheme organisation

The scheme has an integrated organisation structure and run by the Department of Agricultural, technical and extension services, Ministry of Agriculture, Government of Zimbabwe (AGRITEX) with assistance from farmer elected block management committees (IMC) and water bailiffs. AGRITEX controls water flows from night storage dam (NSD), Odzi pump and Nyanyadzi conveyance canal.

The responsibilities of the block IMC include: disciplining irrigators in the scheme (e.g. ensuring irrigation of priority crops such as maize); collecting funds (maintenance and fines); and drafting by-laws for the smooth operation of the scheme. The water bailiffs are responsible for: (i) notifying farmers of their turn to take water (ii) regulating flows to farmers and (iii) charging and issuing tickets to farmers penalised for stealing or misusing the water. Irrigators have no control over water flow and the allocation schedule.

The following rules and regulations exist in the scheme:

- If a farmer is found illegally abstracting water or vandalising control structures, he is charged ZWD 50.00 (about USD 5.00).
- During irrigation, up to eight 50 mm diameter siphons are allowed per abstraction.
- During periods of water shortage, the "one-acre rule" is obeyed in the scheme. The rule allows each plot holder to irrigate one acre at a time, in order to spread the scarcity equitably amongst plot holders. The farmers receive their water allotments for their crops from the bailiff and take turns to irrigate one acre plots of their priority until the water supplies are terminated late in the afternoon.
- At the beginning of the rainy season each plotholder is allowed to plant only an acre of his holding.

3.1.2.3 The water delivery system

Irrigation water is pumped from the Odzi river and abstracted from the Nyanyadzi river by means of a diversion weir. The water is then delivered and distributed by mostly lined canals, on a rotational basis between and within three of the four scheme blocks. In the fields, irrigation is achieved through siphoning water from the tertiary canals into the border strips.

About 90 % of the irrigation water for blocks **A, B** and **D** is pumped from the Odzi river, where the water rights are 485 l/s (Pearce and Armstrong, 1990) and the water is conveyed by a steel pipe to the primary distribution box, situated in a hill near the scheme. From there, the water is distributed directly to various sections of **A, B** and **D** blocks via the night storage dam (NSD). Conveyance to blocks **Bn** and **Am** is via lined canals, but conveyance to blocks **D** & **Bs** is mainly through unlined channels and seepage losses are quite substantial as the underlying soils are highly permeable and the conveyance distance is longer.

In the summer season, supplementary irrigation water is drawn from the Nyanyadzi river by means of a diversion weir and gated off-take into an unlined 10 kilometre conveyance canal leading to NSD via block C (see Fig.1). The water rights at the Nyanyadzi river are 283 l/s (Pearce and Armstrong, 1990).

In distribution canals, flow is regulated by sluice and lift gates, whilst in feeder canals, it is controlled by mostly non-submerged lift gates. The gates are operated on an on/off basis by the water bailiffs, in accordance with the rotational schedule. Temporary earth dikes are constructed in feeder canals to facilitate abstractions to the border strips. At division sections of secondary canals, check dividers were built to facilitate gated division of the channels.

Most secondary and tertiary canals are lined with cement masonry and have trapezoidal cross sections. Where anticipated velocities are high, drop structures were constructed (e.g. near the primary distribution box).

3.1.3. Matanya irrigation scheme: Kenya

3.1.3.1 General description

Location and accessibility

The Matanya irrigation scheme is located (see Fig. 4) near Matanya Business Centre in Laikipia District, Kenya.

The scheme is 310 hectares in extent, benefiting about 200 households. Each farmer has a total holding of about 1.2 hectares and out of this, an average of about 0.58 hectares is irrigated on a supplementary basis.

Climate

The area receives a total of 740 mm of rainfall annually in two rainy seasons associated with the movement of the ITCZ (see Fig. 5). It falls in moisture availability zone v and temperature zone 4 (Ahn and Geiger,1987; Gichuki *et al.*, 1995)(see Appendix 2).

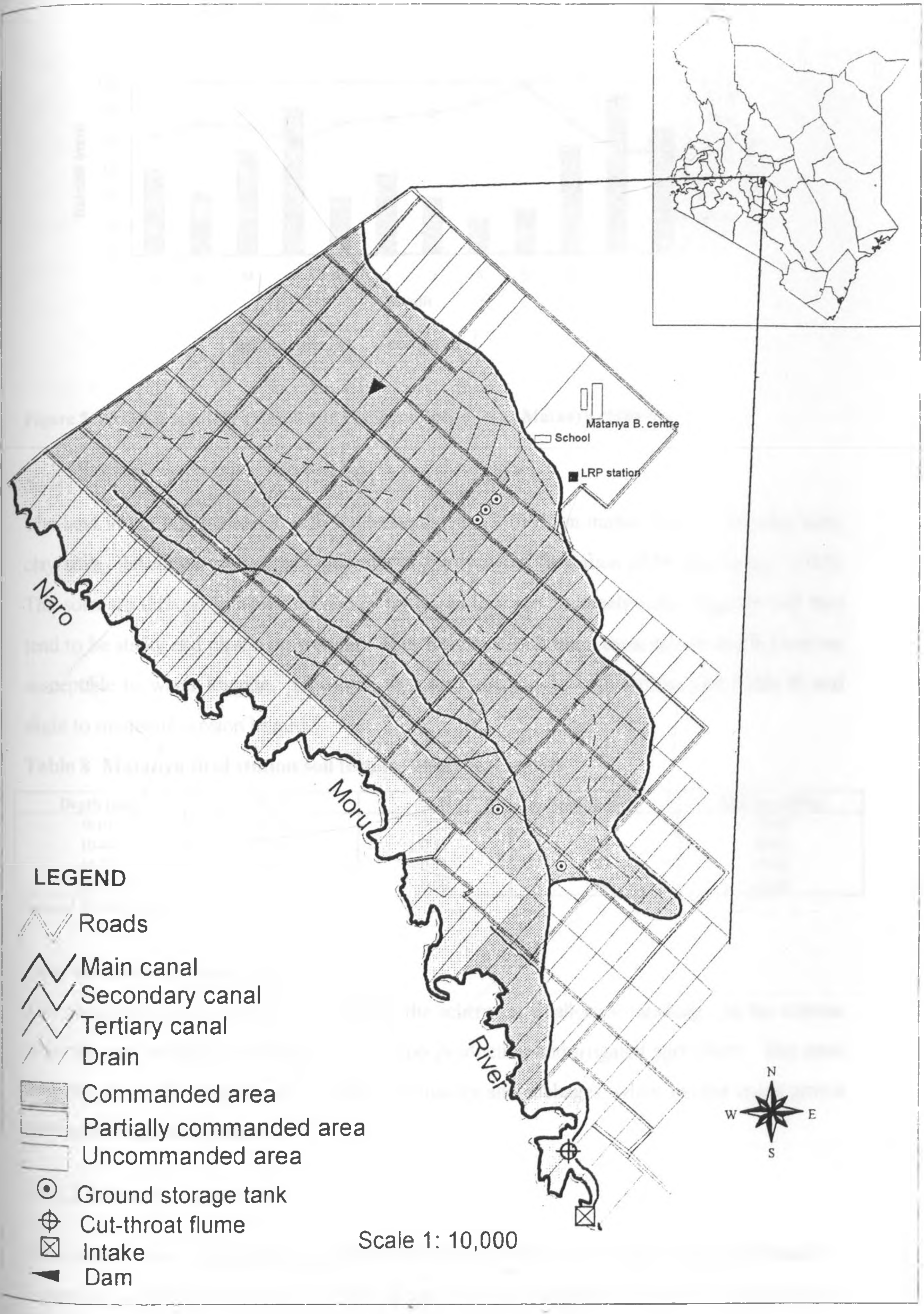


Figure 4 Location map on Matanya and scheme layout

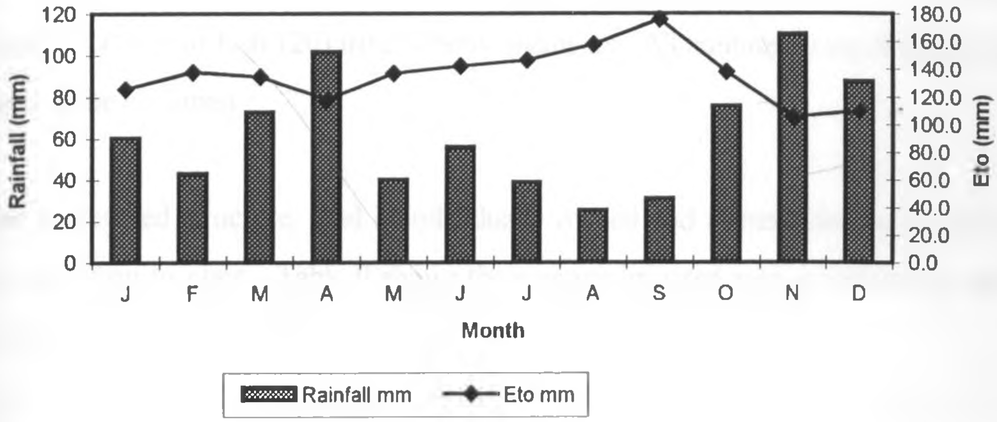


Figure 5 Average monthly rainfall and evapotranspiration at Matanya (1986-95)

Soils

The land in the scheme has low to moderate slopes (< 5%), on mainly deep (>160 cm), dark, clay soils developed on volcanic deposits of the Nanyuki formation (Ahn and Geiger, 1987). The soils are difficult to work on and to traffic, as they are extremely hard when dry and they tend to be sticky and plastic on wetting. They have low infiltration capacities (6 mm/hr) and are susceptible to water logging. However, they have medium to high fertility (see Table 8) and slight to moderate erosion hazard.

Table 8 Matanya field station soil fertility analytical results

Depth (cm)	% C	% N	pH (water)	CEC (me/100g)
0-10	0.79	0.23	6.90	36.40
10-45	0.69	0.18	7.20	48.00
45-90	0.64	0.11	7.50	43.20
90-140	0.31	0.08	7.60	51.20

Source: NRM[3] data base (1996)

Land use and crop production

The main land use in the area surrounding the scheme is small-scale ranching. In the scheme area, the land is used for grazing, rainfed crop production and irrigated agriculture. The main irrigated crops are: maize, beans, potatoes, tomatoes and cabbages, whilst rainfed crops grown are maize, beans and potatoes.

3.1.3.2 Scheme organisation

The scheme has a segregated organisational structure and run by a farmer elected committee, comprising a chairman, secretary, treasurer and sectional committee members. The chairman organises the maintenance of the canals and water allocation to farmers. The secretary keeps the records about the scheme whilst the treasurer collects the contributions, subscriptions and joining fees (of USD 2.40 or Ksh 120) from scheme members. All committee members are accountable to the scheme chairman.

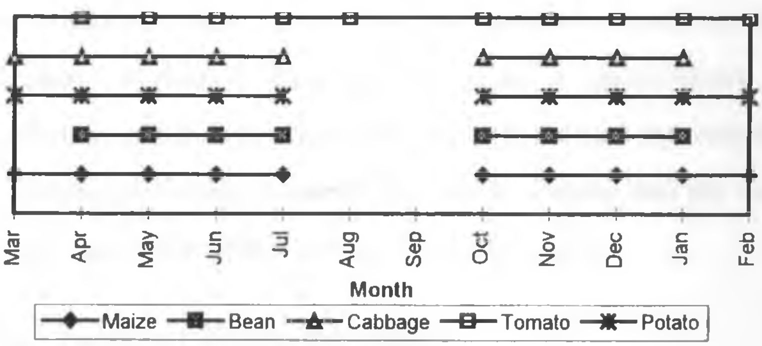
In this segregated structure, land is individually owned and farmers decide on which crops to grow and when to plant. Table 9 shows the average irrigated area grown to the main crops in the scheme.

Table 9 Average irrigated area per farmer in Matanya smallholder irrigation scheme

Crop	Area (ha)
Maize	0.29
Beans	0.10
Potatoes	0.05
Tomatoes	0.04
Cabbages	0.05
Total	0.53

Source: NRM[3] data base (1997)

Farmers plant mostly at the beginning to middle of each rainy season and the cropping patterns are depicted in Fig. 6.



Source: NRM[3] data base (1997)

Figure 6 Cropping pattern of Matanya irrigation scheme

The following rules and regulation exist in the scheme:

- A weekly rotation turn of two or more days is allowed per farmer depending on the water supply situation along the subsidiary canals.
- A maximum diameter of 5.08 cm is allowed at each piped abstraction point
- The farmers should avail themselves for desilting and weeding of distribution canals.

3.1.3.3 Water delivery system

The *canal network* consists of the main canal (Matanya "furrow"), a secondary canal (sub-"furrow") and three tertiary canals (sub-sub "furrows") as shown in Figure 4. The canals are mostly silted and overgrown with weeds due to inadequate and deferred maintenance. Excessive water losses result from consumptive water use by weeds, seepage and overtopping along the canal network.

The *structures* in the delivery system consist of the main intake structures, a cut-throat flume, few ground storage tanks and a small dam (see Fig. 4). Temporary weirs (earth dikes) for open channel diversions are common along the distribution system. The main intake comprise a diversion weir and an off-take sluice gate. The scheme is devoid of most essential water control structures at strategic points, such as division points of canals and road crossings.

3.2 PERFORMANCE EVALUATION OF THE NYANYADZI WATER DELIVERY SYSTEM

The performance evaluation was carried out by qualitative and quantitative means. Qualitative performance evaluation entailed the use of a questionnaire survey, whilst quantitative evaluation involved flow measurements and demand estimation. The overall evaluation of the scheme performance involved problem analysis into the causes, problems and solutions to water delivery problems at the irrigation scheme.

3.2.1 Questionnaire Survey at Nyanyadzi Scheme

3.2.1.1 Purpose

The purpose of the questionnaire survey was to evaluate the qualitative performance of the Nyanyadzi water delivery systems, with regard to adequacy of water supply, reliability and water distribution equity.

3.2.1.2 Selection of survey area

Block **A** was selected, after liasing with the irrigation manager (Mr Marwa), omitting blocks **B**, **C** and **D** from the study, because of time constraints and logistical considerations. Block **A** was further reduced by excluding sub-block **As** from the study as it does not get irrigation water with other sub-blocks during a rotational turn.

3.2.1.3 Sampling Procedure

From the tenant's plot register of Block A, plot holders were randomly selected according to the sampling methodology proposed for Zimbabwean small holder irrigation schemes by Meinzein-Dick *et al.* (1994). A sample size of 30 farmers was arrived at, since the combined total number of plot holders in the sub-blocks (A1, Am, An) was 132.

3.2.1.4 The questionnaire

The irrigators (water users) were to give their views on whether the water supply was good, fair or poor with regard to the water delivery objectives of adequacy, dependability and equity of water distribution. They were also probed into the causes and their preferred solutions to poor water delivery. A close ended questionnaire was used and the details are given in Appendix 3.

3.2.1.5 Questionnaire administration

The plot owners with the selected plots were asked to avail themselves for interviews at selected dates between 15/11/96 and 20/12/96 (see Appendix 4). Observations of water losses, flow abstractions, sedimentation, canal breaches were made in canals supplying water to informants. The observations were made simultaneously with the interviews to find out the most important factors affecting water delivery in the scheme among those mentioned in the questionnaire.

3.2.1.6 Compilation and analysis of questionnaire results

The information collected during the survey include: name of informant, location on the canal network, performance level of water delivery and solutions to problems of the delivery. The details on location and responses are given in Fig. 7 and Appendix 4.

The response of farmers to water delivery objectives , causes and solutions to water delivery problems were expressed as percentages. This was done in order to rank the performance parameters and to ascertain water delivery improvement strategies as preferred by the farmers.

3.2.2 Quantitative performance evaluation of water delivery in Block A

The performance evaluation was based on the determination of the adequacy parameter, which entails the determination of water supplied and crop demand during the rotational turns.

The water supply to block **A** was on a rotational basis within sub-blocks and the rotational schedule during the study period is given in the Table 10. The supply and distribution of water in the block was monitored by under taking discharge measurements at selected sites, using a current meter and flow measurement structures (see Fig. 8).

Table 10 Rotation of water between the A sub-blocks during the study period

Rotation turn	Day	Date	Sub-block (s) served		
			A1	An	Am
1	1	05/12/96	X	X	
1	2	06/12/96		X	
1	3	07/12/96			X
1	4	08/12/96			X
2	1	17/12/96	X	X	
2	2	18/12/96		X	
2	3	19/12/96			X
2	4	20/12/96			X

X: Sub-block supplied with irrigation water.
Source: Agritex (1996)

(a) Discharge measurements using the Velocity-Area method

The determination of discharge involved velocity measurement with a current meter and area approximation from the canal geometry.

Flow velocity measurement

A Valeport "Braystroke" BFM002 miniature current flow meter was used to measure flow velocities in lined canals of known geometry. The measurements were made at the following positions (see Fig. 8):

(i) Feeder canal off-take positions

(ii) Distribution canal off-takes

(iii) After abstraction points along distribution and feeder canals.

Figure 7 Nyanyadzi block A canal network and location of informants

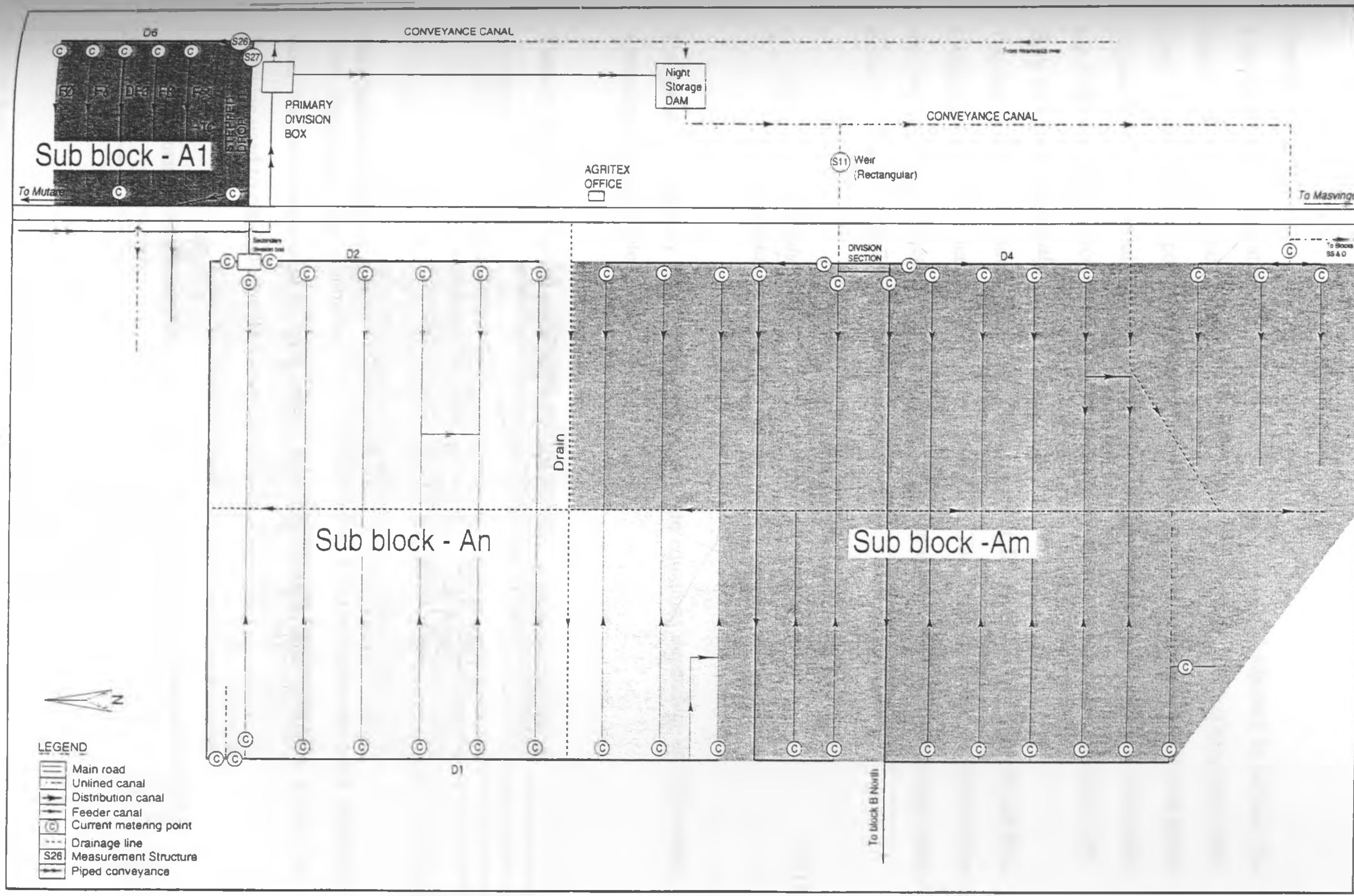


Figure 8 Location of flow monitoring points in Block A

Procedure

The current meter was attached to a rod, held by an observer and adjusted to indicate the mean velocity at a distance above the bottom equal to 0.4 times the depth (Diangman, 1984; Dare, 1972). At every point, three velocity measurements were made using a 5-second period of observation, for normal readings. For low and irregular readings, the period of observation was lengthened from 5 seconds to 10 or more seconds in order to obtain a more accurate count.

Data collection and analysis

The data collected included: date, time of measurement, location on canal network and flow rotation speed. More details are given in Appendix 5. The flow velocity was derived from the time and pulse counts measured by the control unit. The value **n** (revs/sec) was derived using Equation 3.1 prior to application of the velocity formulae.

$$n = \frac{Pulse \quad Count(revolutions)}{Time(\text{ seconds})} \qquad (3.1)$$

The mean flow velocity was computed from the rate equations depending on the average rotation speed (see Table 11).

Table 11 Rate equations of a BFM002 current meter

Rotation speed, **n** (revs/sec)		Flow speed, **V** (m/s)
Minimum	Maximum	
0.26	0.97	1. V = 0.034 + 0.0991**n**
0.97	4.71	2. V = 0.023 + 0.1105**n**
4.71	27.86	3. V = 0.039 + 0.1071**n**

Determination of flow area

Flow depths and canal geometry codes recorded at each current metering point were the basis for the computation of flow area. For the different canal geometry codes, the formulae used to compute the flow area are given in Table 12.

Table 12 Formulae for computing flow area of different canals in Nyanyadzi scheme

Canal code	**Area (m^2)**
1	$A=0.237d+0.58d^2$
2	$A=0.3075d+0.532d^2$
3	$A=0.69d+0.554d^2$
4	$A=0.71d+0.532d^2$
5	$A=0.50d+0.532d^2$

d = flow depth (m)

Source: AGRITEX (1996)

Computation of discharge and supplied volume

Discharges were calculated from multiplying the mean velocities by flow area computed from the fore-going section. The actual volumes (V_a) delivered to the fields below the measuring points were calculated from the average supply duration (10 hours) obtained from pump operator and computed discharges.

(b) Discharge measurement using structures

The measurement structures used to measure daily water supply to sub-blocks **A1, An** and **Am** were: (i) rectangular thin plate weir (S11) and two control gates (marked S26 & S27 in Figure 8). These measurement structures were rated and equipped with graduated gauge boards.

Data collection and analysis

The data collected daily at the weir (S11) included: date, time of observation, stage on the gauge. At the gates (S26 & S27), additional data collected included upstream and downstream heads and the gate opening. More details on the data collection for each structure are given in Appendix 6.

For the three structures (S11, 26 & 27), rating equations were used to convert the stage/gauge to discharges as shown in Table 13.

The total volume supplied (V_a) to the fields below the structures were similarly computed as the product of the average supply duration (10 hours) and the calculated discharges through the structures.

