ASSESSMENT OF IRRIGATION WATER USE FOR AGUTHI, THOME AND MATANYA SMALLHOLDER IRRIGATION SCHEMES

BY

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University.

18/11/99

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This thesis has been submitted to the University of Nairobi for the award of the degree of Master of Science in Agricultural Engineering with my approval as a University supervisor

18/11/99

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DATE

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ABSTRACT

The overall objective of the this study was to assess the performance of smallholder irrigation schemes, identify constraints and develop opportunities for better performance. This study was undertaken in Aguthi, Thome and Matanya smallholder irrigation schemes.

The potential irrigable area was computed basing on the permitted canal water flow, rainfall and maize as a test crop. The actual areas irrigated were then estimated by measuring the fields under irrigation at the time of the study and then compared to the expected irrigable areas. Constraints to better irrigation performance were assessed from field observations, questionnaire response and some technical measurements such as water canal bed levels and their solutions proposed.

It was established that the schemes' performance was too low to meet irrigation objectives. There was no clear indication of quantitative water allocation to the three major uses thus domestic, livestock and irrigation. The irrigation schemes' subsystems thus water conveyance, distribution, application, drainage and appropriate cropping patterns were not effectively addressed leading to this appalling situation.

The constraints that limit full irrigation potential realisation were mainly technical and organizational oriented. The major ones were identified as; unmaintained water canals impeding water flows to farmers, unequal water distribution to farmers coupled with water stealing incidences and untimely cropping patterns with lack of knowledge on crop water requirement and irrigation water requirement.

Solutions to these constraints were suggested and it was concluded that for an irrigation scheme to perform well, a good understanding and undertaking of the subsystems must be enhanced and that management is a vital component to maintain irrigation systems in order so as to efficiently use irrigation water and attain long term irrigation benefits.

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DEDICATION

To my wife Mmbone, sons and daughter

1.0 INTRODUCTION

1.1 Background

Water use efficiency is increasingly becoming an important concept in irrigation schemes. This is because water is a scarce but an essential resource in agriculture. Demand for water is increasing as population increases. Also inefficient water use leads to environmental degradation, an issue that is of global concern. It is therefore essential to use the available water more efficiently to realise increased irrigation benefits and to satisfy domestic water demand.

Ewaso Ngiro catchment has a wide range of water users. There are irrigation schemes, tourist lodges, wildlife, livestock and homesteads. This situation raises concern on how effectively to allocate the water to the varied uses. For each utility process, technically sound approaches must be applied to ensure that water is efficiently used. The study area (Aguthi, Thome and Matanya smallholder irrigation schemes) falls in this Ewaso Ngiro catchment hence prompting these water use concerns to be addressed.

Irrigation is a major consumer of water to satisfy the evapotranspiration requirements of crops. Maize for instance, an efficient user of water in terms of total dry matter production among the cereals, and potentially the highest yielding grain crop requires 36,500 m^3/ha for a growing season of 120 days at 100% of crop water requirement supply (Doorenbos and Kassam, 1986). However irrigation efficiencies are generally low especially for surface irrigation of unlined water channels. Bos and Nugteren (1982) estimates irrigation project efficiency as low as 37%. This implies that considerable water savings can be made by increasing irrigation system efficiencies.

What therefore is of particular importance is the water use efficiency in irrigation schemes, an aspect that should be addressed from conveyance, allocation/distribution and application perfection. Normally, from a canal intake, it is such that the head end farmers manipulate the system to provide themselves with more water than they require at the expense of the tail end farmers who sometimes hardly receive water for even domestic utility. A case may be isolated where a head end farmer conveys water to irrigate a field half a kilometre away yet other farmers who are just several metres from the canal have no water. Such water ends up in considerable conveyance losses.

If such irrigation schemes with low water use efficiency can be enlightened on water saving strategies, convincing demonstration is inevitable in terms of how much yield can be realised for each unit of water and how crop water requirement can be determined. Sagardoy (1982) states that good management of irrigation schemes is becoming increasingly recognised as an essential means to achieve successful irrigated agriculture. Consequently, in recent years, there has been a noticeable interest in studying existing irrigation schemes in order to learn where improvements can be made in their operation and maintenance.

A diagnostic survey is required to establish the potholes in the present irrigation systems which may involve the network of the scheme including how the beneficiaries abstract and allocate the water among themselves and the water uses. Identifying the water losses of such a layout will prompt improvement strategies which will lead to less water abstraction allowing more water for other uses and users along the entire watercourse. Along the canal, all the beneficiaries should enjoy the irrigation benefits optimumly and equally.

There are several physical and operational inadequacies in canal systems ranging from design, on-farm operations and management. This study aims at documenting this and giving remedial suggestions to arrest the situation. Both an adaptive and action research is required to first diagnose the technical problems encountered in the selected schemes and propose improvement strategies aimed at introducing reliability of irrigation benefits. This however requires a multi-displinary cooperation for integration of the problematic factors to rescue the situation.

1.2 Rationale for the Study

This research is aimed at developing recommendations for the irrigation projects which have fallen into disrepair and whose performance is failing to meet the original criteria and needs. It is also hoped that the projects shall be improved to meet the enhanced needs in terms of irrigation benefits. It is the water delivery and allocation systems that shall be reviewed.

Irrigation schemes have to be assessed of their reliability in terms of water productivity since water is the scarce resource here. Better planning of the distribution system is inevitable to enable equity in water distribution to both head end and tail end farmers. The criteria of distribution should depend on the stability and utility to irrigators basing on predicability, certainty and controllability of water. These requirements are important because flow in canals is not constant hence being able to predict flows will have a helpful bearing on planning of water utility with certainty.

Cropping patterns that are viable to make use of the water if developed shall eliminate conflicts among users and uses of water at any time of the year or season. This is to keep the farmer busy all the year round with a diverse cross section of activities. This will enable farmers to incorporate high value commercial crops and food crops interchangeably according to the specific crop water requirements and thus eliminate seasonal stress in food production.

The overall target for the scheme beneficiaries is to realise reliable and sustainable benefits of an irrigation scheme.

1.3 Research Objectives

Overall Objective

To assess the potential, current performance, limitations and feasible solutions of the smallholder irrigation schemes with respect to water delivery and allocation systems.

Specific Objectives

1. Assess the irrigation potential of the area in terms of irrigable acreage based on rainfall and available river flow
2. Determine to what extent this potential has been realised with regard to the present area under irrigation and other land uses
3. Identify the constraints to full exploitation of the existing irrigation potential
4. Propose solutions to the limiting factors identified.

2.0 REVIEW OF LITERATURE

2.1 Water Management

Irrigation management is the process by which water is manipulated (controlled) and used in the production of food and fibre. It should not be confused with water resources, dams, or reservoirs to capture water; nor codes, laws or institutions to allocate water; nor farmers organizations; nor soils or cropping systems. It is however the way these skills and physical, biological, chemical and social resources are utilized for improved food and fibre production (Lowdermilk, 1981).

To realise improved irrigation performance, both water and other resources must be managed well. Water is in most cases a scarce resource but an essential input in agriculture therefore prompting need for careful management. For good management, clearly defined objectives are inevitable. To check whether the objectives are met or not, the system performance must be monitored and evaluated, and a feedback control mechanism devised to meet the project objectives (Lenton, 1986).

Irrigation is a combination of physical works and human activity. For the success of irrigation therefore, commitment is necessary to control and manage the physical systems. The way water is supplied, conveyed, distributed and finally applied will show the level of water management of that particular irrigation scheme. To each of these elements is an attached level of efficiency which can be controlled. Poor management of these activities mean poor water management.

2.2. Assessment of Potential Irrigable Area

Potential irrigable area is the maximum area that can be irrigated for a particular crop in a specific growing season with the available water resources when the crop suits in the climatic and soil conditions (Doorenbos and Kassam, 1986). Different crops respond differently to moisture stress at different stages. Potential irrigable area can therefore be increased by limiting water supply but this may be reflected in the yields.

The factors influencing the potential irrigable area are: Climate (effective rainfall and crop evapotranspiration, available river flow, topography, crop and soil factors).

2.3 Monitoring and Evaluation of Irrigation Projects

Biswas (1990) notes that monitoring and evaluation of irrigation projects has been a neglected subject, but must play a more important role in future if the irrigation management process is to be improved. This is however not an easy task since it requires a multi-displinary involvement. Basically, the process of monitoring and evaluating a project is supposed to deliver a clear state or position of the project in terms of strengths and weaknesses with justifiable conclusions and recommendations.

Monitoring of an irrigation project is the continuous or periodic surveillance over the implementation of the necessary irrigated agricultural activities. It is used to ensure that work schedules, input deliveries, targeted outputs and other required actions are progressing according to the plan. On the other hand, evaluation may be ongoing or periodic, the former being a continuing activity and used to examine whether any changes are necessary for the operation and management of a project. It also ensures that its performance is satisfactory and the overall objectives can be achieved.

While limited literature exists on the integrated monitoring and evaluation of irrigated agricultural projects (Biswas, 1987 and Sagardoy, 1985), there are unfortunately more reports available on pseudo evaluation or superficial evaluation that have been carried out in the recent past at both national and donor agency - both bilateral and multilateral levels. These reports are more concerned with the protection and enhancement of the reputation of the organizations concerned, both within and outside countries, and the individual associated projects. Such types of evaluation have no meaning in meeting the requirements of identifying major project problems and bottlenecks.

There are many reasons as to why irrigation projects have to undergo monitoring and evaluation processes. The two major ones are; to determine the extend of achievements of the goals of a project by assessing actual impacts and then comparing them with expected impacts. The other is to obtain information as to why a project may not have had anticipated impacts by identifying the magnitude, extend, and location of the problems in order that corrective action may be taken to maximize the beneficial project impacts.

The fundamental requirements for designing any monitoring and evaluation system for irrigated agricultural projects are: timeliness, cost-effectiveness, maximum coverage, minimum measurement errors, minimum sampling error, absence of bias and identification of users of information (Biswas, 1990).

For monitoring and evaluation to succeed, we need a new ethos. As Brown

(1976) apically noted, "the heart of evaluation is an attitude, a frame of mind that enables us to review the project activities and performance in a constructive critical light."

2.4 Irrigation Scheme Performance Indicators

In the broadest sense, the common objectives in managing irrigation schemes can be defined as providing water as an input to agriculture at least cost complementary to other inputs required, with a view to achieving an optimal balance between the goals of high productivity, income generation, equity and sustainability (Bottral, 1981). Based on the common objective of irrigated agriculture, Chambers (1976) introduced five performance indicators namely;

1. Productivity
2. Profitability of the irrigated farm enterprises
3. Cost-effectiveness of the scheme operation and management
4. Quality of the water delivery service provided to irrigators.
5. Environmental stability or sustainability.