Table 13 The rating equations for the flow measurement structures in Block A

Structure	Type	Rating equations
11	Rectangular weir	$\mathbf{Q = (1.6 + 0.779\ h_1) \times (h_1 - 0.001)^{2/3}}$ $h_1 = U_{11} - 0.174$
26	Off-take gate	$\mathbf{Q = 1.054 \times W \times (h_1 - h_2)^{0.5}}$ $h_1 = U_{26} - 0.149$ $h_2 = D_{26} - 0.0126$
27	Off-take gate	$\mathbf{Q = 1.745 \times W^{2/3} \times C}$ $C = 0.2185 + R(0.288 - 0.015R)$ $R = (U_{26} - 0.324) \times W^{-1}$

Source: Lewis, 1984

Where: Q = discharge (m^3/s)

U_n = Upstream stage on gauge board of the n^{th} structure (m)

D_n = Downstream stage on gauge board of the n^{th} structure (m)

h_1= upstream head (m)

h_2 = downstream head (m)

W = gate opening (m)

C = discharge coefficients

(c) Irrigation water demand

The irrigation water demand was approximated from secondary data. The information on the planting dates, crop area and rainfall was obtained from the scheme manager. Daily evaporation data was obtained from the nearby ADA Middle Save Meteorological station, experiencing similar climatic conditions to Nyanyadzi. The details on planting dates, cropped area and meteorological data are given Appendices 8 and 9.

Data analysis on demand

Daily and monthly Et_o rates were estimated using the Pan method for the months of October to December 1996 inclusive. The crop water requirements were then computed from the Et_0 and the K_c values for the maize crops planted on 15/10/96 and 07/11/96. Details are given in Appendices 7,8,9 and 10.

The irrigation requirements (mm) for the two maize crops were approximated by summation of the daily Et_c between consecutive irrigation events and discounting for effective rainfall according to Equation 2.9 in section 2.2.3

To get the volume of water required (V_r) at each measuring point, the IR (mm) was multiplied by the cropped area serviced below that point. The area under the command of the distributaries, was a summation of the areas commanded by feeder canals supplied by the Distributary. Calculated canal command areas are given in Appendix 11.

3.2.2.1 4. Computation of performance parameters

The adequacy values at the measuring points were computed as the ratio V_a/V_r according to Equation 2.15 in section 2.5.4.1 (see Appendix 12). The coefficient of variation and standard deviation of this ratio in space and in time, gave measures of water distribution equity and reliability of water supply respectively, during the period in question (see Sections 2.5.4.2 and 2.5.4.3; Appendices 12 and 13). The weekly RWS was computed as another indicator of adequacy using the water supply and demand data (see Equation 2.17 section 2.5.4.1 and Appendix 12).

3.3 ASSESSMENT OF OPPORTUNITIES AND CONSTRAINTS OF WATER DELIVERY SYSTEMS

A complimentary study was done at Matanya irrigation scheme to assess the opportunities and constraints of water delivery, as a follow up to the study carried out on the performance evaluation of Nyanyadzi water delivery system. The main activities were: delimitation of the canal layout, discharge measurements and questionnaire survey.

3.3.1 Status of the Matanya water delivery system

A field visit to the Matanya scheme was made in May 1997 to acquire information on the canal layout, infrastructure, the organisation and the operation and maintenance of the water delivery system.

3.3.1.1 Organisation, Operation and Maintenance

In order to get information about scheme organisation operation and maintenance, a meeting was held with the scheme secretary (Mr. Mwangi) on 26/05/97 to consolidate on what was obtained from literature. The scheme secretary was subjected to a formal interview to provide information on: scheme size, management, land ownership, irrigation water sources, water distribution and allocation and maintenance of the scheme. The details of the questionnaire are given in Appendix 14.

3.3.1.2 Delimitation of the canal layout

The layout of the delivery system was delimited by tracking the main water courses from the intake in the Naro Moru river. A 1:10,000 land sub-division map of the Matanya settlement was used as a base map. The delimitation exercise was done in order of hierarchical importance (starting with the main canal).

Compilation of data and information

In addition to canal delimitation exercise, data collected on the status of the delivery system included: canal slope, flow depth, weed growth status, sedimentation and condition of structures and location of abstraction points. The description was done using the format given in Appendix 14.

The location of the irrigation infrastructure was superimposed onto the land sub-division map of Matanya settlement which was later digitized to produce the layout of the water delivery system at a scale of 1:10,000 (see Fig. 4).

3.3.2. Performance of the delivery system

3.3.2.1 Water supply to the scheme

(a) Discharge measurements at the intake

The water supply to the scheme has been monitored by the LRP using a cut-throat flume installed in the main canal near the intake. Water flows were monitored between 14/11/90 and 31/12/96 with gaps in 1992 and 1993.

Data collection and analysis

The data collected daily at 0900 and 1500 hours included the date, gauge height on staff (GHT), the upstream (H_u) and downstream (H_d) water levels in the flume and type of flow. The data recording sheet used is shown in Table 14.

Table 14 Data collection sheet for the Matanya cut-throat flume

Date	GHT (cm)		H_u (cm)		H_d (cm)		H_u/H_d		Remark		Q (l/s)		Q_{avg} (l/s)
	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500	0900	1500	

Remark: 1= submerged flow; o = free flow

The computation of the flow rate was done by applying the rate equations for the cut-throat flume operating under free flow conditions given by:

$$Q = 28.3\, K_f W^{1.025} H_u^{nf} \qquad (3.2)$$

and under submerged conditions by:

$$Q = 28.3\, K_s W^{1.025} (H_u - H_d)^{nf} / (-\log S_t)^{ns} \quad (3.3)$$

In which:

Q = discharge (l/s)

K_f= flume length coefficient

W = throat width (cm)

H_u= upstream flow depth (cm)

H_d= downstream flow depth (cm)

n_f= free flow exponent

n_s= submerged flow exponent

K_s= submerged flume length coefficient

S_t = submergence (H_d/H_u)

Conversion factors: 1 cfs = 0.0283 m^3/s and 1 foot = 0.3048 m

The values of the constants (K_s, n_f, n_s, K_f, S_t and W) are obtained from flume rating curves given in Walker (1989) and for Matanya flume they are listed in Table 15.

Table 15 Matanya Flume coefficients, exponents and submergence limits

Flume width-W	Flume length	S_t	K_f	K_s	n_f	n_s
40 cm	180 cm	0.74	3.71	2.04	1.64	1.39

Source: Gathenya (1992)

The monthly mean daily flows were computed for the years 1991, 1994, 1995 and 1996 and the details are given in Appendix 15.

(b) Discharge measurement along the main canal

The residual discharge in the main canal was approximated by taking flow measurements along the canal during the delineation of the canal network.

Data collection and analysis

The data collected at each point along the canal near abstraction points included the following: channel slope, depth and width of flow, and approximate roughness from the weed status. The slope was measured with an Abney level, the roughness coefficient was obtained from tables as per channel cleanliness. Discharge capacity was approximated using the velocity area approach, in which, the Manning's formula (Equation 3.4) was used to calculate the flow velocity and the channel dimension, the flow area and more details of the computations are given in Table 16.

$$= \frac{R^{2/3} \quad S^{1/2}}{n} \tag{3.4}$$

Where: V = mean flow velocity (m/s)

R = hydraulic radius (m)

n = roughness coefficient

S = Channel slope (m/m)

Table 16 Data sheet for the determination of residual flows in Matanya main canal

Point	User	distance (m)	w (m)	d (m)	P m	A (m^2)	R	slope %	v (m/s)	Q (m^3/s)	Q (l/s)

(c) Farm level discharge measurements

There were two methods of diverting water to farms identified and the methods used for flow determination varied accordingly. The diversion methods were: (i) by use of temporary weirs and open channels which are common along the secondary and tertiary canals; and (ii) by use of pipes flowing under gravity.

Bucket method

This method was used for discharge measurements in open channel and piped abstractions. In open channels, the determination involved digging a hole, large enough to take a 5 litre bucket in the channels and a small length of pipe was buried, so that all water passes through it. The time required to fill the 5 litre container by the "channel" was the basis of the discharge determination. As for piped abstractions, discharge was measured directly, as the time taken for the pipe to fill the 5-litre container.

Data collection and analysis

The time taken to fill the 5 litre bucket was recorded three times and the data recording sheet used is shown in Table 17.

Table 17 Data sheet for discharge measurement using bucket method

Date	Farm No.	Abstraction type	Filling time (s)				Q
			t_1	t_2	t_3	t_{avg}	(l/s)

The discharge was computed using the following equation:

$$Discharge(l/s) = \frac{Volume \quad of \quad bucket \quad (l)}{Average \quad time \quad taken \quad to \quad fill \quad (s)} \tag{3.5}$$

Float method

In open channels, discharges at the diversion points from main canals, were approximated using the float method. Two points were marked along the bank of a straight length of channel, about 2 metres apart. A stick of wood (float) was then thrown into the middle of the channel and the time taken to travel the 2 metres measured in seconds. The velocity was calculated by dividing the distance by the time whilst the flow area was calculated from the flow depth and width. The discharge was the product of the area and velocity as shown in Table 18.

Table 18 Data sheet for discharge measurement using the float method

Date	Farm No.	section length	Travel time (s)				V	Flow depth	Width	*Flow area	Q
			t_1	t_2	t_3	t_{avg}	(m/s)	(m)	(m)	(m^2)	(m^3/s)

* channels were assumed to be rectangular in cross section

(d) Determination of maximum discharges in abstraction channels

In dry abstraction channels the discharge capacity was approximated at a the off-takes using Manning's formula. The channel attributes measured were: channel slope, roughness coefficient and channel width and depth. The slope was measured with an Abney level, the roughness coefficient was obtained from tables as per channel cleanliness. The following assumption were made: (i) the freeboard is equal to 20% of maximum depth and (ii) the channels had rectangular cross sections. The details of the computations are shown in Table 19.

Table 19 Data sheet for the computation of discharges of off-take abstraction channels

Point	User	LCN	w (m)	d (m)	d max	P (m)	A (m^2)	R	slope	v (m/s)	Qmx (m^3/s)

3.3.2.2 Irrigation water demand

The demand for irrigation water was determined by use of a questionnaire survey data and meteorological data obtained from the LRP database.

(a) Questionnaire survey at Matanya

The purpose of the questionnaire survey was to determine the cropping and irrigation water use by farmers. From the plot register of the water users in the scheme obtained from the secretary, a total of 25 households were selected randomly. The selected farmers were then interviewed simultaneously, with the rest of the field activities between 25/05/97 and 30/07/97.

Data collection

The households in the scheme were asked to give information on: irrigated crops grown, planting dates/calendar and mean irrigated areas. The details are given in Appendix 18.

(b) Meteorological data

The meteorological data for irrigation water demand was obtained from the LRP collected from 1986 to 1995. The data included daily Et_o values computed by the "modified" Penman method and daily rainfall amounts. The mean daily and monthly Et_o values were computed from this data. The monthly effective rainfall amounts were calculated from the monthly rainfall totals (section 2.2.3.1.1).

(c) Demand data analysis

The effective rainfall and Eto data computed from the LRP data base and information on cropping patterns and irrigated areas, obtained from the questionnaire survey were combined to compute irrigation water demand according to FAO (1977). Computation details are given in Appendices 16, 17, 18 and 19.

3.3.2.3 Overall delivery performance assessment

The monthly water supply measured by the cut-throat flume was compared with the irrigation water demand, to assess the quality of the water delivery system.

4.0 RESULTS AND DISCUSSION

4.1.THE PERFORMANCE OF THE NYANYADZI WATER DELIVERY SYSTEM

4.1.1 Quality of water delivery to Block A

The quality of the water delivery system in this block was assessed using questionnaire and water requirement analytical results.

4.1.1.1 Farmer perception on water delivery performance

Farmers in block A were asked to give their opinions on whether the delivery system was good, fair or poor with respect to the performance parameters (Ad, Eq & Dp) and the breakdown is given in Table 20 and Fig. 9. The results show a consistently poor performance by the delivery system.

Table 20 Farmer perception on the quality of water delivery system: Nyanyadzi scheme

PERFORMANCE INDICATOR		FARMER RESPONSE	
Type	level	No.	%
Adequacy	good	8	26.7
	fair	5	16.7
	poor	17	56.7
Reliability	good	2	6.7
	fair	5	16.7
	poor	23	76.7
Equity	good	11	36.7
	fair	3	10.0
	poor	16	53.3

Total number of respondents = 30

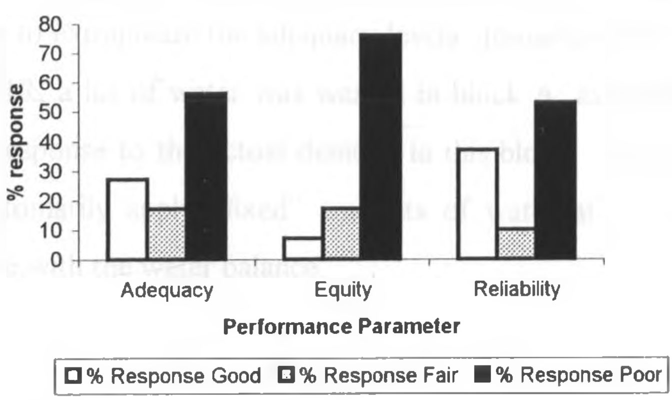


Figure 9 Response of block A farmers to the performance of the water delivery system

4.1.1.2 Performance evaluation based on water requirement

The performance of the water delivery system was assessed in terms of the water delivery objectives of adequacy, equity and reliability of water supply and classified as good, fair or poor using the Molden and Gates (1990) performance ranges.

(a) Adequacy of water supply

The adequacy (A_d) of water supply was computed as the ratio of actual volume (V_a) delivered to required volume (V_r). The 1996 summer season was relatively wet and in most cases, the adequacy of water supply was classified as good from the water requirement analysis (see Table 21), although 57 % of the farmers interviewed in block A perceived, that this performance parameter was poor.

Table 21 Mean of adequacy and mean IR block in block A on irrigation days

Irrigation date	IR (mm)	Adequacy	
		Mean	Remark
5/11/96	16.3	2.80	good
6/11/96	19.6	1.99	good
7/11/96	23.4	1.59	good
8/11/96	27.6	1.21	good
17/12/96	47.8	0.74	poor
18/12/96	50.1	0.96	good
19/12/96	52.7	0.64	poor
20/12/96	54.7	1.01	good

On each irrigation date, Table 20 shows that the value of the adequacy parameter attained depended (R^2=0.89) on the irrigation requirement (IR). The variation of the adequacy parameter with irrigation requirement is shown in Fig.10. The management can thus use IR as a guide to extrapolate the adequacy levels attainable from the delivery system. At lower values of IR, a lot of water was wasted in block A, as the delivery system did not supply water in response to the actual demand in this block. It was observed that farmers in the block customarily apply "fixed" amounts of water at each irrigation, not necessarily in accordance with the water balance.

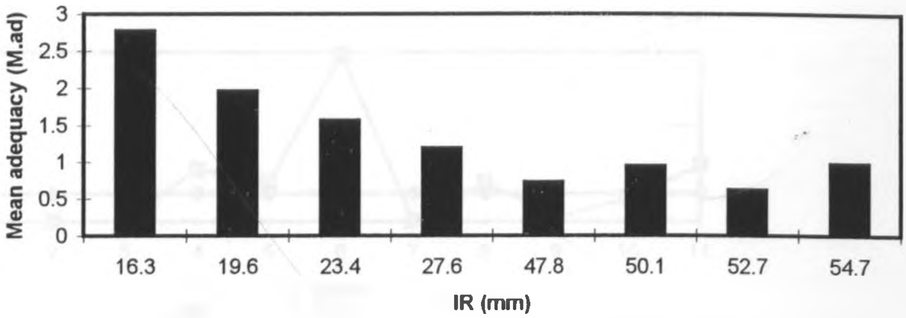


Figure 10 Variation of mean adequacy with irrigation requirement in Nyanyadzi block A

The relative water supply, (RWS) was computed as another indicator of adequacy of water supply at block level. Table 22 shows the computed weekly water supply, demand and relative water supply (RWS) to Block A. The weekly variation of these parameters is also depicted by Figures 11 and 12. The RWS values were quite variable, because of intermittent rainfall events and reported pump breakdowns at the Odzi pumping station.

Table 22 Weekly water supply and demand to block A: Nyanyadzi scheme

Week	Dates		Supply (mm)				Demand (mm)	RWS
	from	to	R	Re [#]	IRGN [+]	Total	CWR	
1	16/10	22/10	0	0	-	-	18.0	-
2	23/10	29/10	0	0	0	0	19.8	0
3	30/10	05/11	0	0	0	0	19.3	0
4	06/11	12/11	37.5	19.96	0	19.96	10.9	1.83
5	13/11	19/11	55.1	31.27	0	31.27	23.23	1.35
6	20/11	26/11	73.5	43.23	0	43.23	7.35	5.88
7	27/11	03/12	7.0	0	0	0	15.57	0
8	04/12	10/12	0	0	52.7	52.7	25.6	2.06
9	11/12	17/12	4.0	0	10.6	10.6	36.8	0.15
10	18/12	24/12	18.0	7.15	41.7	48.85	46.63	1.05
11	25/12	1/1/97	106	64.35	0	64.35	32.4	1.99

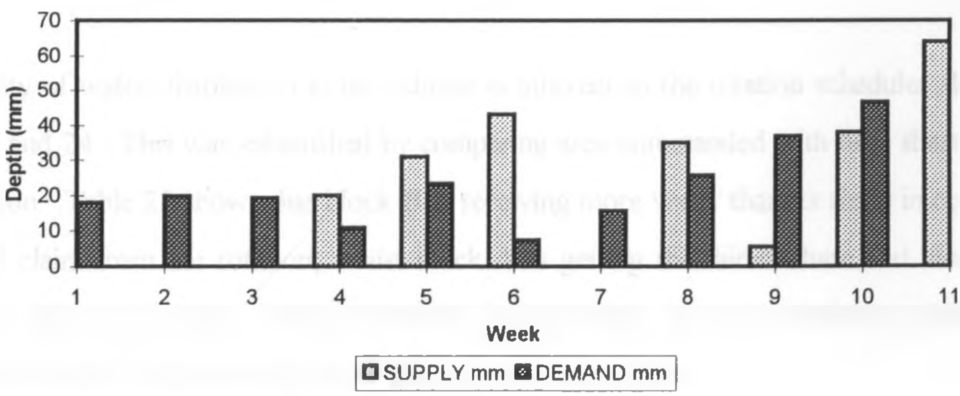


Figure 11 Water supply and demand to block A

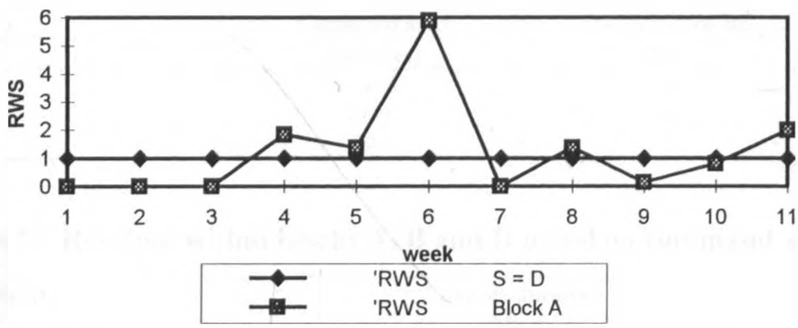


Figure 12 Weekly variation of RWS in block A

Water deficits were experienced in weeks 2,3,7 and 9, when demand was greater than supply or RWS<1 (see Figures 11 and 12). During these weeks, frequent cases of water conflicts were reported, as it was difficult for the management to equitably distribute the limited water amongst the irrigators. Head and middle irrigators were seen constructing temporary cross regulators made of earth and stones in distribution canals in order to increase diversion head to their feeder canals. This affected the equity of distribution. Low economic efficiencies at the end of the season were expected because the RWS values were far much less than the 0.8 threshold value for the maize crop as explained by Keller (1986). Even lower economic efficiencies were expected from the first maize crop which was stressed during the sensitive silking stage in the ninth week.

(b) Water distribution evaluation

Water distribution between blocks A, B and D

The irrigation water was delivered to blocks **A, B** and **D** on a rotational basis between and within them. The rotation turns are based on the time share claimed by the block command areas and the rotation schedules may be seen in Tables 23 and 24 (AGRITEX, 1996).

The inequity of water distribution in the scheme is inherent to the rotation schedules shown in Tables 23 and 24. This was established by comparing area commanded with time share during each rotation. Table 25 shows that block **B** is receiving more water than its share in command area could claim from the rotation, whilst block **A** is getting the fairest share and block **D** is getting the least time share. These disparities have resulted in worse delivery problems in disadvantaged blocks Bs and D at the tail of the conveyance system.

Table 23 Rotation between blocks based on command area at Nyanyadzi scheme

BLOCK	Command area (hectares)	Supply duration (days)	Irrigation interval (days)
A	136.6	4	7
B	143.6	4	7
D	69.0	3	8

Table 24 Rotation within blocks A, B and D based on command area Nyanyadzi scheme

Sub-block(s)	Supply duration (days)	Irrigation interval (days)
A1 + An	2	9
Am	2	9
Bn	2	9
Bs	2	9
D + As	3	8

Table 25 Actual area commanded and plot holders compared with time share

Block	Sub-blocks	command Area (ha)	Plot holders (No.)	% time share based on		
				Current Rotation	Command area	Plot holders
A	**A1,An,Am**	124.9	132	36	36#	30
B	**Bn, Bs**	143.6	222	36	41+	50+
D	**D, As**	80.7	87	28	23-	28#
Total		349.2	441	100	100	100

- prejudiced by current rotation schedule
+ favoured by current rotation schedule
# neutral effect of rotation schedule

If the number of plot holders in each block are used to claim time share of the rotation, then block B should claim more and block **A** less time as shown in Table 25. Block **D** should remain indifferent, but still disadvantaged because of its tail reach on the conveyance system. Therefore, the influence of the conveyance distance should be considered when determining the rotation schedule, for a fairer time share of the rotation and improve the quality of water delivery to disadvantaged sub-blocks.

The equity of water distribution was also influenced by the manner in which holders claimed allotments of irrigation water from the management. The one acre rule has been violated to the extent that some farmers irrigate four acres and others none during the dry season (AGRITEX, 1996). This was brought about by inheriting of irrigation land after the registered holders are deceased (Marwa, Personal communication). e.g. if four acres of land are divided among four heirs. In theory, during the dry season, only one acre in the four acre holding should be irrigated on each turn according to the one acre rule. Alternatively, each heir must irrigate a quarter of an acre in order to spread the water scarcity equitably throughout the holding. This is not socially practical as each heir feels that it is entitled to irrigation water on every turn, resulting in illegal abstraction affecting other users outside the holding, particularly the tail enders.

Water distribution within block A

The equity of water distribution in Block A was assessed in terms of coefficient of variation of adequacy (CoV. Ad) in space. For each day, CoV was determined for several locations throughout block A and the results are given in Table 26 and Appendix 12.

Table 26 Equity of water distribution within block A on different irrigation dates

Irrigation date	IR (mm)	Equity	
		CoV (A_d)	Remark
05/11/96	16.3	0.45	poor
06/11/96	19.6	0.48	poor
07/11/96	23.4	0.76	poor
08/11/96	27.6	0.33	poor
17/12/96	47.8	0.48	poor
18/12/96	50.1	1.14	poor
19/12/96	52.7	0.91	poor
20/12/96	54.7	0.91	poor

The equity was poor throughout the period under review as shown in Table 26 and this is in agreement with what the farmers perceive on water distribution equity. About 53 % of the farmers interviewed confirmed that the equity of water distribution was poor (see Table 20 and Fig 9). The equity of water distribution also varied with the irrigation water requirements and the trend is depicted in Fig. 13.