2.4.1 Productivity

Productivity of irrigated agricultural production can be measured as yield per hectare or yield per unit volume of water depending on which resource is limiting, either land or water. This qualification is based on an assumption that other inputs of production are fully utilized. Hoecht (1990) noted that the estimation of the productivity of water is complicated by difficulties in assessing the amount of rainfall effectively available to crops as well as possible groundwater and conjunctive water use by individual farmers.

2.4.2 Profitability of Irrigated Farm Enterprises

The usual way to determine the profitability of farm enterprises is to draw up crop budgets, that is, to list all production costs against the gross revenue from the crops produced by a unit area of land in the scheme (Chambers, 1988). However, they require a considerable amount of data collection and analysis and therefore cannot be undertaken as a routine exercise within the minimum framework of performance monitoring. This can therefore be worked out on long term basis.

2.4.3 Cost Effectiveness of Running Schemes

For any recommendation to any improvement or rehabilitation of an irrigation scheme to be made, a cost-benefit analysis must be undertaken. Hoecht (1990) points out that capital costs for construction and rehabilitation of irrigation schemes are often higher, and the production considerably lower than the targets anticipated at the design stage. What is important is to try and analyze for long term benefits. Tiffen (1990) stresses that an adequate water supply has to be secured before farmers are willing to pay the operation and management costs of their schemes. If farmers are not able to finance the minimum operation and management required to maintain the scheme initially, because the water supply is inadequate, a downward spiral is predicted of further reductions in water supply, income losses and declining operation and management expenditure.

2.4.4 Quality of water supply to fields

There are three issues worth being addressed here thus adequacy of water supply to fields, equity of spatial distribution of water supply and timeliness and reliability of water deliveries.

2.4.4.1 Adequacy of water supply to fields

Irrigation water is usually a scarce resource and a limiting factor in many areas where irrigation plays a crucial role in agricultural development, the need to make economical use of irrigation water and to avoid excessive losses is commonly acknowledged (Hoecht 1990). Efficiencies are the classical measures for assessing the success in economising the use of resources in production processes. In irrigation, efficiencies provide a measure for the performance of the water delivery system in transmitting water to ultimate users. Several efficiency measures exist (Bos and Nugteren, 1982). The most useful are conveyance efficiency, distribution efficiency (which are ratios of the water volume supplied into a section over the volume delivered from the section in the conveyance or distribution system respectively) and field application efficiency (consisting of the efficiency of the water transport in the field and the efficiency of the application method). Field application efficiency then becomes the ratio between the quantity of water needed to maintain the soil moisture at the level required for the crop and the quantity of water furnished at the point of delivery to the field (Bos and Nugteren, 1982). The overall scheme efficiency is then obtained by multiplying the three efficiencies.

There are two limitations to the value of overall scheme efficiency and field application efficiency as performance indications. First, they require judgement of the effectiveness of rainfall in contributing to the water volume supplied to crops; and secondly they can become highly misleading when the supply is less than needed to satisfy crop water requirements. In this case, calculated efficiencies apparently exceed 100% while the crop may be already suffering from severe water stress (Abernetty, 1990).

This problem does not occur when adequacy instead of efficiency is examined using Relative Water Supply (RWS) as the indicator of choice. RWS is defined as the ratio of irrigation water and rainfall (supply) and the crop water requirements (demand). Relative Water Supply may be calculated by the formula

$$RWS = \frac{I + R}{CWR}$$

Where I = Irrigation water depth supplied at a given level in the system (mm)

R = depth of rainwater requirements (mm)

CWR = crop water requirements (mm)

2.4.4.2 Equity of spatial distribution of water supply

Standard deviation, coefficient of variations, the Ginin coefficient, Christianseris coefficient and inter-quartile ratio are widely used measures for the degree of equity/equality of a distribution (Hoecht, 1990).

In contrast to the indicators above, the flow distribution proposed by Restrepo (1983) and the Theils-Index (slightly modified) which are both based on the deviations of the share of sub-units of total water supply from their share of the scheme area, undoubtedly meet these requirements. Alternatively, equity and adequacy of water supply can be monitored jointly on the basis of relative water supply measurements. The idea is to determine a target RWS for an average sub-unit of the scheme and to define a tolerable range around the target RWS. Defining the target RWS requires a good estimate of the losses within the scheme and should be determined site-specifically; however, a value of 1.4 may be considered as a good first estimate for assessing sub-units. Crops react differently to sub-optimal water supply according to (Doorenbos et al, 1981), but in general it seems that a supply of less than 80% of water requirement leads to significant yield losses.

The samples taken for this analysis must be representative of the scheme thus head-end, mid section and tail-end.

2.4.4.3 Timeliness and reliability of water deliveries

This is a measure undertaken based on cropping patterns, season and available water. Crop water stresses should be well understood at the different stages of growth. Lenton's water delivery performance (Lenton, 1982) provides a quantitative indicator

$$P = \sum k_i \frac{V_a}{Vi}$$

Where:

Va	=	actual volume of water supplied in period (i)
Vi	=	required volume of water in period (i)
Ki	=	water stress factor and summation of Ki = 1
P	=	Lenton's water delivery performance indicator

Lenton suggests that excess water supply is treated by inverting Vi/Va ratio to account for its potentially harmful affects or to limit the maximum achievable value in period 1. The results range from 0 to 1, with 1 signifying a perfect water management regime.

At a scheme level, only farmers satisfied with water supply service will give highly valuable insights into the equity and reliability of the water allocation. On the other hand the sufferers (those who receive less water supply) have negative perspective of the exercise. Well defined guidelines are therefore necessary for all scheme beneficiaries at design and operational stage from relevant professionals backed by extension service.

2.4.5 Environmental Stability

When dealing with water for irrigation, an insight of related problems of wasted water or general environmental impacts caused by water must be considered. The physical changes caused by irrigation which degrade the environment are salinity, waterlogging, groundwater depletion, soil erosion with progressive reduction in fertility, siltation and weed infestation. These are elements that can be prevented or minimised by better irrigation water use efficiency.

2.5 Crop Water Requirements and Yield Rsponse to Water

2.5.1 Crop Water Requirements

Different crops require different amounts of water at the different stages of their growth. Calculation of crop water requirements starts by calculation of reference crop evapotranspiration ET_o.

Cropwat computer program, an in-built of Penman method, utilises climatic data to estimate ET_o. Incorporating crop coefficient of specific crops gives crop evapotranspiration ET_c. Irrigation requirement becomes the crop evaporation less the effective rainfall. Using either the recommended or measured conveyance, distribution and application efficiencies the water to be applied to meet specific crop water requirement can be computed.

2.5.2 Yield Response to Water

According to Doorenbos and Kassam (1986), maize is an efficient user of water in terms of total dry matter production and among cereals, it is potentially the highest yielding grain crop. For maximum production, a medium maturity grain crop requires between 500 and 800 mm of water depending on climate.

Frequency and depth of irrigation and rain has a pronouncedd effect on grain yield. Maize appears relatively tolerant to water deficits during the vegetative and ripening periods. Greatest decrease in grain yield is caused by water deficits during the flowering period. Where water supply is limited, it may therefore be advantageous to meet, as far as possible, full water requirement (ET_m) so as to achieve near maximum yield from a limited acreage rather than to spread the limited water over a larger acreage.

Undr irrigation, a good commercial maize grain yield is 6 to 9 tonnes/ha. The water utilization efficiency for harvested yield for grain varies between 0.8 and 1.6 kg/m^3.

2.6 Availability of Irrigation Water

According to Lowdermilk *et al* (1980), to accomplish problem identification in water availability to irrigators, it is necessary to understand the sequence of major activities including reconnaissance field investigations, designing diagnostic studies, conducting diagnostic field studies, analyzing and interpreting findings, and selecting criteria for ranking significant problems.

There are three main factors that an irrigation system is supposed to accomplish thus equity, adequacy and reliability of water supply to beneficiaries in the command area. The questions to be addressed are as follows according to some Indian irrigation officials (source anonymous):

1. Is the water adequate to the command area?

   The parameters to be compared to answer the question are

   -Scheme area

   -Scheme water requirements

   -Available stream flow

   -Permitted abstraction

   -actual abstraction

2. Is the farmer getting his/her allocated flow?

   What to be investigated here is how much water is allocated to each farmer and does what each farmer get differ from the allocated? If so, how and why? Questions that can be viewed through questionnaire and actual water flow measurements.

3. How is water distributed amongst the farmers?

- The mode of water distribution could be on the basis of rotation, flow rate or at liberty to take on demand by the farmers.
- How often is the farmer allowed to use the water?
- How functional and reliable is the operational schedule? Are the farmers aware or satisfied with the distribution system?
- Is there any bias in allocation of water between tail end and head end farmers? A well structured questionnaire can assist in identifying these issues.

4. What is the technical performance of the conveyance and distribution systems?

Key issues to be considered that effect the amount of water to be expected at point B from point A are;

a) design capacity of the channels
- does water flow at the designed velocity?
- Is the slope of the channels, the designed one?
- Are the channels weed and silt free?

b) Seepage losses
- How much water is lost along the conveyance and distribution systems

c) Operational losses
- How are the farmers irrigating? Sprinkler, furrow or bucket?

d) Adequacy of regulating structures
- Are there any permanent structures like division boxes, weirs or gates to effectively control water flow volumes?

2.7 Causes of Water Channel Losses

There are reasons for any kind of water loss in conveyance channels. In fact before appropriate improvement techniques can be proposed, the causes of the losses must be established. Trout and Kemper (1980) isolated causes of water losses in conveyance channels as

1. highly permeable soils
2. Insect or rodent holes in the banks
3. Weedy and grassy channels
4. Small field sizes requiring extensive channel networks
5. Poor operating procedures
6. Maintenance, or
7. An excess supply of water

These channel losses can be categorised as steady state, transient or wastage depending on the cause of the loss.

2.8 Methods of Water Diversion

For many small scale farmers who use furrow irrigation, water is diverted directly from the stream by opening up a bank to let water in the farm (field research observation). With lack of knowledge or ignorance, some farmers dam the main canal with mud, stones or logs and tree branches to raise the water level such that more water flows to their farms. These abstraction methods usually supply water more than required or that which cannot be handled hence water losses become inevitable.