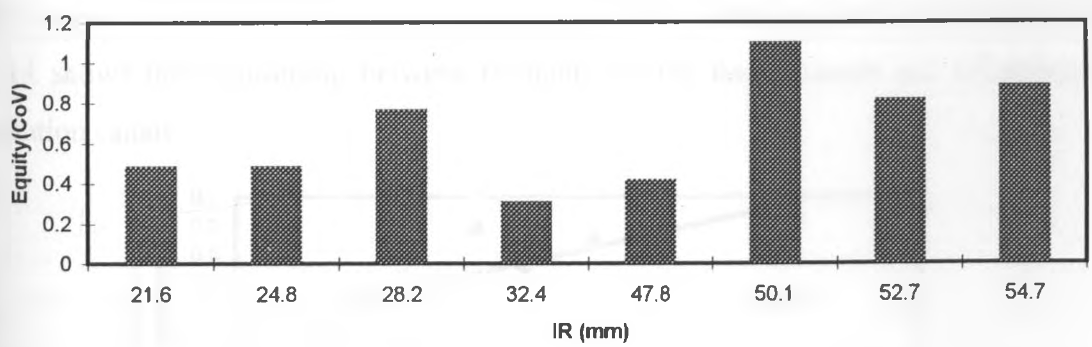


Figure 13 Variation of water distribution equity with irrigation requirement in block A

High values of the equity parameter imply a poor water distribution. So the management capability to distribute water fairly decreased with increase in water demand (IR) or decrease in RWS, which is in agreement with what was found by Keller (1986).

The poor equity in this block can be attributed to lack of precise information on planting dates and thus on areas requiring water. This was due to the violation of the one-acre rule by the farmers who did not plant an acre each of the first maize crop and it was difficult to control the cropping of land at the onset of the summer rains as reported by Marwa (pers.com). Because of the inequity problems, social tensions were higher in the more water scarce second rotation turn, as explained by Sampath (1988). Some irrigators were reported to vandalise control structures and abstracted water illegally in order to irrigate their stressed crops. This further jeopardised the water distribution equity.

(c) Reliability of water supply in A Block

The reliability of water supply was assessed from farmer perception and water requirement analysis. Table 20 and Fig. 9 show that the majority (77 %) of the respondents in the block, perceived a poor reliability on the delivery system.

Water supply reliability was also assessed as the coefficient of variation (CoV) of adequacy for each location on different irrigation days. The reliability (CoV) values computed for 42 different canal positions were quite variable as shown in Appendix 13. According to the Molden and Gates (1990) assessment scale, only five of these locations had good reliability, six fair and 31 had poor reliability. All the locations with good reliability were on feeder canals, implying that the delivery system was performing better at this hierarchical level. Fig. 14 shows the relationship between reliability on the feeder canals and reliability on distribution canals.

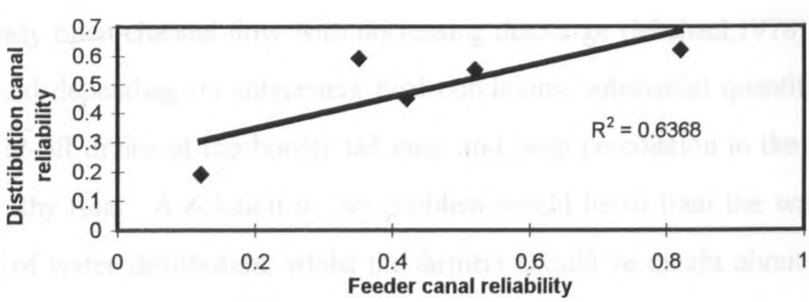


Figure 14 Relationship between reliability of water supply on distribution and feeder canal levels

4.1.2 Problem analysis: causes of inadequate and unreliable water delivery at Nyanyadzi scheme

4.1.2.1 Inadequate flow regulation

a) Flow regulation by unskilled operators

The water bailiffs, who have the responsibility of controlling and distributing water, employ very crude techniques. For example, it was reported that one hole adjustment (24 mm) of a standard lift gate was enough to supply water to eight siphons (Sithole, pers. com.). The actual volumes released from such settings were not known, the siphon head was not uniform as assumed and some farmers were reported to be using more siphons than legalised. This affected the flow consistence in the canals and equity of water distribution among the users.

The water distribution problems in the scheme are also inherent to inadequate water control by the bailiffs and the management. Pearce (1983) pointed out that the scheme bailiffs are effective in carrying out, rather than enforcing water rotas in this complex and widespread network of canals. Furthermore, it is difficult for the management to keep track of how much water has flowed where and to modify those flows and ensure equity.

Most (>90 %) farmers were reported not to have gone beyond the primary level of education (Marwa, pers. Com.). This implies that any operation of control structures by the farmers was associated with inequity problems, since they were not taught on how to appropriately operate them. It is not their responsibility according to the integrated organisational structure. Adopted.

The farmers engaged in uncontrolled flooding of their border strips as there were no design specifications to follow in the scheme and they do not fully understand the hydraulics of this irrigation method. Furthermore, the flow in border strips is complex and it is a case of spatially varied unsteady open channel flow with decreasing discharge (Michael,1978). Because of this complexity and depending on antecedent field conditions, substantial quantities of water were lost to the cut-off drains at the border tail ends and deep percolation in the fast draining soils from the lengthy runs. A solution to this problem would be to train the water bailiffs on the elementaries of water distribution, whilst the farmers should be taught about yield response to water and proper irrigation scheduling.

b) Favours

The water bailiffs are the main communication channel between the scheme management and the farmer. Their duties include mostly, the distribution and control of water flows. According to Sagardoy *et al.* (1986), the success of a smooth relationship between the two parties depends on their honesty. It was reported that the two water bailiffs controlling water are plot holders in the scheme and honesty was not guaranteed.

Favours by the water bailiffs were evident as they allowed unscheduled abstractions to take place. Some farmers can successfully plead with the bailiff to abstract water from canals in defiance of the rotational schedule (rota) and even access it on their "authentic" turn. The favours contributed to variable irrigation intervals, which were reported by Bolding (1996) to range from seven to more than 30 days at farm level. Those with lower intervals being the beneficiaries of water stealing and favours. These are some of the illegal abstractions attributed by 83 % of the farmers interviewed during the study to be the causes of unreliable and inadequate water supplies to the scheme (see Table 27).

Table 27 Farmers' reasons for poor performance by the Nyanyadzi delivery system

Reason for poor performance	*Response of farmers interviewed	
	No.	%
a Position on delivery system	21	70
b. Illegal abstraction	25	83
c. Low capacity channels	10	33
d. Silted of channels	10	33
e. Weeds	18	60
f. Other ,e.g. large holding (4acres)	1	3

*each farmer was asked to give more than one reason
*Total number of respondents = 30

The irrigation management tried to check on this favouritism, by assigning the water bailiffs to operate in the sections of the scheme where they could have minimum influence on water distribution (i.e. very far away from their respective holdings).

c) Inefficient control structures

The siltation of structures in the distribution system is one of the major causes of inadequate flow regulation. The silt comes from river catchment, river banks and conveyance canal banks, as a result of erosion processes. The prevalence of siltation is high at checked division sections of the canals and desilting is not done regularly (see Plate 1). Thus, the efficiencies of such flow regulating sections are lower than anticipated, resulting in poor water distribution equity. Desilting of canals and regulation structures is an obvious remedy and farmers should be educated on the benefits to be accrued from this activity. Data on cost or benefits of desilting should be generated and made available to farmers to convince them on the need.

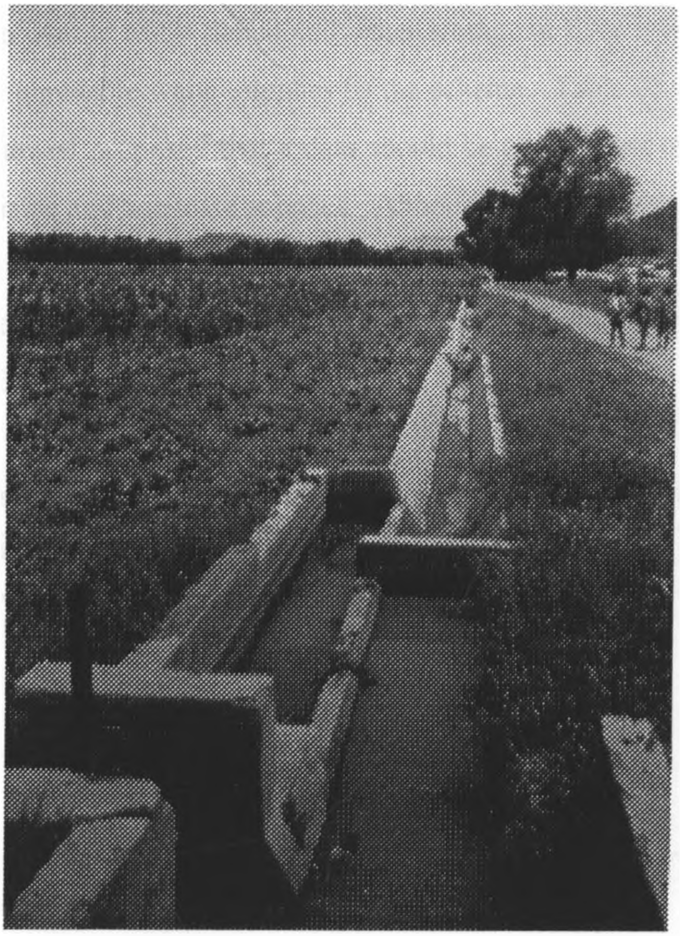


Plate 1 Weedy and silted check divider in block A: Nyanyadzi scheme

4.1.2.2 Inadequate water resource

a) Low river flows during the dry season

Over the years, the Nyanyadzi river has proved to be increasingly unreliable as a source of water due to prevalent drought conditions and irrigation development upstream. About 80 ha of land was reported by Pearce (1983) to be illegally irrigated upstream of the scheme leading to low flows and low water availability in Nyanyadzi river during the dry season

The pump houses (old and new) in Odzi river were built to augment the dwindling water supply from Nyanyadzi river. But, flows in the Odzi river are also low due to siltation of the river and the recent commissioning of the giant Osborne dam, some 120 kilometres upstream. This leaves the scheme with inadequate and unreliable water supply from these rivers in the dry season.

The scheme has an overall water deficit and water storage at river level could be a solution to inadequate and unreliable water supplies to the scheme. Table 28 shows that 100 % of the farmers interviewed proposed that a dam should be constructed in the Nyanyadzi river in order to get reliable and adequate supplies. Although a suitable site was identified, this is not feasible hydrologically (from hydrograph analysis), as the river flows have been dwindling over the years and there is a potential problem of siltation from land-use changes in its catchment (Bolding, 1996).

Table 28 Perceived solutions to water delivery problems at Nyanyadzi

Perceived Solution	*Respondents	
	No.	%
A	30	100
B	27	90
C	5	17
D	17	57
E	27	90
F	28	93
Gln	13	43
Gp	6	20
Gpp	2	7

* each farmer was asked to give more than one reason
*Total number of respondents = 30

Where:
A = Dam constructed in Nyanyadzi river for adequate and reliable water supply (supplies in the past used to be reliable)
B = Increase the number of pumps at the Odzi river pumping station for adequate and reliable supplies
C = Increase the capacity of delivery canals
D = Change the rotation schedule
(i) Increase the irrigation cycle- more days in each block/sub-block
(ii)Reduce the irrigation cycle- fewer days in each block/sub-block
E = Continuous operation/running of engines: people can irrigate at night
F = More frequent maintenance/service of the Nyanyadzi conveyance canal
G_l = Lining of Nyanyadzi conveyance canal
G_p = Installation of pump in Nyanyadzi river
G_{pp} = Piped conveyance from Nyanyadzi river.

b) High seepage losses

The unlined conveyance canal from the Nyanyadzi river and the NSD are underlain by well drained sandy loams, with high seepage rates resulting in low canal flows. Seepage losses in the Nyanyadzi conveyance canal amounts to an average of 75 % of the intake abstraction (Pearce and Armstrong, 1990). These astronomical seepage losses have translated into inadequate supply of water to the scheme. In order to avoid seepage and evaporation water losses, it was observed that no pumped water from the Odzi river is allowed to accumulate in the NSD.

c) Reduced canal conveyance

Siltation

The Nyanyadzi conveyance canal is mainly wide and shallow due to siltation. This implies a small hydraulic radius relative to the discharge (or little amounts of water conveyed). According to the farmers, siltation of canals is not a major cause of inadequate and unreliable water delivery. Only 33 % of the respondents perceived this (Table 28) and 17 % felt that desilting of canals could be a solution to improving water delivery in the scheme.

Weeds

Plants growing along the canal banks directly and indirectly affect the adequacy and reliability of water delivery to the scheme. They increase the transient water losses in canals during wetting through consumptive water use, according to the explanation given by Trout and Kemper (1980). Weeds increase the hydraulic roughness and reduce the channel discharge capacities. The existence of weeds along the water delivery channels is an indication of deferred maintenance. Furthermore, big trees affect the quality of maintenance work to be carried out due to their hindrance effect.

Most (60 %) farmers interviewed felt that the poor water delivery was due to the weed problem in some canals (see Table 27). It was also observed that sections of the Nyanyadzi conveyance canal and distribution canals were overgrown with all weed types (see Plate 2).

d) Lack of adequate storage

Nyanyadzi night storage dam silted

The NSD is the only storage structure in the conveyance system and it is inefficient due to siltation and leaking exit gate. A lot of diverted water from the Nyanyadzi river and collected runoff was observed to be lost from the NSD through premature overspilling. This water could be made available for irrigation later in the season. Desilting of the NSD and repairing of the exit gate or storing the overspilled water at block level, could improve water delivery in the scheme.

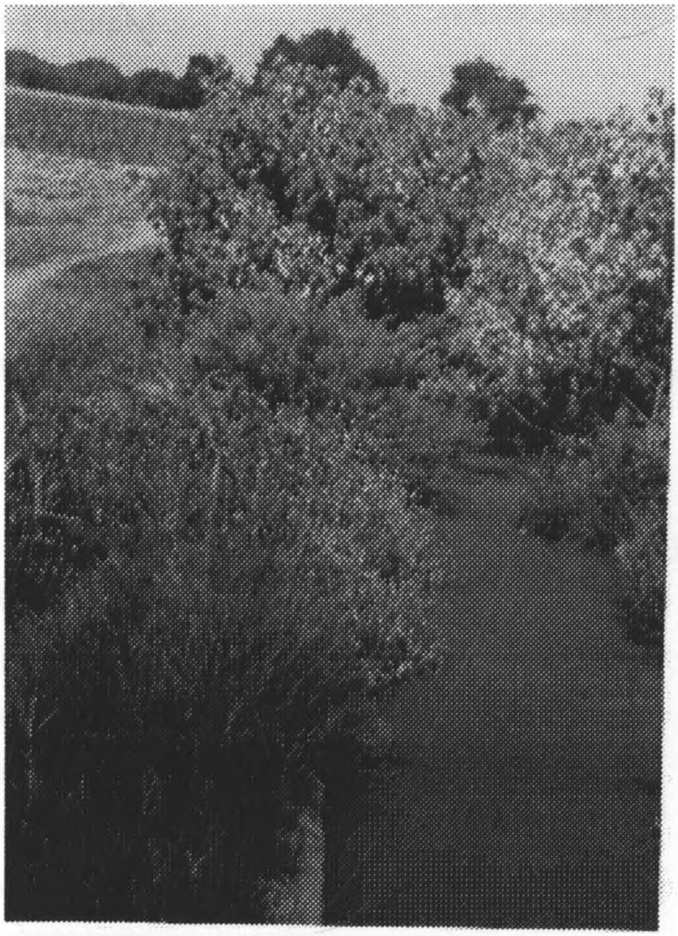


Plate 2 A lined distribution canal overgrown with weeds in block A: Nyanyadzi

No water from Nyanyadzi river

Since the supplies from Nyanyadzi river have dwindled over the years, there is need to store any surplus water that could be pumped from the Odzi river and improve the adequacy of water supplies to blocks **A, B** & **D**.

No on-farm and block night storage

Storage at these levels, is lacking and most of the excess water supplied is lost through the drainage system. The storage of water can be done in reservoirs constructed for such purposes or in the soil. Water storage in the soil entails over-irrigation and water for such purposes is not always available, despite the conducive soil conditions and inclusion of deep rooted cotton in the crop rotation.

c) Inadequate water pumped

Low pump capacity

The operating capacity of pumps used at Odzi is lower (<400 lps) than the designed 500 lps required to meet water requirements of blocks **A, B & D** (Bolding, 1996). In addition, the two Worthington turbine pumps for Nyanyadzi scheme, commissioned in 1993 were not operating simultaneously due to excessive vibrations (Pump operator, pers. com, Bolding, 1996). Thus, the pumping capability of the station is too low, resulting in low in-flow of water into the scheme.

The main causes of vibrations in turbine pumps according to Michael (1978) are:

i. Speed too high
ii. Pump improperly aligned, bolted and leveled
iii. Pump foundation not solid
iv. Crooked well and/or bent shaft
v. Improperly adjusted impellers
vi. Inadequate lubrication of bearings in drive
vii. Foreign material lodged between impeller or bowl passage
viii. Excessive wear in rotating parts
ix. poor suction conditions (e.g. silt, turbulence, eddying, vortexing at pump suction)

Most of the causes of pump vibrations mentioned above are maintenance related, but the chief culprits at Nyanyadzi are (iii), (vii) (viii) and (ix). All these have something to do with sandy/silty nature of intake site.

A short lived remedy to the vibration problem lies in the provision of a pump stabilizer. However, a more lasting solution is to install a different set of pumps. Submergible pumps anchored at the bottom of the pump sump were even proposed right at the design stage (Bolding, 1996). The idea was discarded because of the expense involved in favour of donated and unsuitable Worthington pumps.

The majority (90%) of the farmers interviewed asserted that if the number of the pumps at the pump station are increased, then water supply adequacy and reliability could be improved (see Table 28). However, the suitable pump should be installed, before their number is increased.

Pumping duration

The pumps cannot be operated for more than twelve hours a day, because of technical problems (vibrations, water leakage and breakdowns) and farmers do not have an option of irrigating at night in order to extend their irrigation cycle and maximise on adequacy. Table 28, shows that most (90 %) of the block A respondents proposed that the pumps should be run continuously. However, this option is associated with more problems. Firstly, the application efficiencies at night are lower due large illicit flows despite the lower night evaporation losses (Rijo and Almelda, 1993). Secondly, the water rights at the pumping station could be exceeded causing further problems downstream. Lastly, the productivity per unit of water might not increase, since more water is wasted at night.

Pumps shared by two schemes

There are a total of four pumps at the pumping station, shared equally between the Nyanyadzi and the nearby Nenhowe schemes (Mabika, pers. com.). The later scheme is smaller than the former, but if area was the major determinant in the design, then more pumps should have been allocated to Nyanyadzi scheme. This inequitable pump sharing, has been inevitably passed on to the respective schemes.

Siltation of pump intake

Turbine pumps at the Odzi station are not the best for the silted intake area and there is a high risk of pump wear due to mechanical friction. These conditions could be attributed to the below normal pump discharges attained at the station (Bolding, 1996).

AGRITEX is ill-staffed to maintain the intake area and farmers are called upon to assist in scooping the silt from the intake. Preference to irrigation water is then reportedly given to such farmers who avail their labour for scooping the silted pump intake. This is results in distortions in the water allocation schedule and prejudicing the performance of the water delivery system.

4.1.2.3 Improper management

a) High water demand

During the scheme design, it was assumed that water from the Nyanyadzi river was not limiting and there was implicit equity, a fixed planting programme and fixed irrigated area (Marwa, pers. com). These assumptions no longer hold as flows in the Nyanyadzi river are low and erratic, essential structures are getting silted and the scheme is expanding both in extent and number of holders. These changes have exerted immense pressure on the delivery system to meet the increasing water requirements of the scheme.

Crops with high water demand: type and variety

The Sc501 maize variety is a high yielding cultivar requiring copious amounts of water to fully exploit its genetic potential. Such varieties have resulted in inadequate water supplies to the scheme since maize is a staple crop grown by all irrigators. Short season maize varieties (such as R201 and R215) can be used instead and the cropping calendar adjusted to make use of the natural rainfall.

Irrigated area

Scheme expansion has exerted pressure on the water delivery system to meet the water requirements. Productivity has been reduced by the growing amount of unauthorised expansion of the scheme. The area irrigated influences the depth of water actually applied. Farmers normally attempt to irrigate as much area as possible and often spread the limited supplies for a given irrigation thinly. This was the practice in situations of short and unpredictable supplies. At field level, farmers rarely employ water saving techniques like deficit irrigation, in order to improve the adequacy of irrigation water under limited supplies. The size of land to be irrigated and the crop mix that maximises the benefits of irrigation must be established for deficit irrigation to be fully exploited.

Cropping pattern/calendar

The cropping pattern shown in Fig. 3 strains the delivery system so much, because horticultural crops (tomatoes, beans and vegetables) which require relatively large quantities of water are mainly grown in the winter season when water supplies from the rivers and rainfall are low. Farmers were reported to be a bit liberal when it came to choosing crops to grow and this information was not communicated to the management in time, resulting in inadequate amounts of water allocated (Marwa, pers. com.). Planting programme should be well timed to match peak demand with peak supply and farmers should be encouraged to furnish the management with their intended seasonal cropping programmes.

b) Illegal abstraction

Due to the poor performance of the delivery system, farmers lacked confidence in it and became individualistic as most (83 %) of the respondents attributed the poor water delivery to illegal abstractions (see Table 27). In the scheme, irrigators resort to illegal water abstraction for various reasons, but mostly due to desperation. It was reported that farmers find themselves in a desperate situation by violating the one acre rule, such as planting more area than can be irrigated (Marwa, pers. Com.). This inevitably strained the water delivery system, resulting in belated irrigation turns and inequity, which further forces farmers to indulge into more illegal abstractions. It was also observed that farmers obstructed water flow at division sections of distribution canals, so that they could get more water. This affected water equity in the scheme.

The problem of illegal abstractions can be solved by imposing stiffer financial penalties on offenders, in addition to the ZWD50.00 already in place and the water bailiffs should not give in to "sincere" appeals by irrigators. It was reported that farmers in the scheme were prepared to be fined the ZWD50.00 penalty than face crop failure because of inadequate water supply. Cooperation between farmers, water bailiffs and the management can be of use.

4.1.2.3 Deferred maintenance

The maintenance of structures and channels is the responsibility of the ill-staffed AGRITEX , which cannot cope with the demand. The activities involved include desilting, weeding of unlined conveyance canals, repair of breached sections of lined canals and desilting of Odzi pump intake area. Desilting of the main canals is normally undertaken on an emergency basis (usually soon after heavy storms), which is not frequent enough (Sithole, pers.com.). This deferred or belated maintenance results in water losses and low delivery efficiency.

Farmers also assist the management during maintenance, but high quality work is not guaranteed, as the farmers do not have thorough knowledge of the design specifications of the structures and channels. Maintenance assistance by farmers was reported to cause distortions in the irrigation intervals, as preference to water was given to farmers who availed themselves for maintenance work. This meant that farmers in tail end blocks have to walk very long distances to the intake and the main conveyance canal to take advantage of this arrangement.

4.2 THE STATUS OF MATANYA WATER DELIVERY SYSTEM

4.2.1 Main intake abstractions

The abstractions to the scheme were monitored by a cut-throat flume near the intake, since 1990. Appendix 15 shows the measured mean daily intake abstractions for the years 1991, 1994, 1995 and 1996. The amount of water diverted to the scheme was much more than what is authorised by the permit issued by the Water Apportionment Board of the Ministry of Water Development (Republic of Kenya, 1972). This may be seen in Fig.15. The mean monthly volumes abstracted to the scheme varied as the total rainfalls in these years (see Fig.16). This implies that flow regulation was not effected in most cases at the intake by the management. The off-take control gate at the intake was reported to be operating at maximum opening throughout the year. In the rainy season most of the water abstracted was therefore not useful for irrigation purposes since the irrigation requirements are low.