Pumping is one way of abstracting water whose flow rate can be monitored or regulated on demand to avoid unnecessary water wastage. It is apparent that the water abstraction methods used by many farmers do not correspond to the available canal capacities resulting in water deficiency for tail-end farmers (Gichuki, 1994).

2.9 Irrigation Canal Renovation Strategies

Water losses from conveyance channels range from the simplest of cleaning of vegetation from the banks to lining (Trout and Kemper, 1980). Whichever method to be recommended depend upon the type of losses in each section. The costs and benefits of the undertaking must be well stipulated. The priorities should be well spelt and the time available for specific renovation strategy to be considered. The possible channel improvement techniques include cleaning and repair to control forms of channel losses with a minimum amount of initial capital inputs, earthen renovation which entails destruction of old channel banks and reconstructing hydraulically acceptable ones and lining which is a high cost event but if justified may be recommended.

3.0 MATERIALS AND METHODS

3.1 Selection of Irrigation Schemes

The schemes selected for the study were Aguthi (in Nyeri district), Thome and Matanya (in Laikipia district). The rationale for this selection was that they (irrigation schemes) abstract their water from the Naro Moru river and hence could assist in comparing how the river water is available for irrigation for all the schemes. Irrigation is also a prerequisite to agriculture in these areas since they are generally dry as they are on the leeward side of Mt. Kenya. People residing in these areas long for sustainable agricultural and economical output, the major water source being canal water.

3.1.1 Location

The study was undertaken in Aguthi, Thome and Matanya smallholder irrigation schemes situated along Naro Moru river, a tributary of Ewaso Ngiro river, as shown in Figure 1

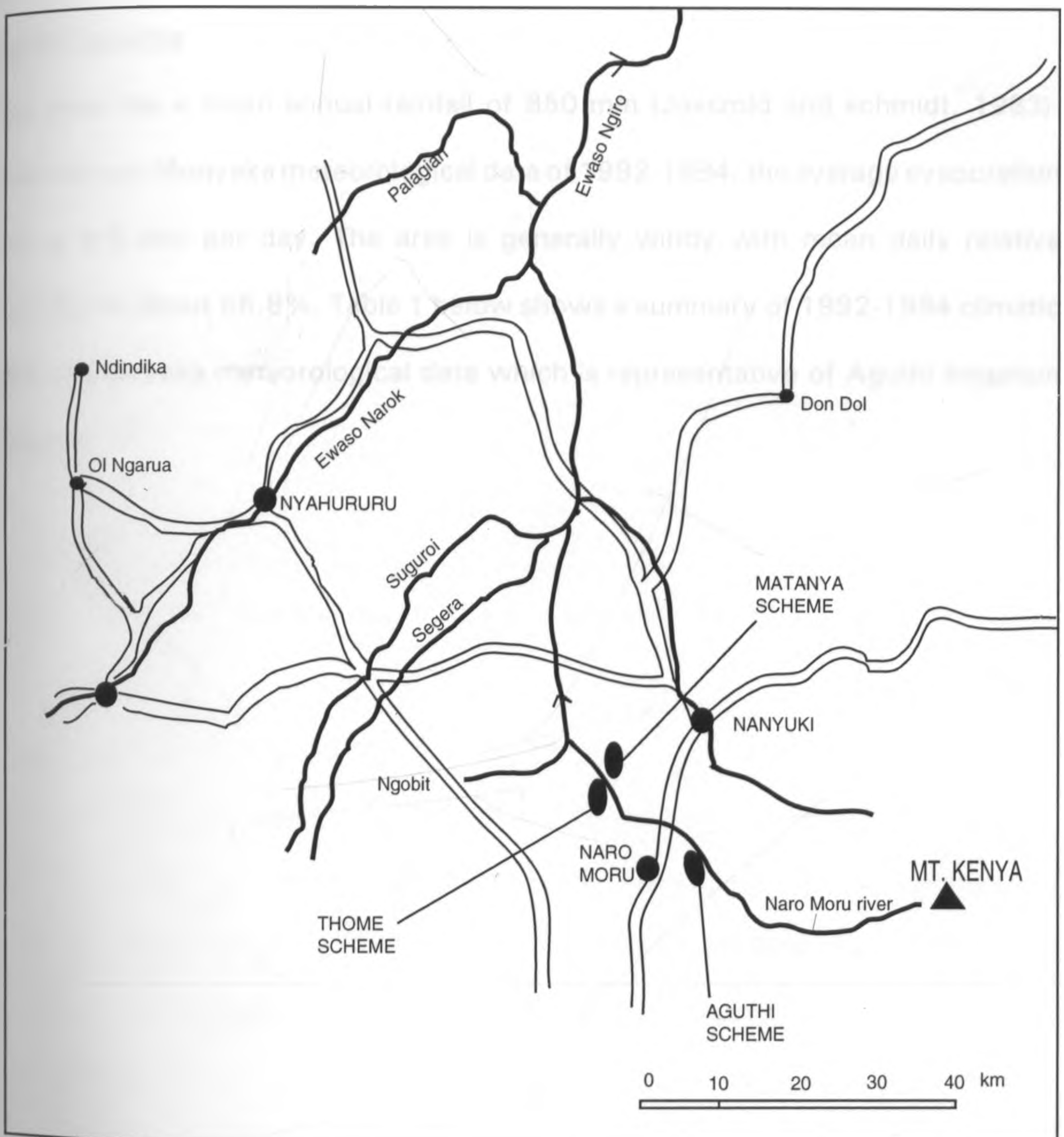


Figure 1: Location of Aguthi, Thome and Matanya Irrigation Schemes (Source: Atlas of Irrigation and Drainage in Kenya (1990))

3.1.2 Climate

Aguthi is in the agro-ecological zone Lower Highlands 4 (LH4). Thome and Matanya are in Agro-ecological zone Lower Highlands 5 (LH5) (Jaetzold and schmidt, 1983).

Aguthi Scheme

This area has a mean annual rainfall of 850 mm (Jaetzold and schmidt, 1983). According to Munyaka meteorological data of 1992-1994, the average evaporation rate is 4.5 mm per day. The area is generally windy with mean daily relative humidity of about 66.8%. Table 1 below shows a summary of 1992-1994 climatic data of Munyaka meteorological data which is representative of Aguthi irrigation scheme.

Table 1: Climatic data of Munyaka meteorological station (1992-1994)

Month	RH (%)	Windrun (km/day)	Temp.(°C)		Sunshine hours	Rainfall (mm)	E_o
			Max	Min			
January	69	98.4	24.2	7.8	6.2	36.5	3.6
February	60	170.4	26.3	7.4	6.5	10.1	4.2
March	67	129.6	25.7	8.4	6.1	53.2	4.3
April	80	120	23.7	10.2	5.8	115.9	3.3
May	80	199.2	22.1	9.8	6.3	19.1	3.4
June	77	235.2	22.4	10.0	7.1	0.4	4.3
July	77	254.4	21.6	9.5	7.5	6.7	4.3
August	74	283.2	21.1	9.1	8.0	3.6	4.7
September	66	307.2	22.1	9.4	6.9	11.6	5.3
October	74	160.8	23.1	9.6	5.3	71.3	3.6
November	74	120	21.4	9.0	4.7	120.9	2.6
December	78	84	21.6	9.4	4.8	102.2	2.5

**Altitude: 2097 m; Latitude: 0.18° S; Longitude: 37.06° E

Matanya and Thome Schemes

These schemes are opposite each other (the Naro Moru river separates them) and have nearly the same climatic characterization. Mean maximum daily temperature is 24.7° and minimum 10.7°. They have two rainfall seasons one in March-May and the other in October-December. The average pan evaporation is 5.0 mm/day (LRP, 1995). This is based on 8 years data from 1986-1993 as shown in Table 2.

Table 2: Monthly means data of Matanya LRP station

MONTH	Rainfall (mm)		Temperature (°C)		Wind	Sunshine	Humidity
	(exc.93)	(inc.93)	(max)	(min)	(km/h/day)	(hrs)	(%)
January	40.2	64.9	25.7	8.3	5.63	6.1	51
February	39.9	46.7	25.8	8.5	6.14	6.3	49
March	82.0	76.5	26.7	9.6	6.10	6.0	53
April	108.9	103.9	24.4	12.1	7.40	4.8	66
May	32.3	39.6	24.0	12.8	12.70	6.5	62
June	66.6	62.3	23.7	11.7	13.34	7.9	59
July	46.6	40.9	22.7	10.1	13.85	8.1	60
August	30.0	27.8	23.5	11.3	15.92	8.6	56
September	34.6	34.3	25.6	11.4	15.00	7.9	51
October	77.1	75.6	25.5	11.1	10.16	6.1	56
November	145.0	141.4	23.4	11.4	6.64	4.8	66
December	93.2	87.5	24.6	10.1	4.75	6.0	60
Total	796.4	803.4					
Valid years	7	6	6	6	6	6	6
Period	86/92	86/93	86/91	86/91	86/91	86/91	86/91

** Altitude: 1840 m; Longitude: 36.58° E; Latitude: 0.04° S

In January and February, 1993 there was unusually high rainfall (213. mm) and (87.5 mm) compared to (73.6 mm) and (48.9 mm) for the same months in 1990, a phenomenon which increased the January means considerably

3.1.3 Soils

Three experimental plots were sampled for the soil textural class. An auger was used to get samples over a depth of 1 m at an interval of 20 cm. One sample was taken in each of the experimental plot (in the three schemes) since the plot size was small (11 m X 8 m)

This was done in December 1994. The soils were generally black to brown in colour with loamy.

3.1.4 Water Intake Description

Aguthi water intake is constructed with a concrete barrier across the river to raise the water head. The design capacity of this canal is 1.4 m^3/s. A diversion box was built which diverted water to a 1 m wide and 0.7 m deep lined section of the canal. a sliding gate was installed to control water flow to the canal while a shield box constructed 15 m from the intake point to divert flood water back to the river.

Thome and Matanya intakes have only concrete barriers across the river but no control gates, the sliding timber gate which was initially installed by the white settlers (for Matanya) was only being used to stop water into the canal during canal maintenance sessions. The weir constructed across the river cracked to form 'spillways' hence less water being diverted into the canal especially when river flows are low (see Plate 1).

Plate 1: Cracked weir of Matanya canal intake point

However, for monitoring the canal water flows in the water canals, flumes were installed 300 m, 30 m, 40 m from the intakes of Aguthi, Thome and Matanya canals respectively. The rationale for the longer distance for Aguthi was that the section in between (intake and flume) was lined and forested hence negligible seepage and evaporation water loss.

3.2. Assessing Irrigation Potential

Monthly climatic data of 1992-1994 was collected for Aguthi scheme from Munyaka meteorological station while for Matanya and Thome schemes, 1986-1993 data was obtained from Matanya meteorological station. Monthly canal water flow data was obtained from the flume gauge readings (which was assumed as the permitted flow) to be used in the computation of potential irrigable areas. Planting date was the variable to determine which season would yield the largest potential irrigable area. Computation methodology for the irrigation potential is as shown in appendix 1, taking maize as a sample crop, planting dates taken on each first day of a month as the start of a growing season with other agronomic factors well attended to. For other crops under irrigation, their equivalent (to sample crop) can be obtained, however, this was not considered in this study. Reference evapotranspiration on monthly basis was obtained from the met. stations and the method below was used.

1. Maize crop coefficients (K_c values) as given by Doorenbos and Kassam (1979) for each crop growing stage were fitted in the corresponding months of the maize growing period during the entire season and then multiplied by the monthly ET_o to obtain reference crop evapotranspiration ET_c.
2. Data on rainfall was obtained from met. stations and its effective equivalent (R_{eff}) obtained by taking 80% of the actual rainfall amount as recommended by Smith

(1992) to calculate irrigation requirement (IR) as below.

3. Daily irrigation requirement (IR) was found from

$$IR = ET_c - R_{eff}$$

4. IR (l/s/ha) was obtained from [IR (mm) x 10000/86400] x 1.43 assuming an application efficiency of 70%.

6. Permitted canal water flow (monthly) in l/s was obtained from the flume gauge readings which when divided by IR(l/s/ha) gave monthly irrigable area in hectares for the entire cropping season.

7. The least area irrigable on monthly interval was taken to be the optimal irrigable area for the crop. Irrigable area can be increased depending on the stress the crop can withstand if non-optimal water is supplied at various crop stages.

This method gives a guideline of the amount of water required during a crop growing season for planning purposes of irrigation requirement estimates. The method can also be used to plan the timing of a crop season where irrigation requirement is minimal if the season is well timed to match the rainfall events. In such cases, it is advantageous to plan such that most of the rainfall falls when the crop requires a lot of water hence less irrigation requirement. In reality or when irrigation is being applied, real time daily data on evapotranspiration and rainfall is required to estimate the irrigation requirement.

3.3 Assessing Irrigated Area

Using a map of the land subdivision of Aguthi scheme, water canals were mapped right from their intakes. In Matanya and Thome, the map of the canals was used. This exercise was undertaken in February - March, 1995 because that was the time experimental plots under maize were being irrigated using the same water from the canals. All delivery points to individual farms were noted on the map. The corresponding areas which were being irrigated using the water were estimated. This was accomplished by use of a tape measure and in some cases where the land was level, an oedometer was used to get the dimensions. The dimensions of the fields under irrigation were then drawn on the map to get the respective areas in hectares. The method of water diversion, conveyance and application was noted together with which crop was being irrigated. A section of the canal showing the piped delivery points and the respective irrigated areas in Aguthi scheme is shown in Figure 2 below. However, some of the areas to which the water was diverted were not under irrigation at the time of the study hence were not marked though they would be cropped any time during the same season.

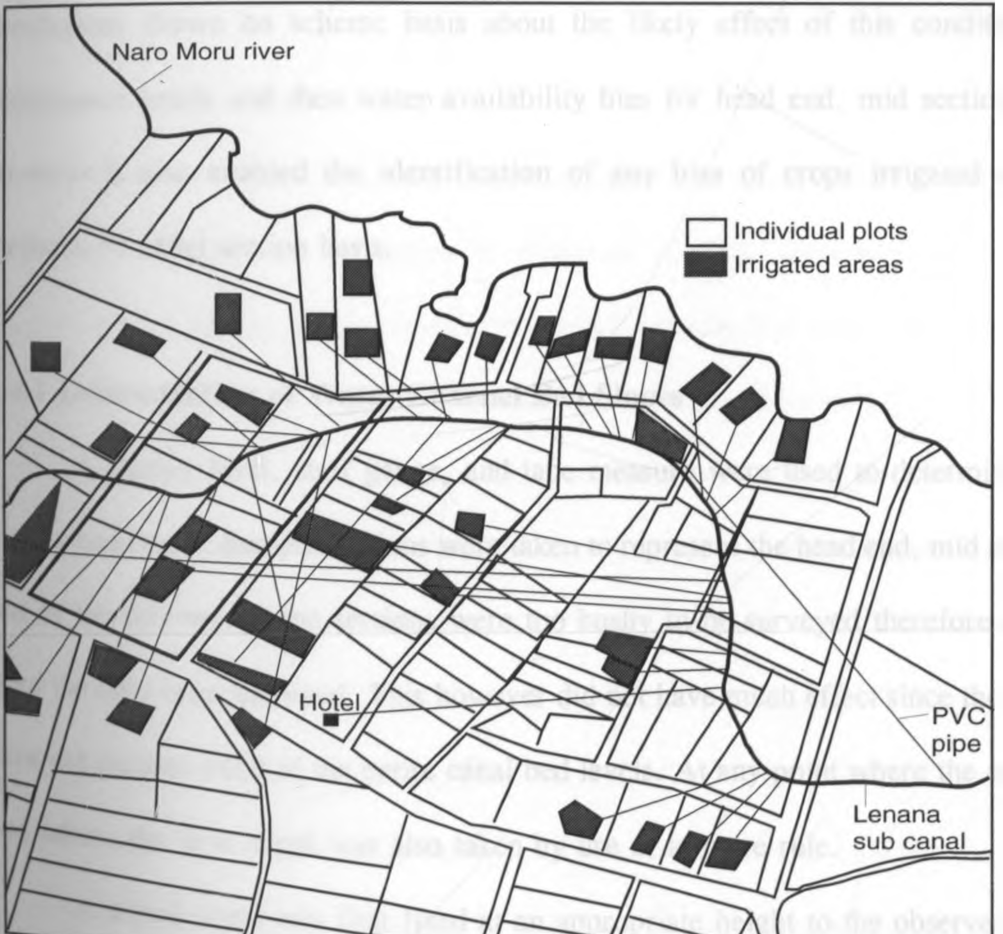


Figure 2: Sample Irrigated Area Mapping for a Section of Aguthi Canal

3.4 Assessing Constraints to Irrigation Potential Realization

The course of the water canals was followed during the surveying period and the subsystems of the irrigation schemes noted for the sample sections that were surveyed. This was recorded in the remarks section with regard to water delivery and conveyance, water distribution, water application, the cropping systems, dimensions of the furrows, the level of maintenance along the water course and the general furrow bed relative levels. Photographs were taken to show the diversion structures, sections of the canal and some methods of water application to fields. This information was recorded in a table as shown in Appendix 2.

This information was combined with the relative canal bed levels obtained and conclusions drawn on scheme basis about the likely effect of this conditions on water conveyance losses and then water availability bias for head end, mid section and tail end farmers. It also enabled the identification of any bias of crops irrigated and irrigation methods on canal section basis.

3.4.1 Determination of Water Channel Bed Slopes

A dumpy level, staff gauge, and tape measure were used to determine the relative furrow bed levels. Sample sections were taken to represent the head end, mid section and tail end of the furrows. Some sections were too bushy to be surveyed therefore clear sections were the only ones surveyed. This however did not have much effect since the samples used gave the general trend of the entire canal bed levels. At any point where the canal bed level was taken, the flow depth was also taken by use of a metre rule.

A tripod stand was first fixed at an appropriate height to the observer and then the dumpy level set. A staff gauge was then placed at the centre of the canal. A backsight (BS) reading was then recorded. A tape measure was then used to measure a distance of 20 m and then the staff positioned at that point in the same way the first was placed then an intermediate sight reading (IS) recorded. This was repeated until the staff could not be sighted. At that point, the last visible staff position, a foresight (FS) reading was recorded and that was termed as a turning point since the dumpy level was to be moved to another position while that particular point where a foresight reading was read was booked as a backsight for continuity of the exercise. The bookings made were; Point, BS, IS, FS, cumulative distance (CD), Rise, Fall, reduced level (RL) and remarks as shown in Appendix 3. Canal sections were classified according to their relative distance from their respective intakes to vividly illustrate the general trends of the canal over the entire course.

3.5 Search for Potential Solutions

For each of the constraints identified, possible solutions were proposed to either reduce the effect of the constraint or eliminate it. This however was done basing on suggestions sighted in literature and experiences of researchers as per the technical or design requirements of effective irrigation systems. The general understanding of the community set up and organization was considered in terms of affordability of suggested remedial measures and more so their contribution towards sustainable irrigation system performance. There were cases like water stealing water wastage weedy canal sections, lack of culverts or bridges at road or path crossing that had obvious remedial suggestions. The other issues like maintenance schedules, distribution, allocation and effective use of canal water required more investigation into the community set up, priorities and interests of scheme members, local authority and administrative influence boiling down to the general understanding of needs and scope of appropriate set up of the scheme to realise the benefits that go with such systems.

3.6 Experimental Site

3.6.1 Site Selection Criteria

The criteria used to select the experimental sites were: the slope of the plot; this was to be a relatively uniform section of land such that there could be no bias of soil fertility and soil water holding capacity gradients. The other criteria was that the size of the plot should fit the plot layout design, which was to be 11 by 8 metres. Also the plots were to be near a water source (canal or river) since the treatments were to involve water application to a crop hence water was to be available throughout the experimental duration. The soil also was to be fertile and this could be identified from the nature of the weeds on the piece of land or the previous crop's performance as per the farmer's history.

3.6.2 Site Description

The fields selected at the three sites were uniform (relatively level) on which the layout of the plots was made. The soils were fertile from the healthy nature of the weeds that were on the fields. On Thome plot, the previous land use had been maize and Irish potatoes; on Aguthi plot, cabbages had previously been put while in Matanya, tomatoes had just been harvested. The size of the plots were adequate to fit the layout desired. At Aguthi, a water pipe from the furrow was just at the site, at Thome, a pump could be used to obtain water from the canal to the plots while in Matanya, the river was just 15 m from the plots. experiment thus the water would be drawn with buckets to fill a drum at the plot site for irrigation exercise.