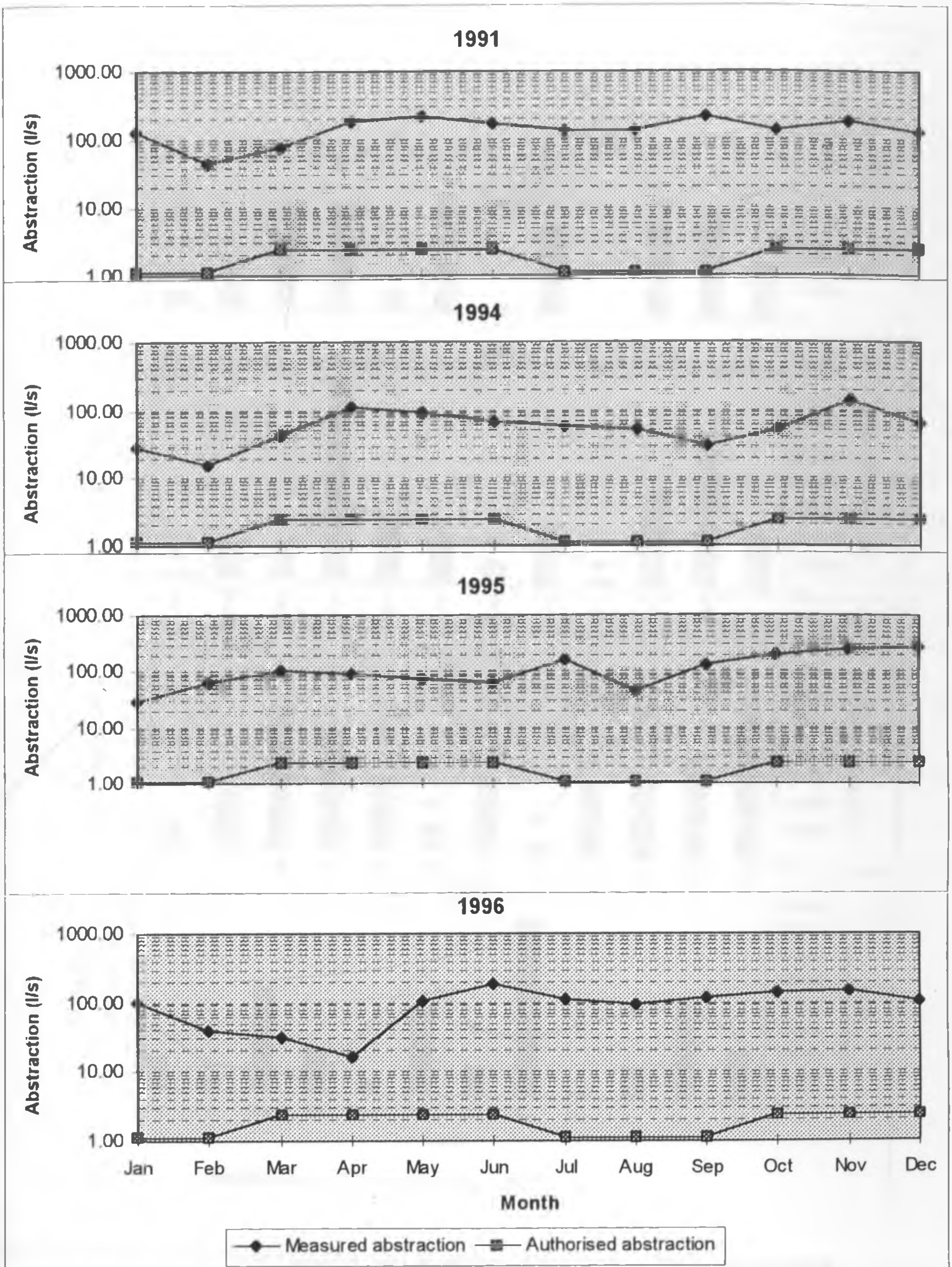


Figure 15 Measured and authorised abstractions at Matanya intake

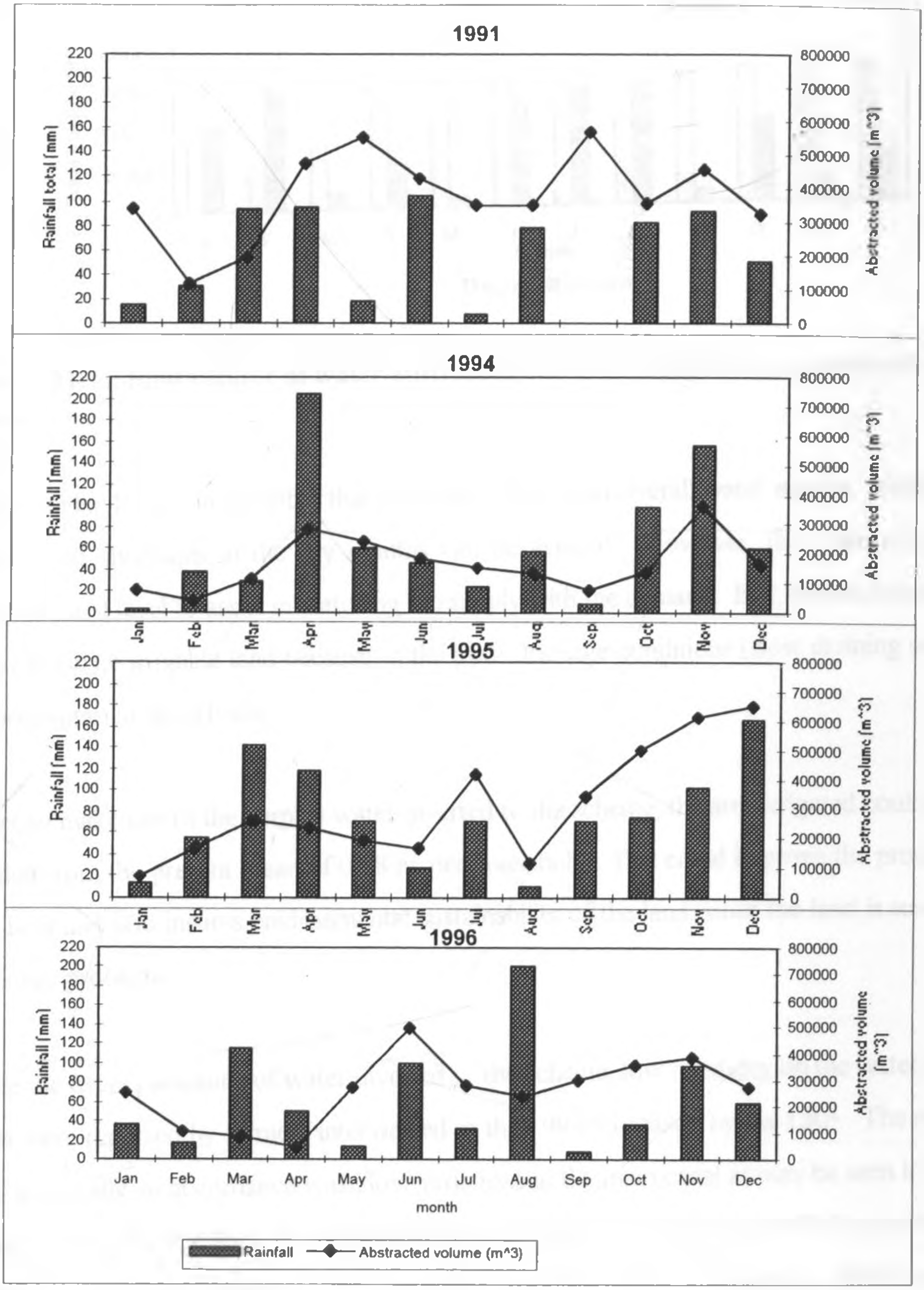


Figure 16 Variation of total rainfall and abstracted volume at Matanya intake

Appendix 19 shows how the irrigation water demand was computed from climatic and cropping data. It was observed that the scheme was abstracting far much more water than is required for irrigation purposes except in the months of January, February and August, when there are deficit because of dry conditions (see Fig. 17 and Table 29).

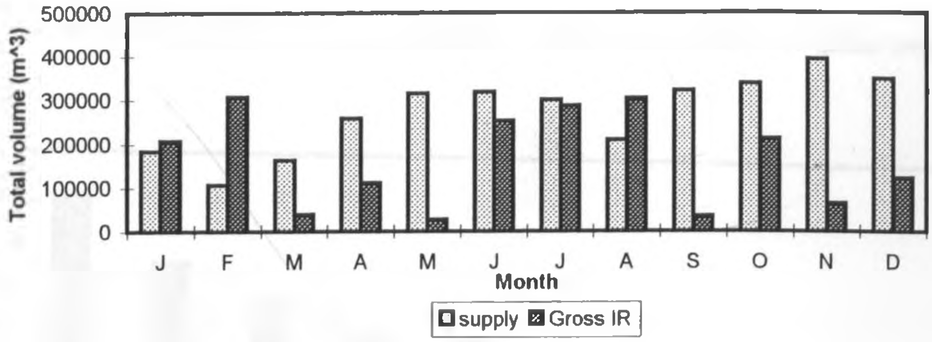


Figure 17 Mean total volume of water abstracted and gross irrigation requirement at Matanya

From Appendix 19, it can be noted that the scheme had a net overall water surplus, which could be stored and shortages in the dry months can be averted. However, there are no storage facilities at canal level to assist in matching the supply with the demand. But, this level of storage can also inundate irrigable land because of the poor drainage conditions (slow draining soils and flat topography) in the scheme.

In order to make use of the surplus water diverted to the scheme, the area irrigated could also be expanded from the present mean of 0.58 ha per household. This could improve the productivity of the land and also insures environmental sustainability of the land, since the land is susceptible to drainage problems.

Despite the excess amounts of water diverted to the scheme, low reliability on the water delivery system were reported by farmers interviewed in the 1994/95 season by the LRP. The reliability varied seasonally, in accordance with flow variations in the main canal as may be seen in Fig. 17. About 95 % of the respondents reported good reliability in wet season and 99 % reported poor reliability in the dry season. The unreliable supplies were invariably a direct result of unauthorised abstractions in the upper reaches of the canals and the inadequate flow regulation observed in the scheme.

4.2.2 Main canal flows

The residual discharge in the main canal was measured in May 1997 and its variation with distance from the intake is depicted in Fig. 18. It followed an exponential trend, similar to flow variation caused by seepage losses along unlined canals (Trout and Kemper, 1980). This could have been the case, as less water was reported to be abstracted for irrigation purposes from the canal, since it was in the middle of the rainy season. Most of the losses or sinks were due to seepage.

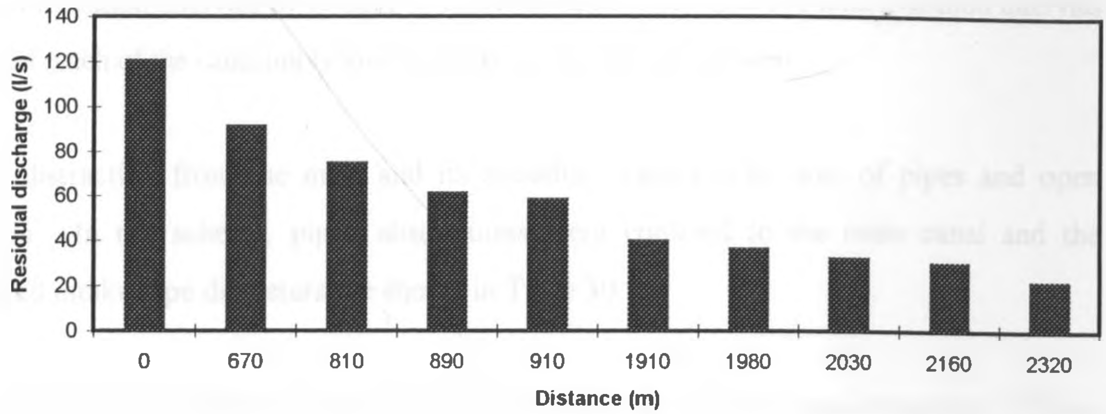


Figure 18 Variation of residual discharge with distance from the intake along the main canal (May, 1997)

From Table 29 it may be seen that the flow area had a greater effect on the flow rate in the canal, since the other factors which affect it were observed to be almost uniform (i.e. flat topography and weedy canal banks).

Table 29 Results of flow measurements along the main canal of Matanya scheme

Point	User	distance (m)	w m	d m	P m	A m^2	R	slope %	v m/s	Q m^3/s	Q l/s
		0									121.2
A3	792	670	1.33	0.27	1.86	0.35	0.19	1	0.26	0.092	91.92
A5	789	810	1.21	0.25	1.71	0.30	0.18	1	0.25	0.075	75.36
A7	723	890	1.42	0.20	1.82	0.28	0.16	0.9	0.22	0.062	61.74
A8	722	910	1.32	0.24	1.79	0.31	0.17	0.6	0.19	0.059	59.05
A15	534	1910	1.10	0.21	1.52	0.23	0.15	0.6	0.17	0.040	40.28
A16	480	1980	1.00	0.23	1.45	0.23	0.16	0.5	0.16	0.037	36.79
A19	479	2030	1.24	0.15	1.54	0.19	0.12	0.8	0.17	0.033	32.8
A24		2160	1.18	0.13	1.45	0.16	0.11	1.2	0.20	0.031	30.92
A27	447	2320	1.06	0.13	1.31	0.13	0.10	1	0.17	0.023	22.74

4.2.3 Farm level off-take

Irrigation water is abstracted from the main canals by means of open channels and pipes to the farms. The irrigation scheduling is not accurate and there are no design specifications. The farmers were reported to irrigate for as long as supply was available(opportunistic irrigation), until the high spots were covered or until water reached the downstream end of field. This is one of the major causes of the inequity and unreliability problems experienced in the scheme. It was observed from a survey carried out in the 1994/95 by LRP that, about 60 % of the respondents at the main canal head reported irrigation intervals below 5 days, whilst at the tail, 62 % of them reported irrigation intervals of 10 days or more for different crops. The long irrigation intervals at the tail reach of the canal imply low reliability on the delivery system.

Water abstraction from the main and its subsidiary canals is by way of pipes and open channels. In the scheme, piped abstractions were confined to the main canal and the measured intake pipe diameters are shown in Table 30.

The regulations stipulate that a maximum pipe diameter at the intake should be up to 5.08 cm (Mwangi, pers. com.). It was observed that 20 % of the intake points in the main canal violated this regulation, contributing towards the inequity problem reported in the scheme (see Table 30).

Table 30 Measured intake pipe diameters in main canal of Matanya irrigation scheme

Diameter (cm)	No.
7.62	1
6.35	2
5.08	10
3.81	2
1.27	1

Open channel abstractions from the secondary and tertiary canals are facilitated by temporary diversion weirs constructed across them. There are no design specifications for these channels and they divert any amount, irrespective of their reach on the distribution canal, causing water inequity (see appendix 20).

The open channel abstraction was practised by water users taping water from the main and subsidiary canals (See Fig. 19). It was observed that the dimensions of the off-take abstraction channels on the distribution canals were not significantly ($p=0.05$) different. Maximum discharges that could be abstracted by these channels were also observed not to be different, as the flow rate mostly depends on the flow area (see Table 31).

The farmers at the head reaches of the distribution canals would benefit from such a uniformity in off-take abstractions from the distribution canals. This is because they can minimise transient water losses, as steady state flow conditions can easily be attained by operating at full channel capacity. However, this cannot be achieved by tail end farmers, where low water supplies are further decimated by transient losses, such as wetting up losses and inequitable water distribution results.

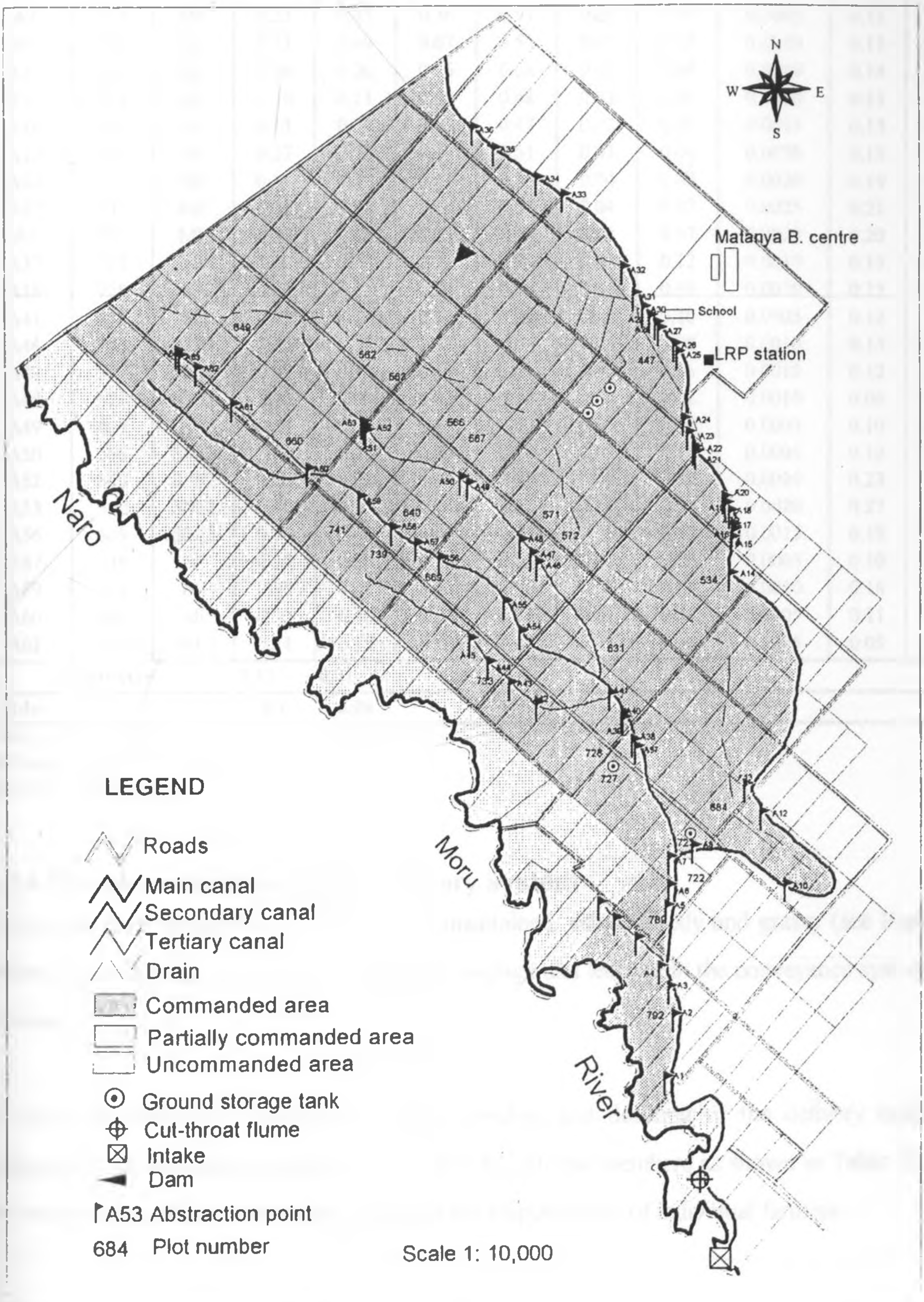


Figure 19 Location of abstraction points in Matanya scheme

Table 31 Discharge capacities of abstraction channels in Matanya scheme

Point	User	LCN	w m	d m	d max	P m	A m^2	R	slope	v m/s	Qmx m^3/s
A3	792	MF	0.10	0.20	0.16	0.42	0.02	0.04	0.0010	0.09	0.001
A5	789	MF	0.45	0.17	0.14	0.72	0.06	0.08	0.0020	0.22	0.013
A7	723	MF	0.25	0.45	0.36	0.97	0.09	0.09	0.0005	0.11	0.010
A8	722	MF	0.41	0.09	0.07	0.55	0.03	0.05	0.0010	0.11	0.003
A13	684	MF	0.30	0.20	0.16	0.62	0.05	0.08	0.0010	0.14	0.007
A15	534	MF	0.30	0.11	0.09	0.48	0.03	0.06	0.0010	0.11	0.003
A16	480	MF	0.15	0.20	0.16	0.47	0.02	0.05	0.0015	0.13	0.003
A19	479	MF	0.27	0.15	0.12	0.51	0.03	0.06	0.0020	0.18	0.006
A24		MF	0.35	0.15	0.12	0.59	0.04	0.07	0.0020	0.19	0.008
A27	447	MF	0.25	0.18	0.14	0.54	0.04	0.07	0.0025	0.21	0.007
A1	797	MF	0.33	0.17	0.14	0.60	0.04	0.07	0.0020	0.20	0.009
A37	727	MF	0.40	0.35	0.28	0.96	0.11	0.12	0.0010	0.19	0.021
A38	728	SF	0.30	0.25	0.20	0.70	0.06	0.09	0.0010	0.15	0.009
A41	631	SF	0.65	0.17	0.14	0.92	0.09	0.10	0.0005	0.12	0.010
A44	733	SSF1	0.35	0.18	0.14	0.64	0.05	0.08	0.0010	0.15	0.007
A47	572	SSF2	0.30	0.13	0.10	0.51	0.03	0.06	0.0010	0.12	0.004
A48	571	SSF2	0.13	0.04	0.03	0.19	0.00	0.02	0.0010	0.06	0.000
A49	467	SSF2	0.34	0.19	0.15	0.64	0.05	0.08	0.0005	0.10	0.005
A50	566	SSF2	0.30	0.36	0.29	0.88	0.09	0.10	0.0005	0.12	0.010
A52	563	SSF2	0.40	0.22	0.18	0.75	0.07	0.09	0.0020	0.23	0.016
A53	562	SSF2	0.40	0.35	0.28	0.96	0.11	0.12	0.0020	0.27	0.030
A56	669	SSF2	0.36	0.18	0.14	0.65	0.05	0.08	0.0015	0.18	0.009
A57	739	SF	0.30	0.20	0.16	0.62	0.05	0.08	0.0005	0.10	0.005
A59	741	SF	0.35	0.25	0.20	0.75	0.07	0.09	0.0010	0.16	0.011
A60	660	SF	0.30	0.30	0.24	0.78	0.07	0.09	0.0005	0.11	0.008
A62	649	SSF3	0.24	0.15	0.12	0.48	0.03	0.06	0.0005	0.09	0.002
AVERAGE			**0.32**	**0.21**							
Stdev			**0.1**	**0.08**							

MF= main furrow
SF= Sub- furrow
SSF= Sub-sub-furrow

4.2.4 Maintenance of the water delivery system

The entire canal network is unlined, poorly maintained, silted, weedy and grassy (see Plate 3). Water losses through consumptive water use, seepage and leakage in the conveyance system are excessive.

In order to reduce the conveyance losses, weeding and desilting of the delivery canals is supposed to be communally carried out weekly by scheme members as shown in Table 32, but the maintenance of the abstraction channels is the responsibility of individual farmers.

Plate 3 A section of main canal overgrown with weeds: Matanya

Table 32 Planned canal maintenance schedule at Matanya scheme (May, 1997)

CANAL	MAINTENANCE DAY
Conveyance/Primary	Saturday
Distribution/secondary	Wednesday
Tertiaries	Wednesday

It was reported that the schedule shown in Table 32 is rarely followed and the quality of maintenance work carried out by the farmers is very low. Weeding and desilting are not thoroughly done as shown in Plate 4.

Since there are no design specifications to follow, the dimensions of the main canals were observed to have almost the same dimensions, regardless of the conveyance level or volume of water delivered. The dimensions of the main canal and its subsidiary canals were not significantly ($p = 0.05$) different as shown in Table 33. This is an indication of poor quality maintenance work done by the farmers with similar expertise.

Plate 4 A 'freshly', weeded section of Matanya main canal

Besides improper channel excavation during maintenance, some sections of the canals were widened (>2.0 m) by watering livestock (Plate 5). It was observed that such sections had small free boards and susceptible to overtopping and seepage losses.

Table 33 Measured dimensions of main canals in Matanya irrigation scheme (May,1997)

	Mean width) (m)	Mean depth (m)	Area (m^2)
Main	1.44	0.45	0.6480
Secondary canal	1.38	0.40	0.5220
Tertiary canals	1.36	0.37	0.5032

In order to solve water loss problems associated with the conveyance system, scheme members think that piped conveyance or lining of the conveyance canal could reduce the water losses. It was also reported that the Ministry of Water was concerned about the excessive water losses incurred at the scheme and it gave the scheme members an ultimatum of September, 1997 to come up with a way of minimising the losses (Mwangi, pers. com.).

Plate 5 A section of main canal widened by watering animals: Matanya scheme

4.2.5 Organisation, staffing and rules

The scheme has a segregated organisational structure, each farmer is responsible for the maintenance and regulation of flows of his part of the irrigation system. Since there is no one assigned to regulate the water flows at the scheme, equity of water distribution is not ascertained. However, appointment of a water bailiff imply extra payment costs, but there are no water charges in place to take care of this. In order for the bailiff to effectively perform his duties, he needs water regulation structures to be installed at strategic points (see Plate 6). Rules and regulations should also be put in place and complemented by respectable juries.

The fact that there is rotational water distribution along the subsidiary canals and continuous distribution along the main canal, partially implies that the flow is not proportionately divided at the main branching point to spread the water scarcity equitably in the scheme. Farmers at the head-reaches of the conveyance system have unlimited access to irrigation water because on the continuous distribution method adopted. Furthermore, the rules & regulations in place very relaxed and there is no water masters (bailiffs) to assist in water distribution.

Plate 6 Division point of Matanya main canal

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The Nyanyadzi and Matanya smallholder irrigation projects are examples of schemes with upstream control delivery systems, such that canal discharges are controlled by operating an off-take gate at the upper reaches of the systems. In schemes like Matanya, where water can only be regulated at the head of the main canal intake by an off-take gate, the performance of the delivery system is low due to inadequate water regulation (rigidity). On the other hand, schemes like Nyanyadzi with gated division delivery systems are more flexible as they allow water to be manually controlled at every bifurcation in the system. However, to ensure good performance of delivery system, the water control structures used need to be operated by skilled personnel aided by rules and regulations in order to realise the anticipated benefits of their usage. These are usually lacking as the water masters/bailiffs of smallholder projects are either semi-skilled or there is little respect for the few rules and regulations in place by the water users. The quality of water delivery in smallholder schemes is therefore, largely a function of the way management manipulate the meagre structures that convey, distribute and apply water according to design specifications.

The performance of delivery systems in smallholder schemes is also related to the ability of the management to handle variable quantities of water delivered in relation to the respective scheme demand. In schemes like Matanya, where water supply is mostly in excess of scheme demand, the management is expected to adequately regulate flows at all reaches in order to minimise water losses and potential drainage problems. On the contrary, smallholder schemes experiencing water inadequacy (such as Nyanyadzi) due to low supplies from the source require more stringent measures when allocating the limited supplies. Sound management, co-operation from irrigators and respect for water masters, rules & regulations would improve the performance of the delivery system.

Sound management and operation of smallholder schemes cannot be successful without good project designs. Design specifications act as standards and references for proper functioning of the schemes. The development of smallholder schemes designs has however, been historically haphazard resulting in farmers adopting potentially detrimental practices. The practices include illegal abstractions and/or vandalisation of structures reported at Matanya and Nyanyadzi schemes resulting in the notorious tail-ender problem. Breakdowns of infrastructure in smallholder irrigation schemes can be attributed to some faults/errors made at the designing stage. For example, at Nyanyadzi scheme, the wrong type of pumps were installed (design error) resulting in pumping problems such as excessive vibrations and low discharges. This negatively impacted on the performance of the delivery system. In such instances the poor performance of the delivery system would be inherent to the system design.

5.2 RECOMMENDATIONS

A number of recommendations can be drawn from the assessment of smallholder delivery systems. Firstly, the performance evaluation of the water delivery systems should be done at all canal reaches and all year round in order to capture the variability (spatial & temporal) of their performance. The management would be in a better position to tell which sections of the water delivery system need attention at what time of the year.

The water distribution schedules in smallholder schemes are a result of trial and error approaches usually based on section/block command areas and number of plot holders and disregarding the conveyance distance to an individual block/section. Water distribution problems have nevertheless continued to hound the schemes. The second recommendation is that, the managers of these schemes should equally weigh conveyance distances when determining the rotation schedules for improved water delivery quality.

Lastly, there should be adequate maintenance of the delivery systems of smallholder projects. Overtopping losses can be minimised by maintaining adequate free boards in canals, canal fencing and use of culverts where roads meet canals to minimse breaching by watering livestock in schemes with mixed agricultural systems. Furthermore, these losses could be reduced by lining or piped conveyance in schemes with unlined delivery systems depending on the economic value of crops to be grown.

Basing on findings from this study, the strategies for improving the equity, adequacy, reliability and efficiency of the water delivery systems of smallholder irrigation projects are:

1. Making *maximum use of the supplied water* the smallholder projects. During periods of excess water supply, smallholder irrigators should be urged to increase their irrigated area to match the excessive amounts of water diverted to the scheme and avoid potential drainage problems. Smallholder schemes experiencing water deficit should employ water saving measures by either cutting total irrigated area or introducing water scheduling methods aimed at increasing water availability to individual blocks (wet blocks). There will not be total crop failure and food security is ascertained.

2. *Storage* of surplus water for use in drier periods of the year. Water storage facilities/techniques in smallholder schemes are either lacking or inadequate or inefficient (due to siltation). Feasibility studies on water storage options at block and field levels should be carried out in the smallholder irrigation projects in order to make use of any surplus amounts of water available to the scheme.

3. Installation of *water control and measurement structures* at strategic points in the delivery systems of smallholder projects to proportionately divide flows and increase water distribution equity. For example, gauged division boxes and control gates should installed at branching points in the delivery systems of schemes like Matanya. The installed control and measurement structures must be inspected for necessary cleaning, repairs and replacement for lasting benefits.

4. *Routine checking of design* specifications of delivery system infrastructure. This is important in schemes susceptible to overtopping losses. Irrigation water delivery computer models could be used as monitoring tools to provide data for accurate matching of the water supplied and irrigation demand. In addition, the maintenance of the canals should be done more thoroughly in the smallholder schemes, with the supervision of trained people well versed with channel design specifications. The canal design specifications should be readily available to all people involved in the maintenance in order to obtain high quality work and ensure improved water delivery efficiency.

5. *Training* of irrigators and water masters in smallholder projects on various aspects of irrigation water use such as yield response to water for farmers and elementaries of

water distribution for bailiffs, should be instituted. Since farmers assist in the maintenance of the delivery system (depending on the type of organisation), information on the benefits of delivery system maintenance should be made available to them. This can be based on evaluation of the irrigation water losses carried in terms of the marginal value to crop production.

6. Introduction of *rules and regulations* which can assist in appropriate distribution of irrigation water. Most smallholder projects do not have clearly defined sets of rules governing the operation of schemes or their enforcement is weak. Recruitment of water masters to facilitate water distribution and guided by set rules and regulations is necessary. The introduction or encouraging payment of water rates would be inevitable as a source of revenue to meet the salary requirements of the water masters and other costs. A move towards the establishment of an irrigation association type of organisations could assist in this respect.

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7.0 APPENDICES

Appendix 1 Performance indicators developed by Molden and Gates (1990)

There is need to note Q_D, the water delivered at a considered point of the irrigation network (Discharge) and Q_T, the targeted water delivery (demand) at the same point. These two variables are thus functions of the time and space: Q_D (x,t) and Q_T(x,t).
The computation of Molten and Gates indicators requires the use of the three basic mathematical notions:
* The notion of sill function:
$Y(x) = x$ if $x < 1$, 1 otherwise
* The notion of average of a function F during a period of time (t_1,t_2) within a certain special range [x_1, x_2]:
* $< F(x,t) > [x_1,x_2] [t_1,t_2]$
* The notion of standard deviation of a function F regarding its temporal or spatial fluctuations:
$S_{t \text{ or } x} (F(x, t))$ x or t
Then:
Adequacy: $Ad = < Y (Q_D/Q_T) > x,t$
Efficiency: $Ef = < Y (Q_T/Q_D) > x,t$
Dependability: $Dp = < S_t (Q_D/Q_T) > x$
Equity: $Eq = < S_x (Q_D/Q_T) > t$

Appendix 2 Average climatic (1986-1995) parameters at the Matanya Field Station

Month	Rain mm	Humi %	Evap (mm/day)	Wind km/day	Max T. °C	Min T°C	S/shi (Hrs)	**Solar rad. (hours)**
Jan	60.2	50.9	4.2	4.89	23.6	8.4	6.9	19227.3
Feb	43.2	45.6	5.1	4.79	24.8	7.9	7.2	19772.0
Mar	72.7	52.0	4.7	5.85	27.3	9.3	6.3	19016.8
Apr	101.8	65.2	3.9	7.33	25.1	11.9	5.3	19741.5
May	40.2	62.8	4.4	12.01	24.2	12.9	6.7	20637.6
Jun	56.0	60.2	4.6	12.16	24.4	11.8	7.9	20317.1
Jul	38.8	60.6	4.9	13.90	23.0	11.2	8.0	20004.4
Aug	25.2	56.8	5.6	15.31	23.8	11.3	8.5	20934.6
Sep	31.1	50.2	6.2	14.81	25.5	11.3	8.1	21403.1
Oct	75.6	56.4	4.8	9.56	25.5	11.4	5.8	19712.7
Nov	110.3	66.2	3.4	5.94	23.7	11.2	4.9	16140.9
Dec	87.6	60.6	3.7	4.49	24.5	10.0	5.9	17903.2

Source: Gichuki, *et al.*(1995)

Appendix 3 Questionnaires administered at Nyanyadzi Small holder scheme
Part 1 Questionnaire to the irrigation manager during the Reconnaissance trip

1. What is the present size of the scheme?
2. How many blocks are there?
3. How many plot holders are in the scheme and in each of the blocks?
4. Where do you get your irrigation water from and how is it conveyed?
5. What is the method of water distribution and what is the basis of the schedules?: *Continuous *Rotational *On-demand
6. Which method (s) of irrigation are used in the scheme?
7. How is the scheme managed ?
8. Maintenance of the water delivery system

a) Responsibility: *Farmer *Agritex *Both
b) Frequency of maintenance and activities

MAINTENANCE ACTIVITY	FREQUENCY	
	Current	In the past
Weeding		
Leak repairs (e.g. cement sealing)		
Desilting		
Others (e.g. rebuilding of broken canals)		

Frequency scores: 1. Monthly 2. Every three months 3. every six months 4. Annually When required (emergency) e.g. after a rain storm

About the farmer

1. Name of informant....................................
3. Location on delivery system:

a) Main canal (conveyance): *Head * Middle *Tail
b) Distributary: *Head *Middle *Tail
c) Unit feeder canal: *Head *Middle *Tail

Farmer perceptions on water supply performance

3. Do you get adequate water supply for the targeted irrigated area ?
   *Good *Fair *Poor
4. How dependable is the water delivery system?
   *Good *Fair *Poor
5. How equitable is the water distributed among farmers ?
   *Good *Fair *Poor
6. Causes of water delivery problems

a. Position on delivery system
b. Illegal abstraction
c. Low channel capacity
d. Canal siltation
e. Weed problem
f. Others (specify) ....

7. What should be done to improve the water delivery to the scheme ?

A. Dam construction in Nyanyadzi river as supplies used to be adequate.
B. Increase the number of pumps at the pumping station in Odzi river.

C. Increase the capacity of the delivery canal.
D. Change the rotation schedule: Increase irrigation cycle (more days in this block).
E. Continuous running of engines: others can irrigate at night.
F. Service of conveyance canal (Nyanyadzi) should be done more often.
G. Other: lining of the Nyanyadzi conveyance canal.

Part 3: Observations made during the survey

1. Water flow in canals: *stable *Unstable
2. Lining: *Unlined *Concrete *Cement Masonry
3. Water losses in the delivery system: * Seepage * Leakage * Wastage * Over topping
4. Bank erosion *Nil *Slight *Severe
5. Sedimentation

Degree: *Nil *Slight *Severe
Nature.................................

6. Weeds in delivery system

Number: *Nil *Few *Common *Many
Location: *along canal edges *canal bed
Nature: *Grass *Shrubs *Trees

Appendix 4 Schedule and Results of Nyanyadzi questionnaire survey

No.	Date	Name of informant	Location				Performance indicator			Cause	Solution
			Distributary		feeder canal						
			code	reach	code	reach	Ad	Dp	Eq		
1	15/11/96	Mukome M.	D5	T	F11	T	F	F	G	abce	AEF
2	15/11/96	Dziwandi P.	D6	M	DF3	T	F	F	P	abde	ABCEF
3	15/11/96	Mukwambo S.	D2	H	F19	T	G	F	F	ab	ABEFG$_L$
4	15/11/96	Chitsiku F.	D2	T	F22	H	P	P	F	abc	ABEF
5	15/11/96	Mwatsikenyere J.	D1	T	F10	T	P	P	P	ab	ABE
6	16/11/96	Chipiro R.	D1	M	F5	H	P	P	P	abc	ABCDEF
7	16/11/96	Bingepinge D.	D1	H	F1	H	P	P	P	abe	ABDF
8	16/11/96	Chipandwa T.	D3	M	F26	T	G	P	G	abd	ABDEF
9	16/11/96	Hlabati J.	D1	T	F9	H	P	P	P	abde	ABCDEF
10	16/11/96	Rwizi M.	D4	T	F30	T	P	P	P	abe	ABEF
11	25/11/96	Mukoko L.	D4	T	F30	M	P	P	P	ab	ABDEFG$_L$
12	25/11/96	Mwaseka M.	D5	M	F32	T	P	P	G	bc	ABDEFG$_I$
13	25/11/96	Masungise T.	D5	H	F33	H	F	F	F	bde	ABDEF
14	25/11/96	Jazi M.	DF2	M	DF2	M	G	P	P	ae	ABDEFG$_L$
15	25/11/96	Mutezo B.	DF2	T	F18	T	P	P	P	ac	ABEFG$_L$
16	27/11/96	Chidhakwa J.	D5	M	F32	T	G	P	G	abce	ABCDEF
17	27/11/96	Mwayengeni R.	D5	H	F33	T	G	P	G	abcde	ABDEF
18	27/11/96	Gwinya R.	DF2	T	F17	T	P	P	G	abe	ABDEFG$_L$
19	27/11/96	Mabika P.	DF2	M	F15	H	P	P	P	abde	ABDEFG$_L$
20	27/11/96	Mutama R.	D6	M	DF3	H	P	G	G	ac	ABCDEF
21	10/12/96	Dziwandi V.	D6	T	Fa	H	P	P	P	bc	ABEF
22	10/12/96	Matumbura M.	DF1	M	F11	H	P	P	P	abe	ABDEFG$_L$
23	10/12/96	Chikotosa C.	D4	M	F28	H	F	F	G	bd	ABDEFG$_L$
24	10/12/96	Katsaura F.	D4	H	F27	T	P	P	G	ade	EFG$_L$
25	10/12/96	Chitsiku C.	DF5	M	DF5	M	G	G	G	abcde	ADEF
26	15/12/96	Baye M.	DF2	H	DF2	H	G	P	P	abcde	ADEF
27	15/12/96	Makuni E.	D2	T	F22	T	F	P	P	abe	ABEFG$_L$
28	15/12/96	Jambaya M.	DF5	H	DF5	H	P	P	P	b	ABDEFG$_L$
29	15/12/96	Mwaziyedzanyi E.	DF2	T	F17	H	P	P	P	abe	ABEFG
30	15/12/96	Dziwandi B.	D1	H	F2	H	G	P	G	abde	ABCDEF

Appendix 5 Current meter measurements in Block A: Nyanyadzi scheme

Turn 1

Day 1 : 5/12/96

Time	Measuring position	Sub-block	d (m)	0.6d (m)	Rotation speed (Revs/t)				t (s)	n Rev/s	Rate Eqn	V m/s	Canal code	A m^2	Q m^3/s
					n1	n2	n3	n'							
09:27	F35	An	0.140	0.084	9	10	11	10.0	10	1.00	1	0.13	5	0.08	0.01
09:37	DF5	An	0.310	0.186	34	34	36	34.7	10	3.47	2	0.41	1	0.13	0.05
09:43	D2 (dist Box)	An	0.305	0.183	39	40	40	39.7	5	7.93	3	0.89	2	0.14	0.13
09:48	D2 (F20/21)	An	0.300	0.180	35	36	34	35.0	5	7.00	3	0.79	2	0.14	0.11
09:51	F21	An	0.270	0.162	26	24	27	25.7	5	5.13	3	0.59	1	0.11	0.06
09:56	D2 (F21/22)	An	0.225	0.135	20	20	21	20.3	5	4.07	2	0.47	2	0.10	0.05
09:59	F23	An	0.190	0.114	24	25	25	24.7	5	4.93	3	0.57	1	0.07	0.04
10:02	F23(a l absr	An	0.180	0.108	11	12	12	11.7	5	2.33	2	0.28	1	0.06	0.02
10:25	Fb	Al	0.175	0.105	30	32	30	30.7	5	6.13	3	0.70	1	0.06	0.04
10:36	FY	Al	0.140	0.084	35	33	37	35.0	5	7.00	3	0.79	1	0.04	0.04
10:40	Fa	Al	0.150	0.090	11	10	11	10.7	5	2.13	2	0.26	1	0.05	0.01
14:15	Fb	Al	0.160	0.096	30	30	30	30.0	5	6.00	3	0.68	1	0.05	0.04
14:21	Fa	Al	0.135	0.081	39	38	40	39.0	5	7.80	3	0.87	1	0.04	0.04
14:41	DF5	An	0.230	0.138	42	41	42	41.7	5	8.33	3	0.93	1	0.09	0.08
14:58	D2 (near BOX)	An	0.240	0.144	40	39	40	39.7	5	7.93	3	0.89	2	0.10	0.09
15:15	F21	An	0.225	0.135	26	26	27	26.3	5	5.27	3	0.60	1	0.08	0.05
15:20	D2 (F21/22)	An	0.170	0.102	30	29	30	29.7	5	5.93	3	0.67	1	0.06	0.04
15:23	F35	An	0.190	0.114	16	13	15	14.7	5	2.93	2	0.35	5	0.11	0.04

NB: (i) Locations; flow measuring points were on canal off takes unless specified, e.g. D2(F21/F22) imply that the flow measurement was undertaken on canal D2 between the off-takes to canals F21 and F22.

(ii) Symbols: d = flow depth (m)

n'= mean rotation speed (revs/t secs)

t =observation period (secs)

n = rotation speed (revs/s)

Rate Eqn = rate equation

v = velocity (m/s)

A = flow area (m^2)

Q = flow rate (m^3/s)

(iii) Sample calculation:

Consider readings taken at 09:27 in canal F35 in Sub-block An

d=0.14, counts per 10 second interval were 9,10 & 11. Then, n'=10 revs/10sec and n=1.0 rev/secs. The velocity rate equation to use is No.1 i.e. V=0.034+0.0991 x 1.0=0.13 m/s.

The canal area code is 5 and flow depth, d=0.14m. Therefore, Flow area.

$A= 0.50 \times 0.14 + 0.532 \times 0.14^2 m^2 = 0.08\ m^2$

Therefore, $Q=V \times A = 0.13\ m/s \times 0.08 m^2 = 0.01 m^3/s$

Appendix 5 (continued).

Turn 1

Day 2: 06/12/96

Time	Measuring	Sub-	d	0.6 d	Rotation speed (rev/t)				t	n	Rate	V	Canal	A	Q
	position	block	(m)	(m)	n1	n1	n3	n'	s	Rev/s	eqn	m/s	code	m^2	m^3/s
07:30	F35	An	0.12	0.07	7	9	8	8.0	5	1.60	2	0.20	5	0.07	0.014
07:35	D2	An	0.13	0.08	13	12	13	12.7	5	2.53	2	0.30	2	0.05	0.015
08:40	F2	An	0.19	0.11	14	16	17	15.7	10	1.57	2	0.20	1	0.06	0.012
08:48	F4	An	0.13	0.08	38	36	37	37.0	10	3.70	2	0.43	1	0.04	0.018
08.:52	F5	An	0.20	0.12	23	26	26	25.0	10	2.50	2	0.30	1	0.07	0.021
08:57	F6	An	0.18	0.11	20	20	18	19.3	10	1.93	2	0.24	1	0.06	0.015
09:02	F6(Main)	An	0.21	0.13	26	19	21	22.0	5	4.40	2	0.51	1	0.08	0.038
09:07	F7	An	0.23	0.14	9	8	9	8.7	5	1.73	2	0.22	1	0.09	0.018
09:15	F8	An	0.14	0.08	24	23	24	23.7	5	4.73	3	0.55	1	0.04	0.023
09:46	F9(Main)	An	0.38	0.23	5	4	5	4.7	5	0.93	1	0.13	1	0.17	0.022
09:48	F20	An	0.12	0.07	23	24	25	24.0	5	4.80	3	0.55	1	0.04	0.020
10:13	F19	An	0.10	0.06	13	15	15	14.3	5	2.87	2	0.34	1	0.03	0.009
10:18	D2	An	0.18	0.11	18	18	19	18.3	5	3.67	2	0.43	1	0.06	0.025
10:24	D1	An	0.29	0.17	23	24	22	23.0	5	4.60	2	0.53	4	0.17	0.090
10:27	F35	An	0.15	0.09	8	9	10	9.0	5	1.80	2	0.22	5	0.09	0.019
10:35	D2	An	0.23	0.14	23	23	23	23.0	5	4.60	3	0.53	2	0.01	0.051
10:39	D1	An	0.30	0.18	30	29	29	29.3	5	5.87	3	0.67	4	0.16	0.107
14:02	F19	An	0.11	0.07	31	30	28	29.7	5	5.93	3	0.67	1	0.03	0.022
14:14	F20	An	0.14	0.08	28	28	29	28.3	5	5.67	3	0.65	1	0.05	0.029
14:16	F4	An	0.21	0.13	14	14	13	13.7	5	2.73	2	0.33	1	0.08	0.024
14:22	F2	An	0.18	0.11	17	17	17	17.0	5	3.40	2	0.40	1	0.06	0.024
14:24	F5	An	0.19	0.11	14	17	17	16.0	5	3.20	2	0.38	1	0.07	0.025
14:28	F6	An	0.17	0.10	11	10	11	10.7	5	2.13	2	0.26	1	0.06	0.014
14:31	F7	An	0.21	0.13	10	10	9	9.7	5	1.93	2	0.24	1	0.08	0.018
14:42	F8	An	0.11	0.06	21	21	21	21.0	5	4.20	2	0.49	1	0.03	0.015
14:49	F9	An	0.23	0.14	13	12	13	12.7	5	2.53	2	0.30	1	0.08	0.025