3.6.2.1 Soil Textural Class

The procedure used to determine the soil textural class was as illustrated by Hinga *et al*, 1980 as follows:

50 g of oven dry soil (dried at 40-45°C) that had passed through a 2 mm sieve in plastic shaking bottles and added 300 ml water followed by 50 ml of dispersing reagent. The bottles were tightly stoppered and placed in a shaker and shaken overnight.

The soil suspension was transferred into a 100 ml graduated cylinder and made up to the mark with water. In another cylinder 50 ml of 5% Calgon was added and made up to 100 ml mark with water. A plunger was used to mix thoroughly to bring to temperature of soil suspension. The hydrometer was carefully lowered into the solution and the scale reading determined, (reading of the blank) at the upper edge of the meniscus surrounding the stem.

The soil suspension was stirred thoroughly with a plunger for one minute. The time was carefully noted when stirring ceased. The hydrometer was carefully placed into the suspension and the reading taken 40 seconds after stirring ceased. This reading and the temperature of the suspension were taken. Stirring of the next cylinder was done at the end of the minute stirring of the previous one ceased, thus it took 2 minutes per sample. After exactly 2 hours from the time stirring ceased, a second hydrometer and temperature readings were taken and recorded for both soil suspension and the blank. Percentage sand, clay and silt were calculated using the equations below

$$\%\ Sand = 100 - [H_1 + 0.2(T_1 - 68) - 2]2$$

$$\%\ Clay = [H_2 + 0.2(T_2 - 68) - 2]2$$

$$\%\ Silt = 100 - (\%\ Sand + \%\ Clay)$$

Where H_1 and H_2 are the first and second hydrometer readings respectively and T_1

and T_2 are temperature readings in degrees Fahrenheit.

3.6.2.2 Soil basic infiltration rates

Double ring infiltrometer was used to find the basic infiltration rate of the soils. This was done in December 1994 on the experimental plots. The installation of the cylinders was done with minimum soil disturbance. The cylinders were placed on the ground and a flat timber bar laid across them. A mallet was used to drive the cylinders in the soil uniformly to a depth of 5 cm. A calibrated rod with a floater was then fixed on the inner ring. Water was poured in the outer ring until it was full and then in the inner ring until the water levels were the same. A stop watch was started and the first reading taken. Other readings were taken after one minute interval during the initial stages of the experiment because the water penetrates in the soil fast. Water was all the time being filled in the outer ring to be on the same level as in the inner ring to ensure uniform movement of water down the soil. When the calibrated rod was just about to touch the ground, water was then refilled in both rings and readings taken again. This was repeated until the rate of water infiltration rate became constant when the time interval and rod readings became the same for three consecutive readings. Three sites were taken on the plot for this experiment to be sure of the uniformity of the soil. The averaged results for each of the scheme site were tabulated which could be fitted in Horton's infiltration equation.

3.7 Experimental Layout and Treatments

The layout comprised three blocks and three treatments. Each block had randomised treatments within the sub-plots. Each treatment plot was 2 m X 3 m with 1.0 m footpath and borders for watering the crops. The layout is as shown in Figure 3 of three treatments and three replicates.

The treatments were water application levels of irrigation requirement being: $T_1 = 33\%$ $T_2 = 66\%$ $T_3 = 100\%$. It was assumed that 'no irrigation' as a control was obviously to give low yields hence not applied. These percentages represented the desired crop water requirement. The other treatment was the site location thus Aguthi, Thome and Matanya.

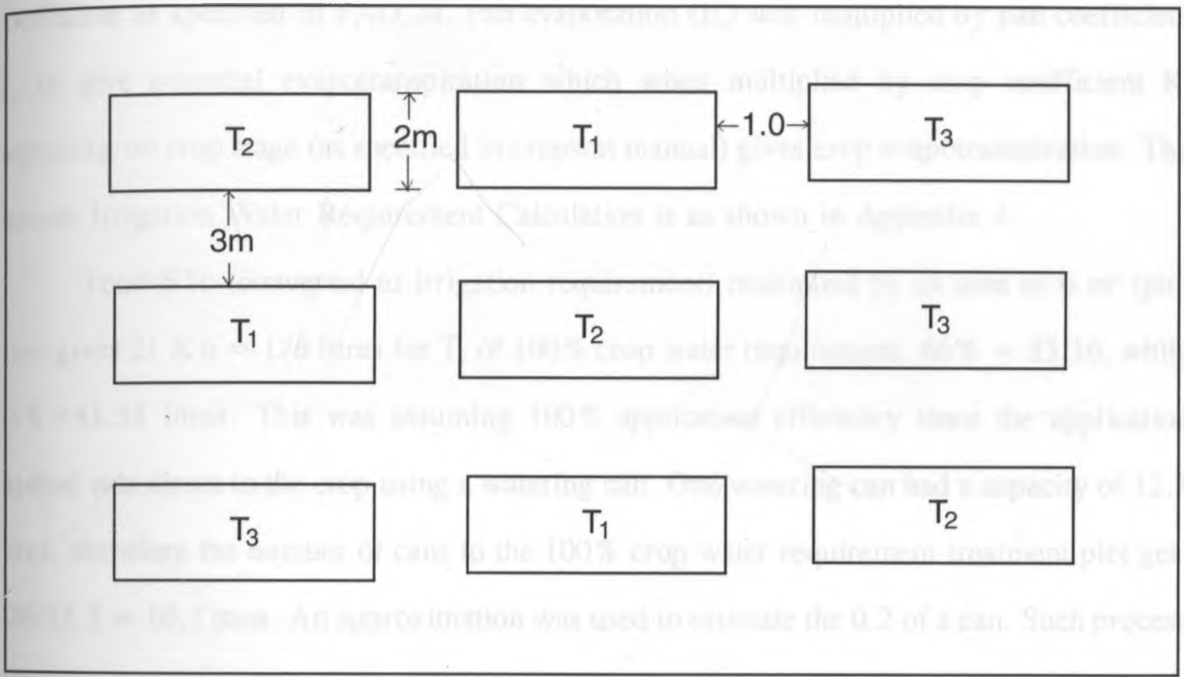


Figure 3: Field Experimental layout

Just after planting, all treatments received 3.2 cm for Aguthi scheme, 2.6 cm for Thome scheme and 2.6 cm for Matanya scheme of water which was to facilitate germination of the maize. This point (soil saturation) was reached when water was seen remaining on the soil surface. Data from nearby meteorological stations, was obtained to estimate the crop evapotranspiration using Rao *et al* (1988) method. This method insists on real-time irrigation scheduling under limited water supply and indicated that in any season, the current weather variables can be significantly different from their probabilistic or stochastic estimates unlike what Mapp and Eidman (1987), Rao *et al.* (1988); Bras and Cordova (1981); Rao *et al.*

(1990) of the many models that determine the optimal irrigation strategies using stochastic and probabilistic models. Use of real-time or current weather data to guide irrigation decisions has been attempted mainly by adopting a 'trigger level' concept of available soil water (Jensen and Wright, 1978).

Data on mean daily relative humidity, daily windrun, rainfall and pan evaporation was collected on a weekly basis. Relative humidity and windrun were required to compute pan coefficient as specified in FAO 24. Pan evaporation (E_o) was multiplied by pan coefficient K_p to give potential evapotranspiration which when multiplied by crop coefficient K_c depending on crop stage (as specified in cropwat manual) gives crop evapotranspiration. The Sample Irrigation Water Requirement Calculation is as shown in Appendix 4.

Total ETc (converted to irrigation requirement) multiplied by an area of 6 m^2 (plot size) gives 21 X 6 = 126 litres for T_3 of 100% crop water requirement. 66% = 83.16, while 33%=41.58 litres. This was assuming 100% application efficiency since the application method was direct to the crop using a watering can. One watering can had a capacity of 12.3 litres, therefore the number of cans to the 100% crop water requirement treatment plot gets 126/12.3 = 10.2 cans. An approximation was used to estimate the 0.2 of a can. Such process was repeated for another cycle of days to replace the water that would have been transpired.

If rainfall fell, then the amount was to be subtracted from the water that was to be applied.

Water application was achieved by use of watering cans as the fields were small to use furrow irrigation. This enabled exact quantification of applied water hence 100% application efficiency was assumed (See plate 2 for water application method). There was a 1 m foot path in between the plots to enable the watering exercise to be done without interfering with the soil on which the maize crop was growing. By means of the watering can, the perforated spout poured water around the maize stems in a shower form with negligible spillage and runoff effects. For every plot therefore, the amount of water applied during the 4-day irrigation requirement treatment was noted. This was summed up as the total water used by the crop hence was used to compare that amount with the yields realised per treatment plot.

Plate 2: Irrigation Method

3.8 Development of Water-Yield Relationship

To each plot, a specific amount of water was applied which could be quantified. Rainfall water was also recorded during the experimental period whose effective values were computed. Since rainfall water was assumed uniform on all the treatment plots, it was added to the supplemental irrigation water applied to each treatment plot. The water used on each plot was therefore extrapolated in hectare basis by multiplying by a factor (10000/6) since the micro plot was 6 m^2 and a hectare is 10000 m^2. This linear extrapolation assumed that on a micro plot, all factors like evaporation losses and infiltration rates were uniform.

Given the yield in kg/ha and total volume of water used in m^3/ha yield in Kg/m^3 could be computed to show the dried grain yield per unit volume of water used on a hectare of maize. The mass of the other biomass such as the stalk and cobs was not considered in this case.