Appendix 5 (continued)
Turn 1
Day 3: 07/12/96

Time	Measuring position	sub-block	d (m)	0.6d (m)	Rotn rate n1	n2	n3	rev/t n'	t s	n Rev/s	Rate eqn	V (m/s)	Canal code	A m^2	Q m^3/s
07:58	DF1	Am	0.16	0.096	27	26	27	26.7	5	5.333	3	0.610	1	0.053	0.032
08:31	F24	Am	0.165	0.099	9	9	8	8.7	5	1.733	2	0.215	2	0.065	0.014
08:37	F24(mn)	Am	0.18	0.108	6	6	6	6.0	5	1.200	2	0.156	1	0.061	0.010
08:47	D^{F1}|F^{11}/F^{12}	Am	0.19	0.114	17	18	17	17.3	5	3.467	2	0.406	5	0.114	0.046
08:49	F12	Am	0.255	0.153	14	14	15	14.3	5	2.867	2	0.340	2	0.113	0.038
09:12	DF2(CNR)	Am	0.14	0.084	15	15	16	15.3	5	3.067	2	0.362	1	0.045	0.016
09:14	F13	Am	0.16	0.096	22	21	19	20.7	5	4.133	2	0.480	2	0.063	0.030
09:18	F15	Am	0.19	0.114	10	11	10	10.3	5	2.067	2	0.251	1	0.066	0.017
09:23	F17	Am	0.17	0.102	6	4	4	4.7	5	0.933	1	0.126	1	0.057	0.007
09:28	D4 (27/F28	Am	0.11	0.066	24	23	23	23.3	5	4.667	2	0.539	1	0.033	0.018
09:30	F28	Am	0.11	0.066	16	16	16	16.0	5	3.200	2	0.377	1	0.033	0.012
09:48	D4(F2/F27	Am	0.25	0.15	30	29	29	29.3	5	5.867	3	0.667	1	0.096	0.064
09:58	F27	Am	0.19	0.114	22	22	22	22.0	5	4.400	2	0.509	1	0.066	0.034
10:03	DF2 O.TK)	Am	0.28	0.168	10	12	13	11.7	5	2.333	2	0.281	1	0.112	0.031
10:15	DF2(mdl)	Am	0.17	0.102	27	26	28	27.0	5	5.400	3	0.617	3	0.133	0.082
10:20	F32	Am	0.13	0.078	25	25	25	25.0	5	5.000	3	0.575	1	0.041	0.023
10:26	D5(F32/33	Am	0.15	0.09	24	24	24	24.0	5	4.800	3	0.553	1	0.049	0.027
10:29	D5(C.CNL)	Am	0.27	0.162	34	33	34	33.7	5	6.733	3	0.760	1	0.106	0.081
10:33	F33	Am	0.22	0.132	20	18	18	18.7	5	3.733	2	0.436	1	0.080	0.035
14:01	D5	Am	0.22	0.132	37	39	39	38.3	5	7.667	3	0.860	1	0.080	0.069
14:04	F33	Am	0.15	0.09	23	25	26	24.7	5	4.933	3	0.567	1	0.049	0.028
14:07	D5|F32/33	Am	0.17	0.102	28	29	30	29.0	5	5.800	3	0.660	1	0.057	0.038
14:11	D5| F31/32	Am	0.14	0.084	42	43	40	41.7	5	8.333	3	0.932	1	0.045	0.041
14:14	F31	Am	0.135	0.081	26	26	23	25.0	5	5.000	3	0.575	1	0.043	0.024
14:26	F28	Am	0.15	0.09	22	22	22	22.0	5	4.400	2	0.509	1	0.049	0.025
14:29	F27	Am	0.2	0.12	25	25	25	25.0	5	5.000	3	0.575	1	0.071	0.041
14:32	D4|D^{F2}/F27	Am	0.21	0.126	31	31	30	30.7	5	6.133	3	0.696	2	0.088	0.061
14:38	DF2 (o.tk)	Am	0.32	0.192	10	11	11	10.7	5	2.133	2	0.259	3	0.278	0.072
14:42	DF2 (mdl)	Am	0.145	0.087	30	30	31	30.3	5	6.067	3	0.689	3	0.112	0.077
14:46	DF4	Am	0.19	0.114	31	31	33	31.7	5	6.333	3	0.717	1	0.066	0.047
15:07	F15	Am	0.16	0.096	12	12	13	12.3	5	2.467	2	0.296	1	0.053	0.016
15:11	F13	Am	0.13	0.078	11	12	11	11.3	5	2.267	2	0.273	1	0.041	0.011
15:17	DF2 (cnr)	Am	0.25	0.15	18	18	18	18.0	5	3.600	2	0.421	2	0.110	0.046
15:20	F12	Am	0.085	0.051	13	14	14	13.7	5	2.733	2	0.325	1	0.024	0.008
15:25	F11	Am	0.125	0.075	6	5	5	5.3	5	1.067	2	0.141	1	0.039	0.005
15:29	DF1 (o.tk)	Am	0.22	0.132	21	20	19	20.0	5	4.000	2	0.465	2	0.093	0.043
15:59	F24	Am	0.135	0.081	20	20	21	20.3	5	4.067	2	0.472	1	0.043	0.020

Appendix 5 (continued)
Turn 1
Day 4: 08/12/96

Time	Measuring position	sub-block	d (m)	0.6d (m)	Rotation speed (revs/t) n1	n1	n3	n'	t s	N Rev/s	Rate eqn	V (m/s)	Canal code	A m^2	Q m^3/s
08:01	DF1 (O.TK)	Am	0.19	0.114	24	25	23	24.0	5	4.800	3	0.553	2	0.078	0.043
08:08	F25	Am	0.225	0.135	20	18	18	18.7	5	3.733	2	0.436	1	0.083	0.036
08:19	DF1/DF4	Am	0.285	0.171	28	27	25	26.7	5	5.333	3	0.610	5	0.186	0.113
08:25	DF1(aft.1ab	Am	0.25	0.15	12	14	14	13.3	5	2.667	2	0.318	2	0.110	0.035
08:41	DF^1(af.2abs	Am	0.22	0.132	10	10	10	10.0	5	2.000	2	0.244	5	0.136	0.033
08:45	DF^1(af.3abs	Am	0.16	0.096	15	14	16	15.0	5	3.000	2	0.355	1	0.053	0.019
08:54	F12	Am	0.19	0.114	12	11	13	12.0	5	2.400	2	0.288	2	0.078	0.022
09:14	DF2/F27	Am	0.25	0.15	30	31	30	30.3	5	6.067	3	0.689	2	0.110	0.076
09:17	DF2(of.tk)	Am	0.19	0.114	29	29	30	29.3	5	5.867	3	0.667	3	0.151	0.101
09:22	D^{F2}(aft.1abs	Am	0.18	0.108	24	27	27	26.0	5	5.200	3	0.596	3	0.142	0.085
09:30	DF2(cnr)	Am	0.2	0.12	16	16	17	16.3	5	3.267	2	0.384	3	0.160	0.061
09:36	F14	Am	0.16	0.096	16	16	16	16.0	5	3.200	2	0.377	1	0.053	0.020
09:39	F15	Am	0.18	0.108	14	13	14	13.7	5	2.733	2	0.325	1	0.061	0.020
09:45	F17	Am	0.105	0.063	9	9	9	9.0	5	1.800	2	0.222	1	0.031	0.007
09:48	F18(O.TK)	Am	0.21	0.126	9	9	9	9.0	5	1.800	2	0.222	1	0.075	0.017
09:51	F29	Am	0.205	0.123	12	13	12	12.3	5	2.467	2	0.296	1	0.073	0.022
10:00	F18(br.)	Am	0.24	0.144	7	7	6	6.7	5	1.333	2	0.170	1	0.090	0.015
10:14	F33	Am	0.155	0.093	29	29	29	29.0	5	5.800	3	0.660	1	0.051	0.033
10:19	D5(C.cnl)	Am	0.23	0.138	34	33	34	33.7	5	6.733	3	0.760	1	0.085	0.065
10:29	F32	Am	0.16	0.096	33	34	34	33.7	5	6.733	3	0.760	1	0.053	0.040
10:34	F30(o.tk)	Am	0.13	0.078	24	23	22	23.0	5	4.600	2	0.531	1	0.041	0.022
10:36	F30(aft.br.)	Am	0.075	0.045	15	16	16	15.7	5	3.133	2	0.369	1	0.021	0.008
10:46	F30^{branch}	Am	0.095	0.057	28	29	28	28.3	5	5.667	3	0.646	1	0.028	0.018
10:49	F27	Am	0.13	0.078	18	17	17	17.3	5	3.467	2	0.406	1	0.041	0.016

Appendix 5 (continued)
Turn 2
Day 1: 17/12/96

Time	Measuring position	sub block	d (m)	0.6d (m)	Rotation speed (rev/t)				t	n	Rate	V	Canal	A	Q
					n1	n1	n3	n'	s	Rev/s	eqn	m/s	code	m^2	m^3/s
10:06	F35	An	0.11	0.066	9	9	9	9.0	5	1.800	2	0.222	5	0.061	0.014
10:24	FY(OF.TK)	A1	0.18	0.108	25	26	27	26.0	5	5.200	3	0.596	1	0.061	0.037
10:26	FY(1ab.)	A1	0.15	0.090	36	35	35	35.3	5	7.067	3	0.796	1	0.049	0.039
10:46	DF3	A1	0.17	0.102	26	26	25	25.7	5	5.133	3	0.589	1	0.057	0.034
10:54	DF5	An	0.195	0.117	27	29	28	28.0	5	5.600	3	0.639	1	0.068	0.044
10:58	DF5(1ab)	An	0.17	0.102	24	26	27	25.7	5	5.133	3	0.589	1	0.057	0.034
11:02	F19	An	0.13	0.078	29	30	29	29.3	5	5.867	3	0.667	1	0.041	0.027
11:04	D2:D^{F5}/F19	An	0.24	0.144	33	30	32	31.7	5	6.333	3	0.717	2	0.104	0.075
11:09	D2:F19/20	An	0.26	0.156	20	21	23	21.3	5	4.267	3	0.494	2	0.116	0.057
11:11	F20	An	0.125	0.075	24	24	23	23.7	5	4.733	3	0.546	1	0.039	0.021
11:14	F21	An	0.2	0.120	21	21	20	20.7	5	4.133	2	0.480	1	0.071	0.034
11:18	F23	An	0.16	0.096	9	10	10	9.7	5	1.933	2	0.237	1	0.053	0.012
15:24	DF3(of.tk)	A1	0.24	0.144	29	27	27	27.7	5	5.533	3	0.632	2	0.104	0.066
15:34	DF3 (end))	A1	0.18	0.108	27	27	28	27.3	5	5.467	3	0.624	2	0.073	0.045
15:40	FY	A1	0.2	0.120	38	36	38	37.3	5	7.467	3	0.839	1	0.071	0.059
15:53	F35	An	0.11	0.066	11	10	11	10.7	5	2.133	2	0.259	5	0.061	0.016
15:58	D^{F5}(af.1abs.	An	0.18	0.108	37	36	36	36.3	5	7.267	3	0.817	1	0.061	0.050
16:04	D^{F5}(af.2abs.	An	0.12	0.072	17	20	18	18.3	5	3.667	2	0.428	1	0.037	0.016
16:08	F19	An	0.1	0.060	29	29	28	28.7	5	5.733	3	0.653	1	0.030	0.019
16:14	D2|F19/D^{F5}	An	0.21	0.126	39	38	38	38.3	5	7.667	3	0.860	2	0.088	0.076
16:23	F20	An	0.13	0.078	21	21	20	20.7	5	4.133	2	0.480	1	0.041	0.019
16:26	F21	An	0.14	0.084	21	21	21	21.0	5	4.200	2	0.487	1	0.045	0.022
16:29	F22	An	0.195	0.117	5	3	4	4.0	5	0.800	1	0.111	1	0.068	0.008
16:35	F23	An	0.175	0.105	17	17	18	17.3	5	3.467	2	0.406	1	0.059	0.024

Appendix 5 (continued)
Turn 2
Day 2: 18/12/96

Time	Measuring position	Sub block	d (m)	0.6d (m)	Rotation speed (revs/t)				t	n	Rate	V	Canal	A	Q
					nl	nl	n3	n'	s	Rev/s	eqn	m/s	code	m^2	m^3/s
08:03	F35	An	0.1	0.060	12	12	12	12.0	5	2.400	2	0.288	5	0.055	0.016
08:07	DF3	Al	0.13	0.078	26	26	28	26.7	5	5.333	3	0.610	1	0.041	0.025
08:09	FY	Al	0.08	0.048	9	9	9	9.0	5	1.800	2	0.222	1	0.023	0.005
08:20	FO	Al	0.185	0.111	25	27	28	26.7	5	5.333	3	0.610	1	0.064	0.039
08:25	D1	An	0.37	0.222	11	12	12	11.7	5	2.333	2	0.281	4	0.336	0.094
08:29	D1(+F35)	An	0.38	0.228	22	21	20	21.0	5	4.200	2	0.487	4	0.347	0.169
08:46	D1(2 CNR)	An	0.37	0.222	32	31	32	31.7	5	6.333	3	0.717	4	0.336	0.241
08:50	F2	An	0.135	0.081	7	8	7	7.3	5	1.467	2	0.185	1	0.043	0.008
09:02	F4	An	0.13	0.078	15	14	12	13.7	5	2.733	2	0.325	1	0.041	0.013
09:12	F5	An	0.14	0.084	19	19	20	19.3	5	3.867	2	0.450	1	0.045	0.020
09:17	F6	An	0.15	0.090	1	1	1	1.0	5	0.200	1	0.054	1	0.049	0.003
09:25	F7	An	0.18	0.108	10	9	9	9.3	5	1.867	2	0.229	1	0.061	0.014
09:34	F8	An	0.13	0.078	22	25	25	24.0	5	4.800	3	0.553	1	0.041	0.022
15:09	F35	An	0.15	0.090	12	14	11	12.3	5	2.467	2	0.296	5	0.087	0.026
15:13	Fb	Al	0.11	0.066	28	28	28	28.0	5	5.600	3	0.639	1	0.033	0.021
15:17	DF3	Al	0.12	0.072	25	26	25	25.3	5	5.067	3	0.582	1	0.037	0.021
15:28	FY	Al	0.09	0.054	17	17	19	17.7	5	3.533	2	0.413	1	0.026	0.011
15:30	FO	Al	0.17	0.102	5	6	5	5.3	5	1.067	2	0.141	1	0.057	0.008
15:38	D1 (+F35)	An	0.335	0.201	24	21	22	22.3	5	4.467	2	0.517	4	0.298	0.154
15:42	D1 (cnr 2)	An	0.26	0.156	27	28	28	27.7	5	5.533	3	0.632	4	0.221	0.139
15:59	F2	An	0.16	0.096	13	14	14	13.7	5	2.733	2	0.325	1	0.053	0.017
16:04	F4	An	0.16	0.096	25	25	24	24.7	5	4.933	3	0.567	1	0.053	0.030
16:10	F5	An	0.14	0.084	24	24	24	24.0	5	4.800	3	0.553	1	0.045	0.025
16:15	F7	An	0.13	0.078	7	9	9	8.3	5	1.667	2	0.207	1	0.041	0.008
16:18	F8	An	0.11	0.066	15	15	15	15.0	5	3.000	2	0.355	1	0.033	0.012
16:22	F9	An	0.135	0.081	7	8	7	7.3	5	1.467	2	0.185	1	0.043	0.008

Appendix 5 (continued)
Turn 2
Day 3: 19/12/96

Time	Measuring	sub-	d	0.6d	Rotation speed			rev/t	t	n	Rate	V	Canal	A	Q
	position	block	(m)	(m)	n1	n1	n3	n'	s	Rev/s	eqn	m/s	code	m^2	m^3/s
08:23	D3|D^{F1}/DF4	Am	0.39	0.234	11	11	11	11.0	5	2.200	2	0.266	5	0.276	0.073
08:29	DF4 (of.tk)	Am	0.24	0.144	26	24	23	24.3	5	4.867	3	0.560	1	0.090	0.051
08:48	DF1 (of.tk)	Am	0.26	0.156	23	22	23	22.7	5	4.533	2	0.524	1	0.101	0.053
08:51	D3F24/F25	Am	0.155	0.093	11	11	10	10.7	5	2.133	2	0.259	5	0.090	0.023
08:55	F24	Am	0.15	0.090	12	11	11	11.3	5	2.267	2	0.273	1	0.049	0.013
09:06	DF1 (cnr)	Am	0.12	0.072	20	21	22	21.0	5	4.200	2	0.487	2	0.045	0.022
09:08	F11	Am	0.17	0.102	10	10	11	10.3	5	2.067	2	0.251	1	0.057	0.014
09:27	DF2 (cnr)	Am	0.11	0.066	23	21	21	21.7	5	4.333	2	0.502	3	0.083	0.041
09:30	F13	Am	0.125	0.075	9	10	10	9.7	5	1.933	2	0.237	1	0.039	0.009
09:35	F16	Am	0.19	0.114	9	8	9	8.7	5	1.733	2	0.215	1	0.066	0.014
09:38	F17	Am	0.12	0.072	11	11	11	11.0	5	2.200	2	0.266	1	0.037	0.010
09:44	F33	Am	0.18	0.108	12	12	12	12.0	5	2.400	2	0.288	1	0.061	0.018
09:47	D5(cnv.cnl)	Am	0.22	0.132	33	33	34	33.3	5	6.667	3	0.753	1	0.080	0.060
10:02	D5(F32/33)	Am	0.22	0.132	27	25	25	25.7	5	5.133	3	0.589	1	0.080	0.047
10:04	F32	Am	0.21	0.126	32	32	33	32.3	5	6.467	3	0.732	1	0.075	0.055
10:07	F29	Am	0.13	0.078	15	16	16	15.7	5	3.133	2	0.369	1	0.041	0.015
10:13	F28	Am	0.155	0.093	24	24	22	23.3	5	4.667	2	0.539	1	0.051	0.027
10:27	F27	Am	0.14	0.084	18	19	19	18.7	5	3.733	2	0.436	1	0.045	0.019
10:30	D4(D^{F2}/F^{27})	Am	0.27	0.162	26	25	25	25.3	5	5.067	3	0.582	2	0.122	0.071
10:37	DF2 (of.tk)	Am	0.22	0.132	29	31	29	29.7	5	5.933	3	0.674	3	0.179	0.120
14:23	D4(D^{F2}/F^{27})	Am	0.17	0.102	20	20	20	20.0	5	4.000	2	0.465	1	0.057	0.027
14:32	DF1 (of.tk)	Am	0.26	0.156	15	15	14	14.7	5	2.933	2	0.347	1	0.101	0.035
14:44	F11	Am	0.18	0.108	11	10	11	10.7	5	2.133	2	0.259	1	0.061	0.016
14:46	F14	Am	0.2	0.120	19	19	18	18.7	5	3.733	2	0.436	1	0.071	0.031
14:52	F16	Am	0.18	0.108	9	9	10	9.3	5	1.867	2	0.229	1	0.061	0.014
14:57	F17	Am	0.11	0.066	10	11	10	10.3	5	2.067	2	0.251	1	0.033	0.008
15:02	F33	Am	0.1	0.060	19	19	19	19.0	5	3.800	2	0.443	1	0.030	0.013
15:06	D5 (c.cnl)	Am	0.15	0.090	31	30	28	29.7	5	5.933	3	0.674	1	0.049	0.033
15:20	D5(F32/33)	Am	0.13	0.078	24	24	23	23.7	5	4.733	2	0.546	1	0.041	0.022
15:22	F32	Am	0.13	0.078	18	18	18	18.0	5	3.600	2	0.421	1	0.041	0.017
15:25	F29	Am	0.12	0.072	14	14	14	14.0	5	2.800	2	0.332	1	0.037	0.012
15:27	F28	Am	0.11	0.066	25	26	27	26.0	5	5.200	3	0.598	1	0.033	0.020
15:33	F27	Am	0.18	0.108	21	21	22	21.3	5	4.267	2	0.494	1	0.061	0.030
15:36	DF2 (of.tk)	Am	0.26	0.156	25	26	26	25.7	5	5.133	3	0.589	3	0.217	0.128
15:38	D4(D^{F2}/F^{27})	Am	0.14	0.084	26	26	25	25.7	5	5.133	3	0.589	2	0.053	0.031
15:40	D3(D^{F4}/D^{F1})	Am	0.38	0.228	13	12	13	12.7	5	2.533	2	0.303	5	0.267	0.081
14:46	DF4	Am	0.22	0.132	38	38	36	37.3	5	7.467	3	0.839	1	0.080	0.067

Appendix 5 (continued)
Turn 2
Day 4: 20/12/96

Time	Measuring position	sub block	d (m)	0.6d (m)	Rotation speed (revs/t) n1	n1	n3	n'	t s	n Rev/s	Rate eqn	V m/s	Canal code	A m^2	Q m^3/s
08:18	D3$^{(DF4/DF1)}$	Am	0.44	0.264	11	10	12	11.0	5	2.200	2	0.266	5	0.323	0.086
08:24	DF4	Am	0.22	0.132	36	37	37	36.7	5	7.333	3	0.824	1	0.080	0.066
08:31	DF2 (of.tk)	Am	0.28	0.168	30	31	30	30.3	5	6.067	3	0.689	3	0.237	0.163
08:33	D4(D^{F2}/F^{27})	Am	0.28	0.168	31	32	30	31.0	5	6.200	3	0.703	3	0.237	0.166
08:39	F27	Am	0.1	0.060	14	13	13	13.3	5	2.667	2	0.318	1	0.030	0.009
09:20	F28	Am	0.12	0.072	26	26	26	26.0	5	5.200	3	0.596	1	0.037	0.022
09:23	F30	Am	0.16	0.096	25	25	26	25.3	5	5.067	3	0.582	1	0.053	0.031
09:26	D5$^{(F32/F33)}$	Am	0.21	0.126	31	30	30	30.3	5	6.067	3	0.689	1	0.075	0.052
09:32	D5 (cv.cnl)	Am	0.26	0.156	34	36	35	35.0	5	7.000	3	0.789	1	0.101	0.080
09:38	F33	Am	0.18	0.108	27	27	27	27.0	5	5.400	3	0.617	1	0.061	0.038
09:41	F32	Am	0.19	0.114	28	28	28	28.0	5	5.600	3	0.639	1	0.066	0.042
09:43	F30$^{(aft\ br)}$	Am	0.14	0.084	25	24	24	24.3	5	4.867	3	0.560	1	0.045	0.025
09:49	F18 $^{(branch)}$	Am	0.33	0.198	11	12	12	11.7	5	2.333	2	0.281	1	0.141	0.040
09:54	F18 (of.tk)	Am	0.32	0.192	20	21	21	20.7	5	4.133	2	0.480	1	0.135	0.065
10:04	F16	Am	0.2	0.120	8	7	7	7.3	5	1.467	2	0.185	1	0.071	0.013
10:07	F14	Am	0.2	0.120	11	12	12	11.7	5	2.333	2	0.281	1	0.071	0.020
10:13	DF2(cnr)	Am	0.34	0.204	21	20	21	20.7	5	4.133	2	0.480	1	0.148	0.071
10:19	F11	Am	0.13	0.078	10	8	9	9.0	5	1.800	2	0.222	1	0.041	0.009
10:27	DF1 (cnr)	Am	0.07	0.042	21	19	19	19.7	5	3.933	2	0.458	2	0.024	0.011
10:32	DF1 (of.tk)	Am	0.21	0.126	20	21	21	20.7	5	4.133	2	0.480	1	0.075	0.036
10:34	F26	Am	0.14	0.084	19	19	21	19.7	5	3.933	2	0.458	1	0.045	0.020
10:39	F24	Am	0.16	0.096	19	20	20	19.7	5	3.933	2	0.458	1	0.053	0.024

Appendix 6 Results of flow measurement using structures in Block A: Nyanyadzi scheme

(i) **Structure 11**: Rectangular flume

Rate equation: $Q = (1.6+0.779h_1) \times (h_1-0.001)^{2/3}$

Where: Q =discharge (m^3/s); $h_1=U_{11}-0.174$ and U_{11} is the gauge height (m)

Readings at S11

date	time	U_{11} (m)	h_1 (m)	Q (m^3/s)	Q_{avg} (m^3/s)
07/12/96	07:58	0.275	0.101	0.362	0.453
07/12/96	14:46	0.350	0.176	0.544	
08/12/96	07:35	0.340	0.166	0.520	0.472
08/12/96	15:23	0.300	0.126	0.424	
19/12/96	08:29	0.320	0.146	0.473	0.497
19/12/96	15:50	0.340	0.166	0.520	
20/12/96	08:24	0.390	0.116	0.400	0.483
20/12/96	14:01	0.360	0.186	0.566	

Sample calculation:

consider readings taken on 08/12/96 at 07:35: U_{11}=0.34

Then, h1=0.34-0.174=0.166m

Therefore Q=(1.6+0.779 x 166) x (0.166-0.001)$^{2/3}$ m^3/s = 0.520 m^3/s

Appendix 6 (continued)

(ii) **Structure 26**: Lift gate

Rate equation: $Q=1.054 \times W \times (h_1-h_2)^{0.5}$

where: $h_1=U_{26}-0.149$

$h_2=D_{26}-0.0126$

U_{26} = upstream gauge height

D_{26} = downstream gauge height and W is gate opening

Readings at S26

Date	time	U_{26}	D_{26}	*W	h_1	h_2	Q (m^3/s)	Q_{avg} (m^3/s)
05/12/96	08:49	0.595	0.30	0.216	0.446	0.2874	0.091	0.1005
05/12/96	15:15	0.640	0.27	0.216	0.491	0.2574	0.110	
17/12/96	10:11	0.550	0.26	0.18	0.401	0.2474	0.069	0.063
17/12/96	15:13	0.520	0.28	0.168	0.371	0.2674	0.056	
18/12/96	08:07	0.700	0.40	0.120	0.551	0.3874	0.051	0.050
18/12/96	16:13	0.69	0.41	0.120	0.541	0.3974	0.048	

*The lift gate had the following characteristics: (i) Maximum gate opening (W_{max}) = 0.36m (ii) The gate had 15 holes and distance between the centre of consecutive holes = 0.024m

sample calculation:

consider readings taken on 05/12/96 at 08:49: $U_{26}=0.595$, $D_{26}=0.30$ and w=0.216

Then h1 = 0.595-0.149=0.446 and h2=0.30-0.0126 =0.2874

Therefore: $Q=1.054 \times 0.216 \times (0.446-0.2874)^{0.5}$ m^3/s =0.091 m^3/s

(iii) **Structure 27**: Lift gate

- the gate was identical to gate 26

Rate equation: $Q=1.745 \times W^{2/3} \times C$

where $C=0.2185+R(0.288-0.015R)$ and $R=(U_{26}-0.324) \times W^{-1}$

Readings at S27

Date	time	U_{26} (m)	W (m)	R	C	Q (m^3/s)	Q_{avg} (m^3/s)
05/12/96	09:00	0.595	0.288	0.941	0.476	0.362	0.378
05/12/96	15:20	0.640	0.288	1.097	0.516	0.393	
06/12/96	09:02	0.690	0.240	1.525	0.623	0.420	0.424
06/12/96	14:16	0.700	0.240	1.567	0.633	0.427	
17/12/96	10:13	0.550	0.216	1.046	0.503	0.316	0.305
17/12/96	15:58	0.520	0.216	0.907	0.467	0.294	
18/12/96	08:09	0.700	0.192	1.958	0.724	0.421	0.418
18/12/96	15:17	0.690	0.192	1.906	0.713	0.414	

Sample calculation:

consider readings taken on 05/12/96 at 09:00: $U_{26}=0.595$, and w=0.288

Then R=(0.595-0.324)/0.288 = 0.941 and C= 0.2185 + 0.941(0.288-0.015 x .941) =0.476

Therefore $Q=1.745 \times 0.288^{2/3} \times 0.476 = 0.362$ m^3/s

Appendix 7 Average K_c values of crops grown in the study areas

Crop	Stage	Days in stage	K_c value
Maize	Initial	25	0.40
	development	40	0.80
	mid season	40	1.15
	late season	20	0.85
Bean	Initial	15	0.35
	development	20	0.75
	mid season	40	1.13
	late season	25	0.70
Cabbage	Initial	25	0.45
	development	35	0.75
	mid season	25	1.03
	late season	15	0.95
Tomato	Initial	35	0.45
	development	40	0.75
	mid season	50	1.15
	late season	25	0.80
Potato	Initial	25	0.45
	development	35	0.75
	mid season	45	1.13
	late season	30	0.90

Source: FAO,(1977)

Appendix 8 Planting dates and developmental stages of the maize crops in block A

Maize crop	%cropped area	Growth stage	Days in stage	Dates	K_c
1	25	Planting	-	15/10/96	-
		initial	25	16/10/96-10/11/96	0.40
		development	40	11/11/96-21/12/96	0.80
		mid-season	45	22/12/96-05/02/97	1.15
-		late season	30	06/02/97-07/03/97	0.85
2	50	Planting	-	07/11/96	-
		initial	25	08/11/96-02/12/96	0.40
		development	40	03/12/96-12/01/97	0.80
		mid-season	45	13/01/96-27/02/97	1.15
		late season	30	27/2/97-29/3/97	0.85

Source: AGRITEX, (1996) and FAO, (1977)

Appendix 9 Daily Rainfall and Pan evaporation at Nyanyadzi: OCT'96 TO JAN'97

Pan evaporation (mm)				Rainfall (mm)			
Date	Oct-96	Nov-96	Dec-96	Oct-96	Nov-96	Dec-96	Jan-97
1	-	7.90	2.90	0.00	0.00	0.00	0.00
2	-	9.60	8.80	0.00	0.00	0.00	0.00
3	-	10.10	11.40	0.00	0.00	7.00	0.00
4	-	12.00	3.60	0.00	0.00	0.00	0.00
5	-	13.30	5.50	0.00	0.00	0.00	0.00
6	-	2.30	5.90	0.00	37.50	0.00	23.00
7	-	1.80	6.00	0.00	0.00	0.00	13.00
8	-	3.90	7.50	0.00	0.00	0.00	0.00
9	-	4.60	7.60	0.00	0.00	0.00	0.00
10	7.80	5.90	9.90	0.00	0.00	4.00	0.00
11	8.40	7.80	4.50	0.00	0.00	0.00	0.00
12	9.50	9.60	7.90	0.00	0.00	0.00	0.00
13	10.30	10.80	12.00	0.00	0.00	0.00	6.00
14	11.20	11.20	9.20	0.00	0.00	0.00	0.00
15	9.90	11.40	11.30	0.00	0.00	0.00	52.00
16	9.70	13.10	11.10	0.00	0.00	0.00	0.00
17	8.50	13.50	9.90	0.00	0.00	0.00	0.00
18	8.30	1.00	10.70	0.00	55.10	0.00	0.00
19	7.80	1.00	11.20	0.00	0.00	0.00	0.00
20	8.80	1.00	12.10	0.00	58.00	0.00	38.00
21	10.20	2.30	10.80	0.00	0.00	0.00	0.00
22	11.10	0.30	12.60	0.00	11.50	0.00	0.00
23	10.60	1.80	13.10	0.00	0.00	0.00	0.00
24	10.30	3.90	7.90	0.00	0.00	18.00	11.00
25	9.80	4.60	10.20	0.00	0.00	0.00	0.00
26	10.00	5.50	11.00	0.00	4.00	0.00	0.00
27	10.50	3.50	12.10	0.00	0.00	0.00	16.00
28	9.60	3.50	12.40	0.00	0.00	0.00	8.00
29	9.30	3.40	2.70	0.00	0.00	106.00	0.00
30	8.20	2.10	0.20	0.00	0.00	0.00	0.00
31	8.00		1.70	0.00	0.00	0.00	0.00

Appendix 10 Crop water requirements for summer maize crops Nyanyadzi irrigation scheme

Maize 1 (Planted on 15/10/96)

Date	*Et_o (mm)			K_c			**Et_c, (mm)		
	Oct	Nov	Dec	Oct	Nov	Dec	Oct	Nov	Dec
1		5.5	2		0.4	0.8		2.2	1.6
2		6.7	6.2		0.4	0.8		2.68	4.96
3		7.1	8		0.4	0.8		2.84	6.4
4		8.4	2.5		0.4	0.8		3.36	2
5		9.3	3.9		0.4	0.8		3.72	3.12
6		1.6	4		0.4	0.8		0.64	3.2
7		1.3	4.2		0.4	0.8		0.52	3.36
8		2.7	5.3		0.4	0.8		1.08	4.24
9		3.2	5.3		0.4	0.8		1.28	4.24
10		4.1	6.9		0.4	0.8		1.64	5.52
11		5.5	3.2		0.8	0.8		4.4	2.56
12		6.7	5.5		0.8	0.8		5.36	4.4
13		7.6	8.4		0.8	0.8		6.08	6.72
14		7.8	6.4		0.8	0.8		6.24	5.12
15		8	7.9		0.8	0.8		6.4	6.32
16	6.8	9.2	7.8	0.4	0.8	0.8	2.72	7.36	6.24
17	6	9.5	6.9	0.4	0.8	0.8	2.4	7.6	5.52
18	5.8	0.7	7.5	0.4	0.8	0.8	2.32	0.56	6
19	5.5	0.7	7.8	0.4	0.8	0.8	2.2	0.56	6.24
20	6.2	0.7	8.5	0.4	0.8	0.8	2.48	0.56	6.8
21	7.1	1.6	7.6	0.4	0.8	0.8	2.84	1.28	6.08
22	7.8	0.2	8.8	0.4	0.8	1.15	3.12	0.16	10.12
23	7.4	1.3	9.2	0.4	0.8	1.15	2.96	1.04	10.58
24	7.2	2.7	5.5	0.4	0.8	1.15	2.88	2.16	6.325
25	6.9	3.2	7.1	0.4	0.8	1.15	2.76	2.56	8.165
26	7	3.9	7.7	0.4	0.8	1.15	2.8	3.12	8.855
27	7.4	2.5	8.5	0.4	0.8	1.15	2.96	2	9.775
28	6.7	2.5	8.7	0.4	0.8	1.15	2.68	2	10.005
29	6.5	2.4	1.9	0.4	0.8	1.15	2.6	1.92	2.185
30	5.7	1.5	0.1	0.4	0.8	1.15	2.28	1.2	0.115
31	5.6		1.2	0.4	0.8	1.15	2.24		1.38

*Et_o = Kpan x Epan and Kpan = 0.7

** Et_c= Kc x Eto

Appendix 10: (Cont.) Maize 2 (Planted on 7/11/96)

Date	Et_o (mm)		K_c		Et_c (mm)	
	Nov'96	Dec'96	Nov'96	Dec'96	Nov'96	Dec'96
1	5.5	2		0.4		0.8
2	6.7	6.2		0.4		2.48
3	7.1	8		0.8		6.4
4	8.4	2.5		0.8		2
5	9.3	3.9		0.8		3.12
6	1.6	4		0.8		3.2
7	1.3	4.2		0.8		3.36
8	2.7	5.3	0.4	0.8	1.08	4.24
9	3.2	5.3	0.4	0.8	1.28	4.24
10	4.1	6.9	0.4	0.8	1.64	5.52
11	5.5	3.2	0.4	0.8	2.2	2.56
12	6.7	5.5	0.4	0.8	2.68	4.4
13	7.6	8.4	0.4	0.8	3.04	6.72
14	7.8	6.4	0.4	0.8	3.12	5.12
15	8	7.9	0.4	0.8	3.2	6.32
16	9.2	7.8	0.4	0.8	3.68	6.24
17	9.5	6.9	0.4	0.8	3.8	5.52
18	0.7	7.5	0.4	0.8	0.28	6
19	0.7	7.8	0.4	0.8	0.28	6.24
20	0.7	8.5	0.4	0.8	0.28	6.8
21	1.6	7.6	0.4	0.8	0.64	6.08
22	0.2	8.8	0.4	0.8	0.08	7.04
23	1.3	9.2	0.4	0.8	0.52	7.36
24	2.7	5.5	0.4	0.8	1.08	4.4
25	3.2	7.1	0.4	0.8	1.28	5.68
26	3.9	7.7	0.4	0.8	1.56	6.16
27	2.5	8.5	0.4	0.8	1	6.8
28	2.5	8.7	0.4	0.8	1	6.96
29	2.4	1.9	0.4	0.8	0.96	1.52
30	1.5	0.1	0.4	0.8	0.6	0.08
31		1.2		0.8	0	0.96

Appendix 11 Calculated canal command areas and plot holders in Block A (Nyanyadzi, 1996)

Sub-Block	DistributionCanal	Feeder Canal	Area m²	Plot holders
A1	D6	Fa	31300	4
		Fb	27300	3
		Fy	27300	3
		Fo	27300	3
		D/F3	27300	3
		D.C total	140500	16
	DF3	D/F3	27300	3
		F34	11700	1
		D.C total	39000	4
SUB-BLOCK TOTAL			15300	17
An	D1	F1	7800	1
		F2	16300	2
		F3	16300	2
		F4	16300	2
		F5	16300	2
		F6	16300	2
		F7	16300	2
		F8	41000	4
		F9	35200	3
		F10	33800	3
		total	215600	23
	F35	F35	11700	1
	DF5	D/F5	50800	5
	D2	F19	28100	3
		F20	28100	3
		F21	45900	5
		F22	13100	1
		F23	29500	3
		total	144700	15
SUB-BLOCK TOTAL			422800	45

Appendix 11 (cont)

Sub-Block	Distribution canal	Feeder Canal	Area m^2	Holders
Am	D3	F24	49700	5
		F25	49700	5
		F26	49700	5
		DF1	113300	12
		total	262400	27
	DF1	(D)F1	64700	8
		F11	24300	2
		F12	24300	2
		total	113300	12
	DF4	DF4	59200	4
	DF2	(D)F2	16300	6
		F13	16300	2
		F14	16300	2
		F15	16300	2
		F16	16300	2
		F17	16300	2
		F18	23400	2
		total	164100	18
	D4	F27	29500	3
		F28	29500	3
		F29	29500	3
		F30	59100	7
		total	147600	16
SUB-BLOCK TOTAL			613200	65
As	D5	F31	11400	1
		F32	41400	4
		F33	7800	1
		total	60600	6
SUB-BLOCK TOTAL			60600	6
GRAND TOTAL			1248900	132

Appendix 12 Computation of Adequacy and Equity of water distribution in A block

Turn: 1 IR (M1)= 21.6 mm
Day 1:05/12/96 IR (M1)= 11.0 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume m^3	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL		
D6(S26)	A1	68850	76150	1487.2	837.7	2324.8	3618	1.56
D6(S27)	An	251100	287550	5423.8	3163.1	8586.8	13608	1.58
FY	A1	4050	5850	87.5	64.4	151.8	918	6.05
D2\near d.	An	60750	72350	1312.2	795.9	2108.1	4878	2.31
DF5	An	20250	25400	437.4	279.4	716.8	2358	3.29
D2/F20/21	An	36450	44250	787.3	486.8	1274.1	3960	3.11
F21	An	20250	22950	437.4	252.5	689.9	1998	2.90
D2F21/22	An	16200	21300	349.9	234.3	584.2	1494	2.56
F23	An	12150	14750	262.4	162.3	424.7	1332	3.14
Fa	A1	16200	15650	349.9	172.2	522.1	414	0.79
Fb	A1	12150	13650	262.4	150.2	412.6	1368	3.32
DF3	A1	12150	13650	262.4	150.2	412.6	1224	2.97
							Mad	2.80
							S.Ad	1.30
							CoV	0.45

Turn 1 IR (maize 1) = 24.8 mm
Day 2: 06/12/96 IR (maize 2) = 14.4 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume m^3	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL		
D6(S27)	An	182250	211400	4519.8	3044.2	7563.96	15264	2.02
F35	An	4050	5850	100.4	84.2	184.68	612	3.31
D2	An	60750	72350	1506.6	1041.8	2548.44	1188	0.47
F2	An	8100	8100	200.9	116.6	317.52	648	2.04
F4	An	8100	8100	200.9	116.6	317.52	756	2.38
F5	An	8100	8100	200.9	116.6	317.52	828	2.61
F6	An	8100	8100	200.9	116.6	317.52	540	1.70
F7	An	8100	8100	200.9	116.6	317.52	648	2.04
F8	An	16200	20500	401.8	295.2	696.96	684	0.98
F9	An	12150	17600	301.3	253.4	554.76	828	1.49
F10	An	12150	14050	301.3	202.3	503.64	700	1.39
F19	An	12150	14050	301.3	202.3	503.64	2016	4.00
D1	An	93150	107800	2310.1	1552.3	3862.44	5364	1.39
							Mad	1.99
							CoV	0.46

Turn 1 IR (maize 1) = 28.2 mm
Day 3: 07/12/96 IR (maize 2) = 18.6 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume m^3	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL		
Weir	Am	117400	156500	3310.7	2910.9	6221.58	16308	2.62
DF4	Am	16200	19550	456.8	363.6	820.47	1138	1.39
DF1	Am	20250	28300	571.1	526.4	1097.43	1458	1.33
F24	Am	20250	24850	571.1	462.2	1033.26	576	0.56
D3t	Am	20250	24850	571.1	462.2	1033.26	612	0.59
DF1|F11/1	Am	8100	12150	228.4	226.0	454.41	816	1.80
F12	Am	8100	12150	228.4	226.0	454.41	738	1.62
DF2 l.c	Am	24260	24680	684.1	459.0	1143.18	1170	1.02
F13	Am	8100	8200	228.4	152.5	380.94	648	1.70
F15	Am	8100	8200	228.4	152.5	380.94	594	1.56
F17	Am	8100	8200	228.4	152.5	380.94	144	0.38
D4|F27/28	Am	12150	14750	342.6	274.4	616.98	688	1.12
F28	Am	12150	14750	342.6	274.4	616.98	666	1.08
D4	Am	24300	29500	685.3	548.7	1233.96	2250	1.82
F27	Am	12150	14750	342.6	274.4	616.98	1314	2.13
DF2	Am	36400	54300	1026.5	1010.0	2036.46	1188	0.58
F32	Am	16200	20700	456.8	385.0	841.86	846	1.00
D5|F32/33	Am	20250	26400	571.1	491.0	1062.09	1170	1.10
D5|m.c	Am	24300	30300	685.3	563.6	1248.84	2682	2.15
F33	Am	4050	3750	114.2	69.8	183.96	1134	6.16
							Mad	1.59
							CoV	0.76

Appendix12 (continued)
Turn 1 IR (maize 1) = 32.4 mm
Day 4: 08/12/96 IR (maize 2) = 22.8 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL	m3	
Weir	Am	157930	182890	5116.9	4169.9	9286.8	16992	1.83
D3	Am	44500	53200	1441.8	1213.0	2654.8	3024	1.14
DF1	Am	24300	28300	787.3	645.2	1432.6	1548	1.08
F25	Am	20250	24850	656.1	566.6	1222.7	1296	1.06
F12	Am	8100	12150	262.4	277.0	539.5	792	1.47
D4|Df2/F1	Am	52690	59040	1707.2	1346.1	3053.3	2736	0.90
DF2	Am	44510	51100	1442.1	1165.1	2607.2	3636	1.39
F14	Am	8100	8200	262.4	187.0	449.4	720	1.60
F15	Am	8100	8200	262.4	187.0	449.4	720	1.60
F17	Am	8100	8200	262.4	187.0	449.4	252	0.56
F18	Am	8100	8200	262.4	187.0	449.4	612	1.36
F29	Am	12150	14750	393.7	336.3	730.0	792	1.08
D5|c.cnl	Am	24300	30300	787.3	690.8	1478.2	2700	1.83
F32	Am	16200	20700	524.9	472.0	996.8	1440	1.44
F30	Am	28350	29550	918.5	673.7	1592.3	792	0.50
F27	Am	12150	14750	393.7	336.3	730.0	576	0.79
DF4	Am	16200	19550	524.9	445.7	970.6	866	0.89
							Mad	1.21
							CoV	0.32

Appendix 12 (cont.)
Turn 2 IR (maize 1) = 47.8 mm
Day 1: 17/12/96 IR (maize 2) = 47.8 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL	m3	
F35	An	4050	5850	193.6	279.6	473	540	1.14
D6 (S27)	An	97300	127010	4650.9	6071.1	10722	10980	1.02
D6 (S26)	A1	12150	19500	580.8	932.1	1513	2268	1.50
DF3	A1	12150	19500	580.8	932.1	1513	1332	0.88
F34	A1	8100	7650	387.2	365.7	753	440	0.58
DF5	An	20250	25400	968.0	1214.1	2182	1692	0.78
F19	An	12150	14750	580.8	705.1	1286	828	0.64
D2|DF5/f1	An	60840	76260	2908.2	3645.2	6553	2736	0.42
D2|F20/21	An	36460	46760	1742.8	2235.1	3978	2052	0.52
F20	An	12150	14750	580.8	705.1	1286	720	0.56
F21	An	20250	22950	968.0	1097.0	2065	1008	0.49
F22	An	4050	9050	193.6	432.6	626	648	1.03
F23	An	12150	14750	580.8	705.1	1286	108	0.08
							Mad	0.74
							S.Ad	0.37
							CoV	0.48

Turn 2 IR (maize 1) = 50.1 mm
Day 2: 18/12/96 IR (maize 2) = 50.1 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL	m3	
F35	An	4050	5850	202.91	293.085	495.99	756	1.52
D6	A1	36470	40960	1827.15	2052.096	3879.243	1930	0.50
D6	An	93300	129400	4674.33	6482.94	11157.27	7250	0.65
DF3	An	12150	13650	608.72	683.865	1292.58	720	0.56
FY	An	12150	13650	608.72	683.865	1292.58	288	0.22
FO	An	12150	13650	608.72	683.865	1292.58	828	0.64
D1	An	52800	82600	2645.28	4138.26	6783.54	4572	0.67
D1+F35	An	52800	82600	2645.28	4138.26	6783.54	5292	0.78
F1	An	4050	3750	202.91	187.875	390.78	1772	4.53
F2	An	4050	8150	202.91	408.315	611.22	468	0.77
F4	An	4050	8150	202.91	408.315	611.22	792	1.30
F5	An	4050	8150	202.91	408.315	611.22	828	1.35
F6	An	4050	8150	202.91	408.315	611.22	54	0.09
F7	An	4050	8150	202.91	408.315	611.22	396	0.65
F8	An	16300	20500	816.63	1027.05	1843.68	612	0.33
F9	An	12150	17600	608.72	881.76	1490.475	270	0.18
							Mad	0.92
							CoV	1.10

Appendix 12 (continued)
Turn 2 IR (maize 1) = 52.7 mm
Day 3:19/12/96 IR (maize 2) = 52.7 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL	m3	
Weir	Am	141750	195520	7470.225	10303.9	17774.13	17892	1.01
D3	Am	44550	69350	2347.785	3654.7	6002.53	2736	0.46
DF4	Am	16200	19550	853.74	1030.3	1884.025	2106	1.12
DF1	Am	24300	44500	1280.61	2345.2	3625.76	1584	0.44
D3|F24/25	Am	20250	24850	1067.175	1309.6	2376.77	864	0.36
F24	Am	20250	24850	1067.175	1309.6	2376.77	704	0.30
DF1|L.cnr	Am	8100	12150	426.87	640.3	1067.175	756	0.71
F11	Am	8100	12150	426.87	640.3	1067.175	558	0.52
DF2|cnr	Am	32400	32800	1707.48	1728.6	3436.04	1568	0.46
F13	Am	8100	8200	426.87	432.1	859.01	162	0.19
F14	Am	8100	8200	426.87	432.1	859.01	576	0.67
F16	Am	8100	8200	426.87	432.1	859.01	504	0.59
F17	Am	8100	8200	426.87	432.1	859.01	324	0.38
F33	Am	4050	3750	213.435	197.6	411.06	56	0.14
D5|C.CNL	Am	24300	30300	1280.61	1596.8	2877.42	1674	0.58
D5|F32/33	Am	4050	3750	213.435	197.6	411.06	1242	3.02
F32	Am	16200	20700	853.74	1090.9	1944.63	1212	0.62
F29	Am	12150	14750	640.305	777.3	1417.63	486	0.34
F28	Am	12150	14750	640.305	777.3	1417.63	846	0.60
F27	Am	12150	14750	640.305	777.3	1417.63	882	0.62
DF2	Am	44550	62400	2347.785	3288.5	5636.265	1584	0.28
D4|main	Am	36430	44230	1919.861	2330.9	4250.782	2556	0.60
							Mad	0.64
							CoV	0.91

Appendix 12 (continued)
Turn 2 IR (maize 1) = 54.7 mm
Day 4: 20/12/96 IR (maize 2) = 54.7 mm

POSITIO	Sub-block	AREA under (m^2)		REQUIRED VOLUME (m^3)			ACTUAL Volume	Ad
		Maize 1	Maize 2	Maize 1	Maize 2	TOTAL	m3	
Weir	Am	186310	214300	10191.16	11722.2	21913.37	17388	0.79
D3|mn	Am	68870	78010	3767.189	4267.1	8034.336	2885	0.36
DF4	Am	16200	19550	886.14	1069.4	1955.525	2376	1.22
DF2|offtk	Am	48600	57700	2658.42	3156.2	5814.61	5868	1.01
D4|DF2/F	Am	52650	59050	2879.955	3230.0	6109.99	5976	0.98
F27	Am	12150	14750	664.605	806.8	1471.43	327	0.22
F28	Am	12150	14750	664.605	806.8	1471.43	792	0.54
F30	Am	28350	29550	1550.745	1616.4	3167.13	1116	0.35
D5|F32/33	Am	4050	3750	221.535	205.1	426.66	1515	3.55
D5|F31/33	Am	24300	30300	1329.21	1657.4	2986.62	2883	0.97
F33	Am	4050	3750	221.535	205.1	426.66	1368	3.21
F32	Am	16200	20850	886.14	1140.5	2026.635	1512	0.75
F30|aft.br	Am	4050	7800	221.535	426.7	648.195	900	1.39
F18|off.tk	Am	8100	11700	443.07	640.0	1083.06	2340	2.16
F16	Am	8100	8200	443.07	448.5	891.61	468	0.52
F14	Am	8100	8200	443.07	448.5	891.61	1224	1.37
DF2|cnr	Am	24300	28000	1329.21	1531.6	2860.81	2556	0.89
F11	Am	8100	12150	443.07	664.6	1107.675	324	0.29
DF1|cnr	Am	8100	12150	443.07	664.6	1107.675	396	0.36
DF1|of.tk	Am	28350	28350	1550.745	1550.7	3101.49	1296	0.42
F26	Am	20250	24850	1107.675	1359.3	2466.97	720	0.29
F24	Am	20250	24850	1107.675	1359.3	2466.97	864	0.35
							Mad	1.00
							CoV	0.89

Appendix 12b: Computation of RWS in block A

(I) Depths of irrigation water applied during the irrigation days

Irrigation day	*Total area (m^2)	Total volume supplied	Irrigation depth (mm)
05/12/96	1,248,900	17,226	13.8
06/12/96	1,248,900	15,264	12.2
07/12/96	1,248,900	16,308	13.1
08/12/96	1,248,900	16,992	13.6
17/12/96	1,248,900	13,248	10.6
18/12/96	1,248,900	16,830	13.5
19/12/96	1,248,900	17,892	14.3
20/12/96	1,248,900	17,388	13.9

* Assumption: The irrigation water was spread evenly on an area of 1,248,900 m^2 (total for the sub blocks, A1, An and Am), calculated in Appendix 11.