4.0 RESULTS AND DISCUSSION

4.1 Irrigation Potential

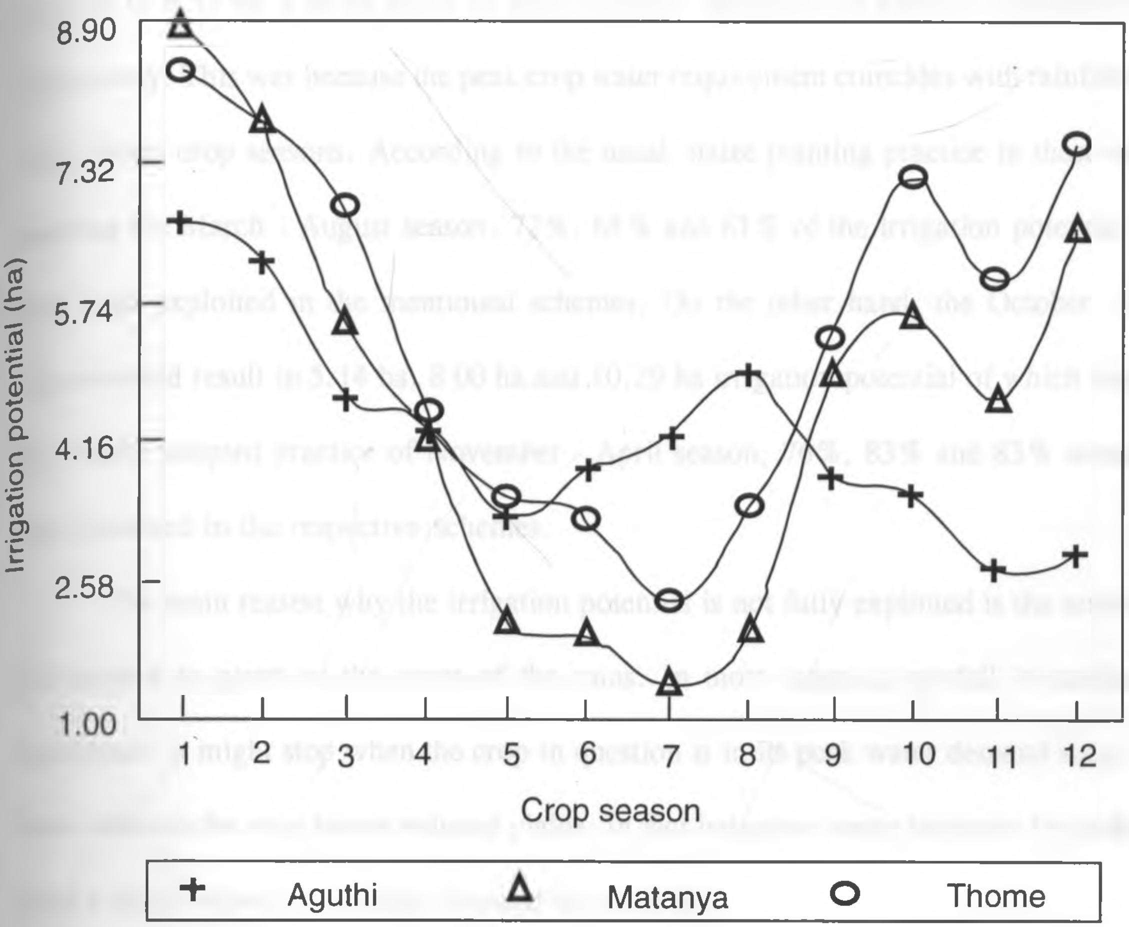
This was based on the permitted canal water flow and effective rain water for the entire year which was to involve the cropping seasons. Table 3 shows the irrigation potential based on acreage for the three experimental sites for different planting dates all the year round. This irrigation potential implied that those were the areas that could be optimumly irrigated without water being a limiting factor, the crop under irrigation being maize. This computation was based on assumption that the crop was planted on January 1st 1995 though in the experimental fields at the three schemes, planting dates were 31st December, 1994 at Aguthi, 2nd January, 1995 at Matanya and 17th January, 1995 at Thome which had no significant difference.

The results shown in Appendix 1 are meant to give guidelines as the amount of water required on monthly basis throughout a crop season. The reason why certain months have a higher irrigation potential is the fact that there could be more water both in the canal and rainfall while the growth stage of the crop does not require much of the water; this however does not help one to aim at planting the resulting acreage. The driving irrigation potential to be achieved throughout the crop season is the least area obtained due to rainfall and available river water. With this guiding value, all other crop stage water requirements would be met with in fact less irrigation requirement.

The irrigation potential results obtained from the computations were summarised as in Table 3 below, indicating the irrigation potential which are the least values obtained during the growing season on monthly basis in the three schemes. Graphically, a presentation as in Figure 4. clearly the seasons with the highest irrigation potential as the favourable ones for adoption. The cropping seasons with least irrigable areas indicate that it is better to utilise the water in other ways than put maize under irrigation for water here becomes a great limitation to more acreages to be cultivated for maize production. The crop under study in this case was maize and the same analysis can be done for other crops of interest in the scheme which when the results are superimposed, a clear decision can be made on which enterprise to go for during which season.

Table 3: Irrigation Potential based on varied Crop seasons for Aguthi, Thome and Matanya Schemes

Crop season	Aguthi IP (ha)	Matanya IP (ha)	Thome IP (ha)
Jan - Jun	6.67	8.89	8.37
Feb - Jul	6.22	7.79	7.80
Mar - Aug	4.65	5.53	6.84
Apr - Sep	4.41	4.21	4.51
May - Oct	3.32	2.10	3.57
Jun - Nov	3.87	1.96	3.33
Jul - Dec	4.24	1.37	2.33
Aug - Jan	4.96	2.03	3.45
Sep - Feb	3.78	4.92	5.33
Oct - Mar	3.59	5.59	7.20
Nov - Apr	2.73	4.66	6.00
Dec - May	2.90	6.60	7.56



1: Jan - Jun | 7: Jul - Dec

2: Feb - Jul | 8: Aug - Jan

3: Mar - Aug | 9: Sep - Feb

4: Apr - Sep | 10: Oct - Mar

5: May - Oct | 11: Nov - Apr

6: Jun - Nov | 12: Dec - May

Figure 4: Maize Irrigation Potential for Aguthi, Matanya and Thome based on cropping seasons

The January - June maize crop season (six months) yielded the maximum irrigation potential of 6.47 ha, 8.89 ha and 8.37 ha for Aguthi, Matanya and Thome irrigation schemes respectively. This was because the peak crop water requirement coincides with rainfall season unlike other crop seasons. According to the usual maize planting practice in these areas of adopting the March - August season, 72%, 65% and 81% of the irrigation potential would have been exploited in the mentioned schemes. On the other hand, the October - March season would result in 5.14 ha, 8 00 ha and 10.29 ha irrigation potential of which basing on the usually adopted practice of November - April season, 76%, 83% and 83% would have been achieved in the respective schemes.

The main reason why the irrigation potential is not fully exploited is the tendency of the farmers to plant on the onset of the rains. In most cases as rainfall is stochastic in occurrence, it might stop when the crop in question is in its peak water demand stage casing more stress to the crop hence reduced yields. In fact irrigation water becomes limited during the dry spells when it is at high demand by the crop.

One of the most important solution to this situation is for the farmers to fully understand the rainfall patterns based on long term data from the nearby meteorological stations in their region and being able to time planting dates such that rainfall occurs when the crop is in a peak water requirement stage. This will reduce irrigation requirement and achieve both an enlarged irrigated area and better crop yields.

4.2 Actual Irrigated area

During the time of study (February - March 1995), the areas under irrigation using the canal water were 17 hectares for Aguthi, 12 hectares for Thome and 10 hectares for Matanya. These were estimations found by measuring the fields where water was applied, not necessarily during the time of visit but the fields under a crop for a farmer who had diverted canal water to his field. Out of the irrigated area, only 2.2 ha, 3.6 ha and 2.8 ha were under maize for Aguthi Thome and Matanya. This was the maize planted during the October - March crop season. Appendix 2 shows an extract record sheet of farmer based landuse where the actual irrigated areas were noted (the farm numbers shown are not the land registration but the farm position along the main water canals or sub-canals, ranked by the researcher).

Field work result was compared to the estimated irrigation potential as previously computed in Appendix 1 and summarised in Tables 4. Two seasons were considered in this case, January - June (the highly recommended from computation) and the October - March (in which the duration of study matched). The result of the comparison could clearly indicate irrigation water use bias to other crops than to maize and the need to shift the cropping season should maize be a major crop as it is in most parts of this country.

Table 4: Comparison of irrigation potential, total irrigated area and area under maize

Irrigation Scheme	Aguthi	Thome	Matanya
Total irrigated area (ha)	12	8.4	7
Maize irrigation potential (ha)			
January - June	6.47	8.37	8.89
October - March	3.59	7.20	5.59
Actual irrigated area under maize (ha) (October - March)	2.2	3.6	2.8
% of actual irrigated area for maize to total irrigated area	12.9	30.0	28.0
% of actual irrigated area for maize to maize irrigation potential			
January - June	23.8	30.1	22.0
October - March	42.8	35.0	35.0

From the information given in Table 4 above, it is clear that more than 50% of the irrigation water was used to other crops other than maize. This was so because farmers had put emphasis to other short season but high value crops like snowpeas (specifically in Aguthi), tomatoes, irish potatoes and cabbages.

On the other hand, comparing the area under irrigation for maize to the maize irrigation potential for the two seasons (January - June and October - March), they were both below the potential. For instance, if the crop (maize) was planted in the January - June season, then only 23.8%, 30.1% and 22% of the irrigation potential would have been achieved in Aguthi, Thome and Matanya respectively. Applying the same comparison on the October - March season (which was actually the case studied), only 42.8%, 35.0% and 35.0% of the irrigation potential was achieved. The reason for this was not established since water that would have irrigated maize might have been applied to other crops. This could be attributed to the assumption that maize would require most of the water available as it was noted that only 3.60 ha, 7.20 ha and 5.59 ha would be irrigated (if maize was the only crop) instead of the 12 ha, 8.4 ha and 7 ha that were under irrigation for Aguthi, Thome and Matanya schemes respectively.

There were both cases of under irrigation and over irrigation in some cases where intercropping was practised. For instance, If maize, irish potatoes and cabbage were on the same piece of land (which was a common practice), then sprinkler irrigation applied, that was a clear indication that some crops were receiving more water while others less than their respective water requirement. Pure crop stands could be the only solution to this if rightful amounts of water irrigation water was to be monitored.

On individual basis, as illustrated in Appendix 2, the size of the farm had no relation to the area irrigated. In fact the farmers with large farms used most of them for grazing since irrigation water was limited while the farmers with small farms used most of them for growing crops either under rainfed or irrigated agriculture.

One reason why small maize fields were irrigated was that the farmers regard the March - October as the major maize growing season while the October - March as a minor one. Ideally, the January - June season would have been studied, it would establish a better view of why maize is a major or a minor crop although that practice is unrecognized.

It could be deduced that most of the water in the canals goes to domestic and livestock utility basing on the small areas that were being irrigated compared the farmers' available land and the available water flows in the canals.

The actual area under irrigation is not a fixed quantity hence could not be estimated accurately. This was because of the fluctuation of permitted water flows (canal water flows for this case). It so happens that whenever it rains, that is when the canals have full capacity flows hence the water goes into wastage by overflowing canal banks or domestic usage alone instead of some being used for irrigation since the fields do not require a lot of water by then. This is the water that could be stored to be used during dry spells.

During dry seasons, when irrigation is required mostly, the canals barely have water. This implies that whenever one irrigates, he is restricted to the area to apply water by the water availability. Plate 3 below shows the water let to flow down the river at the Thome canal abstraction point (that seen in the pipe). That could tell how little the water can be in the Matanya canal (though not quantified), which is 300 m downstream of Thome canal, for irrigation. Plate 4 shows an almost dry Naro Moru river. This section was 5 m and during a heavy rain downpour the water would rise to 3 m; giving the water an average velocity of 2 m/s would result in a volumetric flow rate of 30 m^3/s which may persist for 24 hours before subsiding gradually. In dry seasons, a clear marked depth of water cannot be measured unless obstructed as by the tree trunk seen in the plate. This scenario reveals the limited available water for irrigation during dry seasons, reflecting in the small irrigated areas that were measured.

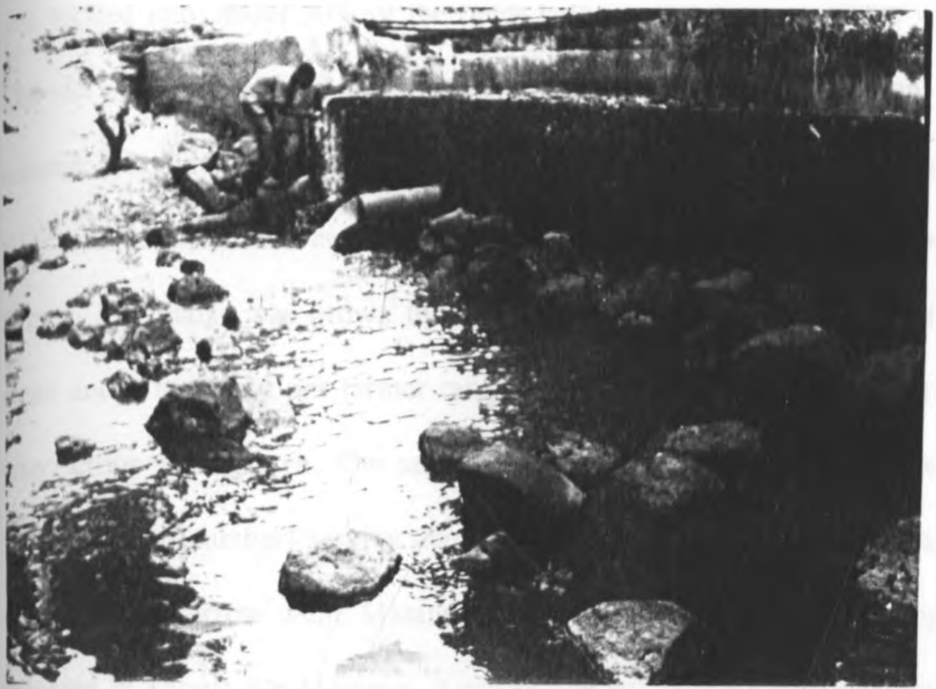


Plate 3: Flow Remaining in river at Thome Canal Water abstraction point

Plate 4: Dry season river flow scenario of a section of Dry Naro Moru River

During the time of this study, around January - March 1995, when this particular item was looked into, about 30% of the fields belonging to farm members were under irrigation The rest of the fields were under grass for livestock or un-irrigated crops. Farmers of Aguthi scheme, who had water from the canal on their farms were using it on small areas, irrigating high value, short season crops like snowpeas, tomatoes, irish potatoes, onions and cabbages. A crop like maize was grown by almost every farmer but under rainfed agriculture. The areas under irrigation per farmer ranged from 0.01 to about 0.1 hectares but subdivided if many crops were grown. The same Aguthi scheme had an extensive network of secondary canals (five in number) serving about 1200 farmers but not all irrigating. Thome canal had no secondary furrow while Matanya canal had three. Although also high value crops were irrigated in Thome and Matanya, it was by the few farmers who used pumps to lift the water to their fields or who had their farms at a reasonable head relative to the water canal to convey the water to the crop by pipe or by furrow. Maize and nappier grass were however noticeably being irrigated. The layout of the main canal and secondary canals including the approximate regions under irrigation for the three schemes is as shown in the Figures 5 and 6 below. Some units of fields under irrigation were so small that could not be presented in the figure of the layout hence a block system was adopted to show the distribution network or trend of the then areas under irrigation.