Sample calculation:

On 06/12/96 Va=15,264 m^3

Irrigation depth = total volume delivered (Va)/ total block area

=15,264 M^3/1,248,900 m^2

=12.2 mm

(ii) Computation of weekly Effective rainfall

Week	Dates		Rainfall (mm)	Effective Rainfall (mm)
	from	to		
1	16/10/96	22/10/96	0	0
2	23/10/96	29/10/96	0	0
3	30/10/96	05/11/96	0	0
4	06/11/96	12/11/96	37.5	19.96
5	13/11/96	19/11/96	55.1	31.27
6	20/11/96	26/11/96	73.5	43.23
7	27/11/96	03/12/96	7.0	0
8	04/12/96	10/12/96	0	0
9	11/12/96	17/12/96	4.0	0
10	18/12/96	24/12/96	18.0	7.15
11	25/12/96	01/01/97	106	64.35

Sample calculation: In week 4, 37.5 mm of Rainfall were received

The formula used to compute effective rainfall was:

Re = 0.65(R-7) mm/week

where R = weekly rainfall (mm)

Therefore, Re (week 4) = 0.65 (37.5-7) = 19.96 mm

(iii) Computation of weekly RWS to block A

Week	Dates		Supply (mm)				Demand (mm)	RWS
	from	to	R	Re [#]	IRGN [+]	Total	CWR	
1	16/10	22/10	0	0	-	-	18.0	-
2	23/10	29/10	0	0	0	0	19.8	0
3	30/10	05/11	0	0	0	0	19.3	0
4	06/11	12/11	37.5	19.96	0	19.96	10.9	1.83
5	13/11	19/11	55.1	31.27	0	31.27	23.23	1.35
6	20/11	26/11	73.5	43.23	0	43.23	7.35	5.88
7	27/11	03/12	7.0	0	0	0	15.57	0
8	04/12	10/12	0	0	52.7	52.7	25.6	2.06
9	11/12	17/12	4.0	0	10.6	10.6	36.8	0.15
10	18/12	24/12	18.0	7.15	41.7	48.85	46.63	1.05
11	25/12	1/1/97	106	64.35	0	64.35	32.4	1.99

Sample calculation of RWS:

RWS = Supply/demand

= (IRGN + Re)/CWR

Therefore: RWS (week 10) = (41.7+7.15)/46.63 = 1.05

Appendix 12 Computed water reliabilities in Block A

POSITION	'ADEQUACY, Ad					Dp		
	Turn 1		Turn 2		Mean (Ma_d)			
	day1	day2	day1	day2		$S.A_d$	$CoV.A_d$	Remark
D6 (S26)	1.30		0.64	0.50	0.81	0.35	0.43	3
D6 (S27)	1.19	1.15	1.06	0.65	1.01	0.21	0.21	2
F35	6.08	3.33	1.14	1.52	3.02	1.95	0.65	3
DF3	3.00		0.88	0.56	1.48	1.08	0.73	3
D1		1.39		0.67	1.03	0.36	0.35	3
DF5	3.30		0.78		2.04	1.26	0.62	3
F19		4.01	0.64		2.33	1.69	0.72	3
F20		1.39	0.56		0.98	0.42	0.43	3
F21	2.90		0.49		1.70	1.21	0.71	3
D2	2.31	0.47	0.42		1.07	0.88	0.82	3
F23	3.10		0.08		1.59	1.51	0.95	3
F2		2.04		0.77	1.41	0.64	0.45	3
F4		2.38		1.30	1.84	0.54	0.29	3
F5		2.6		1.35	1.98	0.63	0.32	3
F6		1.7		0.09	0.60	0.78	1.31	3
F7		2.04		0.65	1.35	0.70	0.52	3
F8		0.98		0.33	0.66	0.33	0.50	3
F9		1.5		0.18	0.84	0.66	0.79	3
DF1	1.33	1.08	0.44	0.42	0.82	0.40	0.49	3
F26				0.29	0.29	0.00	0.00	1
F25		1.06			1.06	0.00	0.00	1
F24	0.56		0.30	0.35	0.40	0.11	0.28	3
F11			0.52	0.29	0.41	0.12	0.28	3
F12	1.63	1.47			1.55	0.08	0.05	1
DF4	1.39	0.89	1.12	1.22	1.16	0.18	0.16	2
DF2	0.58	1.39	0.28	1.01	0.82	0.42	0.52	3
F13	1.70		0.19		0.95	0.76	0.80	3
F14		1.6	0.67		1.14	0.47	0.41	3
F15	1.56	1.6			1.58	0.02	0.01	1
F16			0.59	0.52	0.56	0.04	0.06	1
F17	0.38	0.56	0.38		0.44	0.08	0.19	2
F18		1.36		2.16	1.76	0.40	0.23	2
D4	1.82	0.9	0.60	0.98	1.08	0.45	0.42	3
F27	2.13	0.79	0.62	0.22	0.94	0.72	0.76	3
F28	1.08		0.60	0.54	0.74	0.24	0.33	3
F29		1.08	0.34		0.71	0.37	0.52	3
F30		0.5		0.35	0.43	0.08	0.18	2
F32	1.00	1.44	0.62	0.75	0.95	0.31	0.33	3
F33	6.16		0.14	3.20	3.17	2.46	0.78	3
D5	2.15	1.83	3.55	0.58	2.03	1.06	0.52	3
Weir (S11)	1.47	1.11	0.51	0.78	0.97	0.36	0.37	3
D3			0.46	0.36	0.41	0.05	0.12	2

Dp=CoV (Ad)of specific locations in time

Remark: 1=good; 2= fair and 3= poor

All computations were based on canal off-take adequacies.

APPENDIX 14: Questionnaire to the Matanya irrigation project secretary

1. What is the scheme size?
2. How is the scheme managed ?
3. Who owns the land and how many plot holders are in the scheme?
4. Where do you get your irrigation water from and how is it conveyed?
5. Which method of water distribution do you use and what is the basis of the schedules?:
6. Which method (s) of irrigation are used in the scheme?
7. Maintenance of the water delivery system

a) Responsibility: ....

b) Frequency of maintenance and activities carried out

Appendix 13 Description of Matanya water delivery system

General description

1. Location on delivery system

a) Reach: * Primary furrow * Secondary furrow

b) Distance from the intake............m

c) Descriptive location (with respect to farm boundary) ....

2. Slope......%

3. Flow depth ....m

4. Sedimentation: * nil * moderate * severe

5. Weeds in furrow

a) location bed/edges; b) density.. few/many

c) Nature grasses/shrubs/trees

6. Surface water flow ......m/s * low * medium * high

7. Need for structure. Yes/No

Structure required

* Measurement: weir/flume/gate.....

* Control: silt trap/drop/chute

* Storage: tank volume......m^3

* division box

Water abstraction points

1. Location

a) * Primary furrow * Secondary furrow

b) Distance from the intake.............km

c) Descriptive location (with respect to farm boundary) ....

2. Type of abstraction

a) Open channel/furrow

width..................cm; depth..................cm

slope...................%

Qmax (approx)......l/s

Abstraction height......cm

b) Pipe

diameter....(cm)

length...........m

slope.............%

Qmax.............l/s

Abstraction height......cm

3. Channel conditions at Upstream/downstream of abstraction point

parameter	Upstream		Downstream	
	width (cm)	Depth (cm)	Width (cm)	Depth (cm)
shape siltation				

Part 4:structures

1. Location on delivery system

a) * Primary furrow * Secondary furrow

b) Distance from the intake.............m

c) Descriptive location (with respect to farm boundary) ....

2. Function:

* Measurement: weir/flume/gate.....

* Control: silt trap/drop/chute

* Storage: tank volume......m^3

3. Working condition: * good * fair * bad

4. Is it serving the intended purpose ? Y/N.

Appendix 14 Average daily flows to Matanya scheme and total rainfall

Year	Month	Total rainfall (mm)	Average daily discharge (l/s)
1990	Jan		
	Feb		
	Mar		
	April		
	May		
	Jun		
	Jul		
	Aug		
	Sep		
	Oct		
	Nov		59.83
	Dec		129.35
1991	Jan	16	130.08
	Feb	30.1	44.93
	Mar	92.7	75.92
	Apr	95.2	181.70
	May	17.7	212.48
	Jun	103.4	165.19
	Jul	8	134.49
	Aug	78.6	135.58
	Sep	0	217.79
	Oct	83	137.58
	Nov	91.4	175.63
	Dec	50.6	123.44
1994	Jan	3.1	28.12
	Feb	38.2	15.56
	Mar	29.5	43.78
	Apr	204.9	108.63
	May	60.8	93.55
	Jun	47.5	70.42
	Jul	24.2	57.78
	Aug	57.2	51.03
	Sep	8.0	29.07
	Oct	99.4	52.37
	Nov	155.2	139.02
	Dec	60.3	64.14

Appendix 15(cont.)

Year	Month	Rainfall mm	Average daily discharge (l/s)
1995	Jan	13.9	27.94
	Feb	55.5	62.89
	Mar	142.7	99.26
	Apr	117.5	90.03
	May	70.2	73.32
	Jun	28.2	62.60
	Jul	71.6	160.87
	Aug	10.6	44.84
	Sep	70.3	130.87
	Oct	73.9	192.06
	Nov	103.0	234.90
	Dec	166.8	250.26
1996	Jan	35.4	96.26
	Feb	16.3	39.07
	Mar	115.7	31.00
	Apr	50.6	16.27
	May	13.5	105.42
	Jun	100.2	190.62
	Jul	33.4	108.69
	Aug	201.0	90.70
	Sep	6.8	115.54
	Oct	35.5	137.26
	Nov	97.1	147.75
	Dec	58.6	105.27
Overall	Jan	60.2	70.60
	Feb	43.2	40.61
	Mar	72.7	62.49
	Apr	101.8	99.16
	May	40.2	121.19
	Jun	56	122.20
	Jul	38.8	115.46
	Aug	25.2	80.54
	Sep	31.1	123.32
	Oct	75.6	129.82
	Nov	110.3	151.43
	Dec	87.6	134.49

Appendix 15 Mean daily potential evapotranspiration by the Modified Penman method

Month	PENMAN Eto (mm/day)								
	1987	1988	1989	1990	1991	1992	1994	1995	1996
J	4.24	3.98	4.13	4.05	4.50	4.17	5.45	4.87	4.15
F	4.78	4.77	4.23	4.03	4.98	4.75	6.08	5.07	5.26
M	5.08	4.26	4.31	3.76	4.80	4.73	5.31	3.93	4.14
A	4.35	4.18	3.55	3.24	4.10	4.15	4.07	3.47	4.52
M	4.78	4.72	4.71	3.70	4.54	4.89	3.56	3.55	3.95
J	4.19	5.05	4.55	5.10	4.33	5.21	3.70	3.96	3.02
J	5.42	4.43	4.69	5.34	4.42	4.94	4.00	3.95	3.60
A	6.18	4.77	5.27	5.13	5.02	5.17	4.48	5.37	4.09
S	6.50	5.07	5.51	6.45	5.70	5.92	5.92	4.85	4.67
O	6.00	3.93	4.42	4.58	4.33	4.35	4.36	3.69	4.47
N	3.76	2.84	3.77	3.48	3.44	3.70	2.61	3.27	3.26
D	4.12	3.55	3.45	3.55	3.81	3.44	3.02	3.26	4.43

Appendix 16 Irrigation water use questionnaire at Matanya scheme

1. Farm Name ....
2. Date ..../.../97
3. Farm number.........
4. Soil type: clay/loam/sand
5. Irrigated area

a) Total....ha/acres

b) Irrigated main crops

Crop	Area	
	Hectares	Acres
1.		
2.		
3.		
4.		

6. Cropping calendar of the three main irrigated crops.

Crop	Planting date	Transplanting date
1.		
2.		
3.		

Appendix 17 Questionnaire schedule at Matanya scheme

Name of informant	Date	Farm Number	Irrigated acres under						Total
			maize	bean	cabbages	tomato	potato	other	
M. Ndungu	27/05/96	684	0.00	0.00	0.25	0.25	0.50	0.00	1.00
S. Munyiri	27/05/96	657	1.50	0.00	0.00	0.00	0.00	0.75	2.25
H. Ngima	27/05/96	672	1.00	1.00	0.00	0.00	0.00	0.00	2.00
F. Karenga	27/05/96	671	0.50	0.50	0.00	0.00	0.00	0.00	1.00
F. Kibiru	27/05/96	668	1.50	0.50	0.00	0.00	0.75	0.00	2.75
M.Wang'ombe	27/05/96	795	0.50	1.00	0.00	0.00	0.00	0.00	1.50
R. Kimani	27/05/96	797	0.13	0.13	0.13	0.25	0.13	0.00	0.75
G. Ngetha	27/05/96	734	0.75	0.00	0.13	0.00	0.75	0.00	1.63
H. Kinyua	27/05/96	727	0.00	0.75	0.75	0.25	0.00	0.25	2.00
I. Njenga	27/05/96	643	0.50	0.00	0.00	0.00	0.00	0.00	0.50
K. Yoweri	27/05/96	792	0.00	0.50	0.25	0.00	0.13	0.00	0.88
J. Kabiru	28/05/96	791	0.00	0.50	0.25	0.25	0.00	0.00	1.00
N. Kamathia	28/05/96	789	1.00	0.50	0.25	0.00	0.00	0.00	1.75
T. Kimani	28/05/96	534	0.25	0.00	0.00	0.00	0.00	0.00	0.25
J. Kimani	28/05/96	480	0.50	0.00	0.00	0.00	0.25	0.00	0.75
I. Gicohi	28/05/96	478	0.25	0.00	0.13	0.00	0.13	0.50	1.00
W. Mugwe	28/05/96	476	0.13	0.00	0.00	0.00	0.00	0.00	0.13
M. Ndegwa	28/05/96	475	0.50	0.50	0.00	0.00	0.00	0.50	1.50
S. Ngatia	28/05/96	447	0.50	0.00	0.00	0.00	0.00	0.25	0.75
J. Wangu	29/05/96	474	2.00	0.00	0.00	0.00	0.00	0.00	2.00
P. Mugo	29/05/96	570	0.50	0.00	0.50	0.00	0.50	0.00	1.50
E. Macharia	29/05/96	452	0.00	0.00	0.50	0.75	0.00	0.13	1.38
M. Gichuki	29/05/96	468	2.50	0.00	0.00	0.00	0.00	0.00	2.50
K. Mwangi	29/05/96	469	2.50	0.00	0.00	0.00	0.00	0.00	2.50
T. Ndegwa	29/05/96	728	0.75	0.75	0.00	0.25	0.00	0.00	1.75
J. Gachuru	29/05/96	733	1.00	0.50	0.00	0.75	0.00	0.00	2.25
G. Gaturu	29/05/96	635	2.00	0.00	0.25	0.00	0.00	0.00	2.25
G. Irungu	29/05/96	571	0.00	0.00	0.25	0.00	0.00	0.50	0.75
..ang'ata	29/05/96	566	0.00	0.00	0.13	0.25	0.00	0.38	0.75
otal			**20.8**	**7.13**	**3.75**	**3.00**	**3.13**	**3.25**	**41.0**
Mean (acres)			**0.72**	**0.25**	**0.13**	**0.10**	**0.11**	**0.11**	**1.41**
Mean (ha)			**0.29**	**0.10**	**0.05**	**0.04**	**0.05**	**0.05**	**0.58**

Appendix 19 Computation of monthly Irrigation Water requirements at Matanya irrigation scheme.

Month	Eto (mm)	Re (mm)	maize		bean		potato		cabbage		tomato	
			Etc (mm)	IR (mm)	Etc (mm)	IR(mm)	Etc(mm)	IR(mm)	Etc (mm)	IR (mm)	Etc (mm)	IR (mm)
J	125.35	26.12	105.29	79.17	104.04	77.92	106.55	80.43	97.77	71.65	102.79	76.67
F	190.45	15.92	159.98	144.06			161.88	145.96	148.55	132.63	156.17	140.25
M	134.7	33.62					114.50	80.88			110.45	76.83
A	117.85	56.44	98.99	42.55	97.82	41.38	100.17	43.73	91.92	35.48	96.64	40.20
M	136.7	14.12	114.83	100.71	113.46	99.34	116.20	102.08	106.63	92.51	112.09	97.97
J	142.15	23.60	119.41	95.81	117.98	94.38	120.83	97.23	110.88	87.28	116.56	92.96
J	146.2	13.80	122.81	109.01	121.35	107.55	124.27	110.47	114.04	100.24	119.88	106.08
A	157.7	5.12	132.47	127.35	130.89	125.77			123.01	117.89	129.31	124.19
S	175.75	8.60									144.12	135.52
O	138.05	35.48	115.96	80.48	114.58	79.10	117.34	81.86	107.68	72.20	113.20	77.72
N	104.95	63.24	88.16	24.92	87.11	23.87	89.21	25.97	81.86	18.62	86.06	22.82
D	109.5	45.08	91.98	46.90	90.89	45.81	93.08	48.00	85.41	40.33	89.79	44.71

Appendix 19 (continued)

	IR (m^3/plot)						Gross IR	
Month	maize	bean	potato	cabbage	tomato	Total	m^3/plot	m^3/scheme
	(0.29 ha)	(0.10 ha)	(0.05 ha)	(0.04 ha)	(0.05 ha)			
J	229.60	77.92	40.21	28.66	38.33	414.73	1036.83	207367
F	417.77	0.00	72.98	53.05	70.12	613.93	1534.82	306963
M	0.00	0.00	40.44	0.00	38.42	78.85	197.14	39427
A	123.41	41.38	21.87	14.19	20.10	220.94	552.35	110470
M	292.05	99.34	51.04	37.00	48.99	528.42	1321.05	264211
J	277.84	94.38	48.61	34.91	46.48	502.23	1255.57	251114
J	316.12	107.55	55.24	40.09	53.04	572.04	1430.10	286020
A	369.31	125.77	0.00	47.15	62.10	604.33	1510.83	302166
S	0.00	0.00	0.00	0.00	67.76	67.76	169.39	33879
O	233.40	79.10	40.93	28.88	38.86	421.17	1052.93	210585
N	72.26	23.87	12.98	7.45	11.41	127.97	319.93	63986
D	136.01	45.81	24.00	16.13	22.36	244.30	610.75	122150

Assumptions made:

(i) All crops planted at the beginning of each rainy season

(ii) The average reported cropped areas per plot were used to compute the required irrigation volumes: Maize (0.29 ha),Beans (0.10 ha), potato (0.05 ha), tomato (0.04 ha) and cabbage (0.05 ha).

(iii) The total required amount of irrigation water is the summation of the individual crop requirements per plot.

(iv)Total number of plot holders =200

Sample calculation of monthly water demand:

For maize in the month of January: Eto (Penman) =125.35 mm/month

Weighted average Kc = 0.84, Therefore, Etc = 125.35 *0.84 mm=105.29 mm

The effective rainfall, Re = 26.12 mm

Then, IR = Etc - IR = 105.29 - 26.12mm = 79.12mm

The average reported area grown to maize under irrigation = 0.29 ha

Therefore, volume of water required to irrigate maize = 79.17mm*10^{-3} m/mm*0.29ha*104m^2/ha =229.60m^3/plot

Similar computations were performed for the other crops and the volumes of water required per plot were:
Beans = 77.92 m^3
Potato = 40.21 m^3
cabbage = 28.66 m^3
maize = 229.60 m^3
Total = 414.73 m^3

Assuming an irrigation efficiency of 40 %, Gross IR = 414.73/0.4 m^3/plot = 103683 m^3/plot
No. of plot holders = 200
Therefore, the scheme irrigation requirement for the month of January = 200*1036.83 m^3
=207367 m^3/month
These computations were carried out for the other months of the year.

Appendix 19 (continued): Monthly irrigation water supply and demand at Matanya scheme

Month	daily mean Flows l/s	Total supply m^3	Gross IR m^3	Surplus m^3
J	70.60	182995	207367	-24372
F	40.61	105261	306963	-201702
M	62.49	161974	39427	122547
A	99.16	257023	110470	146553
M	121.19	314124	26411	287713
J	122.20	316742	251114	65628
J	115.46	299272	286020	13252
A	80.54	208760	302166	-93406
S	123.32	319645	33879	285766
O	129.82	336493	210585	125908
N	151.43	392507	63986	328521
D	134.49	348598	122150	226448

Appendix 20: Computed discharges by the float Method in Matanya scheme (May,1997)

Date 97	Farm No.	Abstr	l (m)	travel time (s) t1	t2	t3	t_{avg}	V (m/s)	depth (m)	width (m)	Area (m^2)	Q (m^3/s) X 10^{-3}
27/5	795	A2	1.80	7.1	7.2	7.4	7.2	0.25	0.07	0.20	0.014	3.50
27/5	534	A15	1.80	9.9	10.1	10.0	10.0	0.18	0.11	0.30	0.033	5.94
27/5	-	br.pt	4.00	10.0	11.0	12.5	11.2	0.36	0.14	0.80	0.112	40.1
28/5	467	A49	2.00	19.9	20.0	20.1	20.0	0.10	0.06	0.34	0.204	2.04
28/5	740	A58	2.00	39.0	40.0	41.0	41.0	0.05	0.11	0.45	0.050	2.41
28/5	566	A50	2.00	16.5	20	22	19.5	0.10	0.08	0.30	0.024	2.46
28/5	741	A59	2.00	59.0	60.0	60.0	60.0	0.03	0.25	0.35	0.086	2.92
28/5	660	A60	2.00	59.9	60.1	60.2	60.1	0.03	0.05	0.30	0.015	0.50