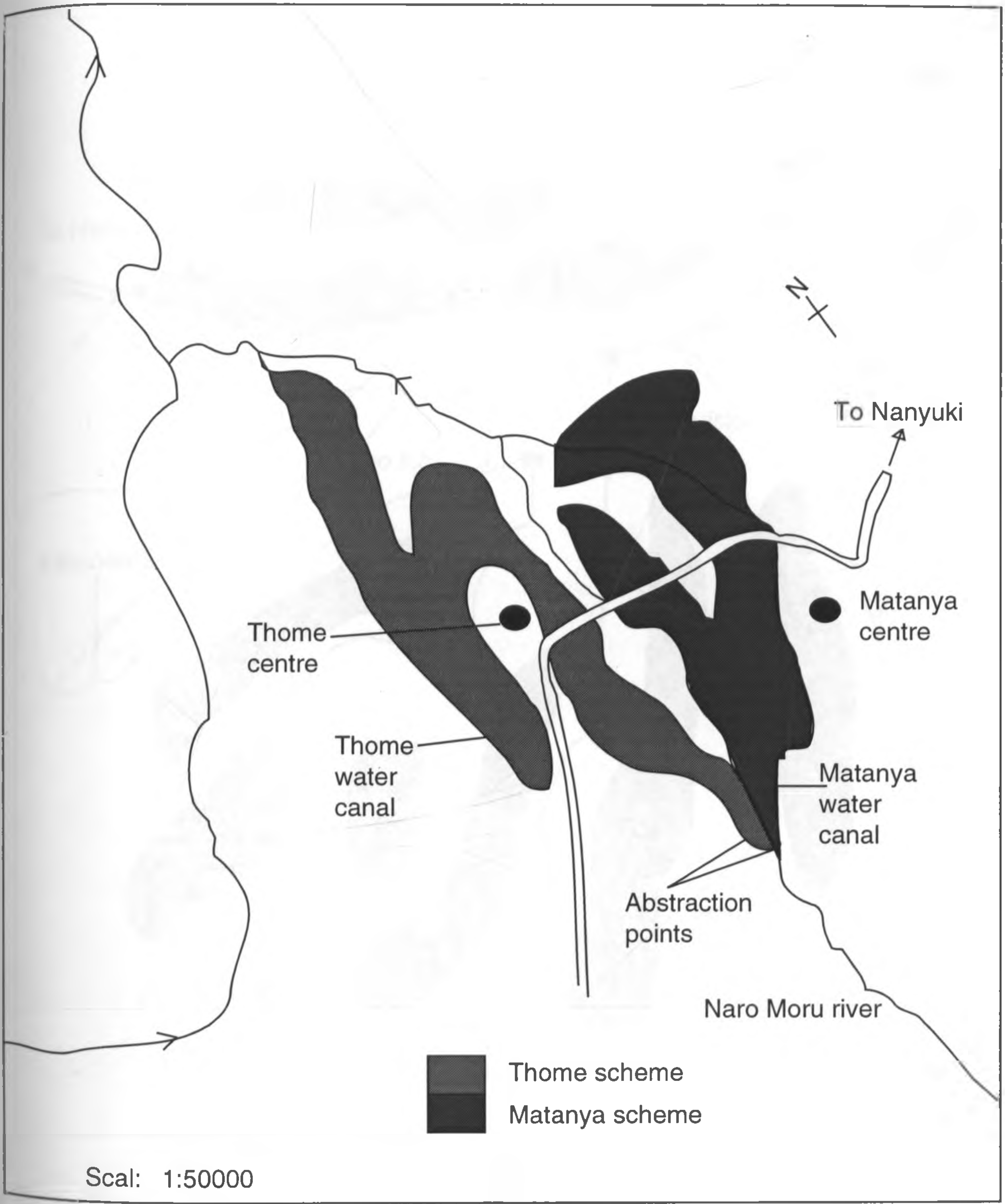


Figure 5: Thome and Matanya Schemes' Irrigated Areas

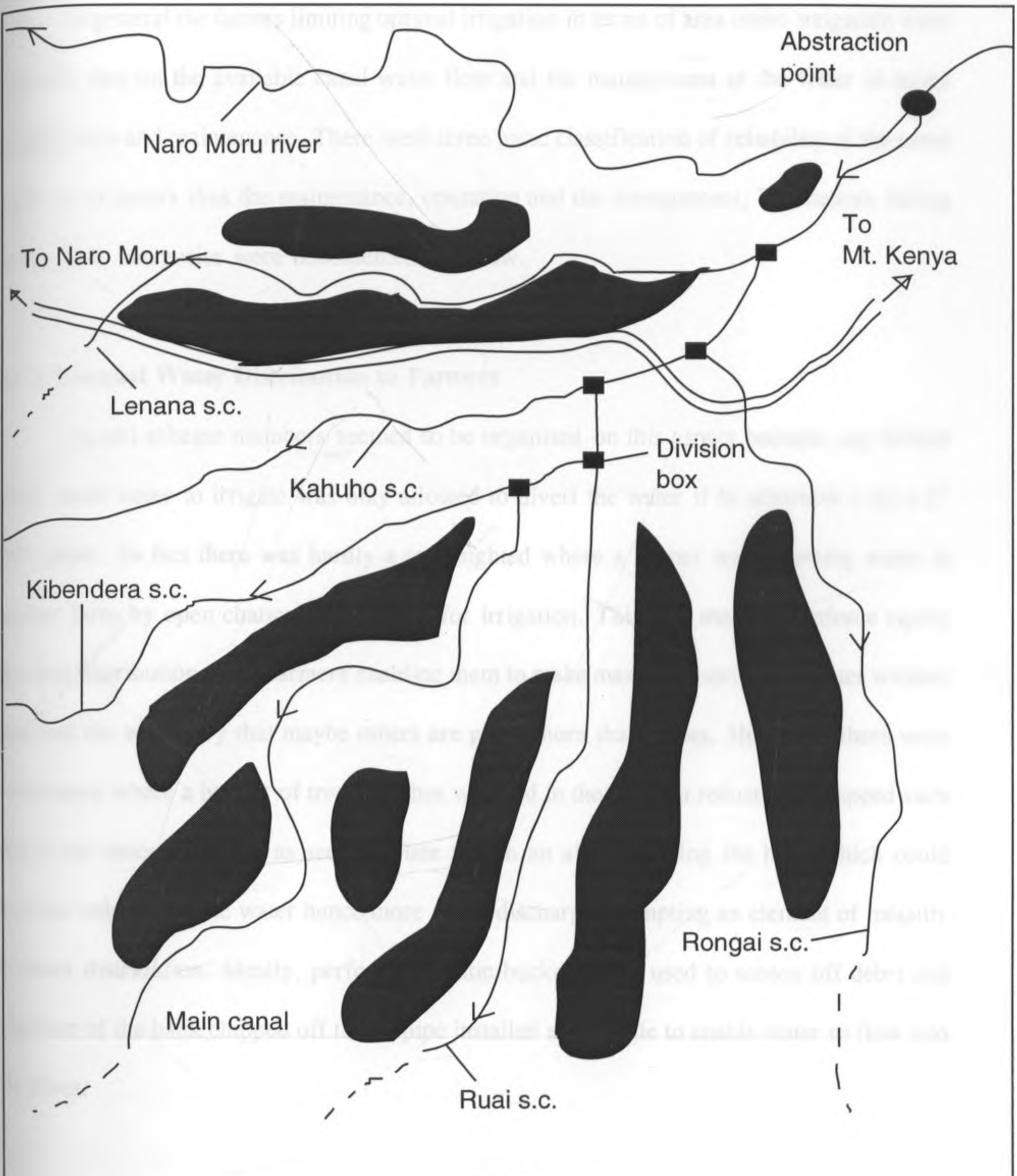


Figure 6: Aguthi Scheme's Irrigated Area

4.3 Identified Constraints to Optimising Irrigation potential

In general the factors limiting optimal irrigation in terms of area under irrigation were basically tied on the available canal water flow and the management of the water in terms of allocation and maintenance. There were three basic classification of reliability of the canal water to irrigators thus the maintenance, operation and the management. The factors falling in the three categories were documented as below.

4.3.1 Unequal Water Distribution to Farmers

Aguthi scheme members seemed to be organised on this aspect because any farmer using canal water to irrigate was only allowed to divert the water if he abstracts it by a 2" PVC pipe. In fact there was hardly a case sighted where a farmer was diverting water to his/her farm by open channel conveyance for irrigation. This was meant to enforce equity in water distribution to the farmers enabling them to make maximum use of the water without bias and not with envy that maybe others are given more than others. However, there were some cases where a barrier of tree branches was laid in the canal to reduce water speed such that it can enter the pipes as seen in plate 5 with an aim of raising the head which could increase velocity of the water hence more water discharge prompting an element of inequity in water distribution. Ideally, perforated plastic buckets were used to screen off debri and a section of the bank chipped off then a pipe installed at an angle to enable water to flow into the pipes.

Plate 5: Barriers at pipe intake points

For Matanya and Thome water canals, farmers had just opened the canal bank letting water to flow to the field at liberty as shown in plate 6, until the water becomes 'anuissance', waterlogging the field being irrigated, then that was the time to close the bank.Those who attempted to have their delivery system piped did it in a poor way where an open pipe would just be inserted in the canal (exposed to silt and debri blockages) as illustrated by Plate 7. These delivery systems had no control measure of how much water was meant or being diverted to individual fields. Cases were sighted of raising the water head by using stones and logs of wood either as a barrier or an obstacle in an effort to raise the water head at a delivery point. This vividly showed that irrigation water was unequally allocated to the users. Other farmers blocked water canals, usually at night diverting all the water to their farms. This was a hide and seek game suggesting unequal water distribution among the farmers, a practice that could not be easily quantified yet persistent.

Plate 6: Open channel delivery point of uncontrolled water flow in Matanya scheme

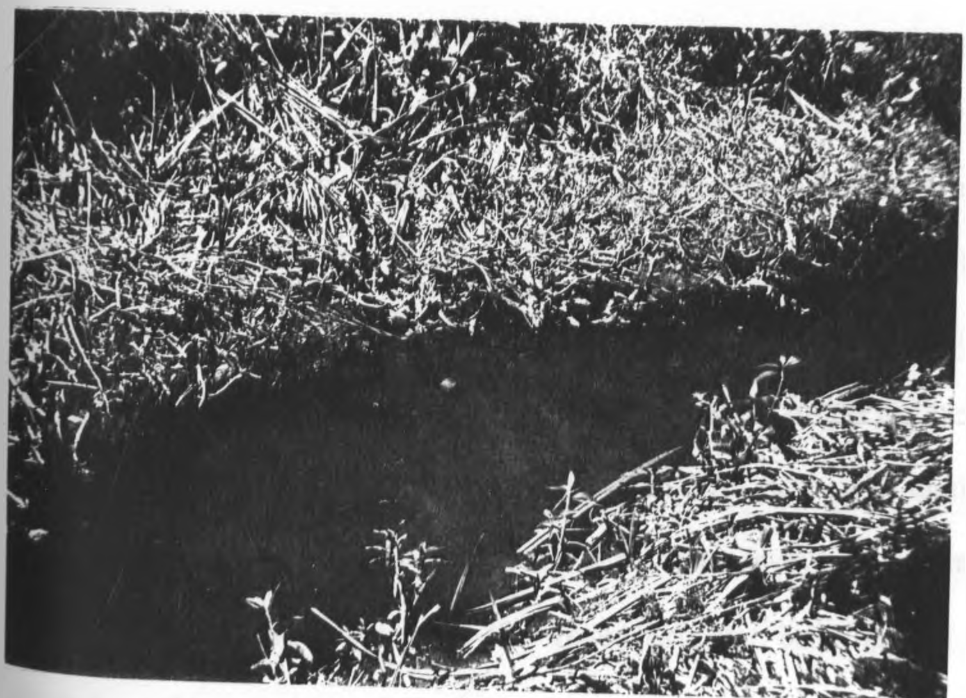


Plate 7: Open pipe delivery point prone to debri and silt blockage in Matanya scheme

4.3.2 Furrow Maintenance

The level of maintenance for the three water furrows could be categorized as bad for Aguthi, worse for Thome and worst for Matanya. This as established by visual observation as one moved along the canals was an obvious scenario. Most sections of the canal passed through bushes and sometimes they were covered totally with weeds, some floating and the others growing right from the canal bed. Where maintenance was attempted, desilting and removing weeds was done with little knowledge of retaining canal dimensions, this resulting in deeper and wider sections which increased the wetted perimeter of the cross sections hence increasing seepage losses. Plate 8 shows some weedy section of Aguthi main canal, where one can hardly recognise the canal. This portrayed a poorly maintained conveyance system.

In Matanya and Thome, most sections had weeds right in the canal covering the water totally such that water seemed stagnant and in some cases, one would hardly recognise the presence of water in such sections. On determination of ground and water channel slopes, there were irregularities revealing poor maintenance activities; slopes not consistently maintained, a condition deteriorating from head end to tail end. The water canal sections were also irregular as the widths ranged from o.5 m to 2 m and in some places where livestock used to drink water widths of 3 m to 3.5 m were observed. This was far from a water conveyance design requirement of uniform canal shape for certain required flows.

For unlined water conveyance systems, regular and proper maintenance becomes an essential activity in order to maintain relatively uniform flows with minimized conveyance losses. Weeds and other forms of obstacles in a water conveyance system interferes greatly with design parameters of water flow like wetted perimeter, bed slope and surface roughness, which from this negative maintenance attitude depict reduced flows than ideally designed.

Plate 8: A poorly maintained section of Aguthi canal

4.3.3 Organization of Water Use and Irrigation Methods

There was no clear-cut on how much water one is to take and when for Matanya and Thome canal water users. This resulted in some farmers taking more water than others. However, this study did not quantify the specific amounts of water abstracted by the farmers. Water could be seen being abstracted at the intake but at the tail end the canals were almost dry leaving the water users hardly with enough water even for domestic utility. Water would have been lost along the earthen conveyance canals through seepage (though not quantified here) but the way farmers were tapping the water to their farms unregulated was a strong contributing factor to poor organisation of canal water use. There should have been a strong managerial team to initiate and adopt the rotation system of water distribution, one way of ensuring that every member plans for the water at his/her disposal at specific time, for all users to benefit (Sagardoy *et al*, 1982). The European Commission on Agriculture (1971) quotes that 'no man may waste a drop of water that another man may turn into bread...' This is a reality and it is only through proper organization on water use among the scheme members that all can enjoy the irrigation benefits. Aguthi scheme seemed to be doing well on restricting water to be taken by each member. During times when water volume becomes little, rationing was performed such that every secondary canal misses water for two days in rotation. This was possible because of the division boxes which were constructed at water diversion points.

Strictly sprinkler irrigation method was applied by Aguthi water canal irrigators but for Thome and Matanya, it was furrow irrigation with only few farmers using sprinklers. In fact for the latter two schemes water reaches their farms mainly by seepage as the main canal is too deep to open up a furrow and let the water to the fields unless for those who had water pumps, especially during dry periods. Though sprinkling has its water application loss, its water can be controlled during irrigation than open channel irrigation.

4.3.4 Furrow Bed Levels

Aguthi canal had generally uniform bed gradients as seen from the sample bed levels in the figures below. Water generally flows uniformly and was clean. For Thome and Matanya, The relative bed levels were not uniform especially in the mid section and at the tail end. In fact in other sections water tended to move backwards and pond until it could gain a small head for the water to flow forward. For canal bed levels that were not sloping, it implied that water could not flow at the designed velocity hence water could not reach the farmers at the designed volumes. On the other hand water flowing slower than designed in the main canals increases soil - water contact time enhancing seepage hence reduced water to downward sections. These levels were spoilt mainly due to poor ways of desilting and weed removal from the canals. Sample relative levels for the three schemes are shown in graphical form as below with regard to the sections of the canals. It was noted that at the head end, the levels were sloping while the trend changed at the tail end due to siltation and poor maintenance.

Figures 7, 8, and 9 show the relative water canal bed levels and the water level determined against distance of sampled canal sections in the three schemes (see also Appendix 9). This was representative of the head end, mid section and tail end of the three canals. The water levels in all the canal had consistent trend implying that however deep the canal bed was, water had to maintain a head for it to flow. The slope irregularities reduced water velocities increasing seepage and hence less water volumes realised downwards.

In Matanya, the sampled tail end section of the canal had rising bed. In fact water was not moving but the available water may have been that which filled the canal when there had been rain of the previous season, no wonder it was reported that at times the canals dry up completely when that water has been used up and evaporated.

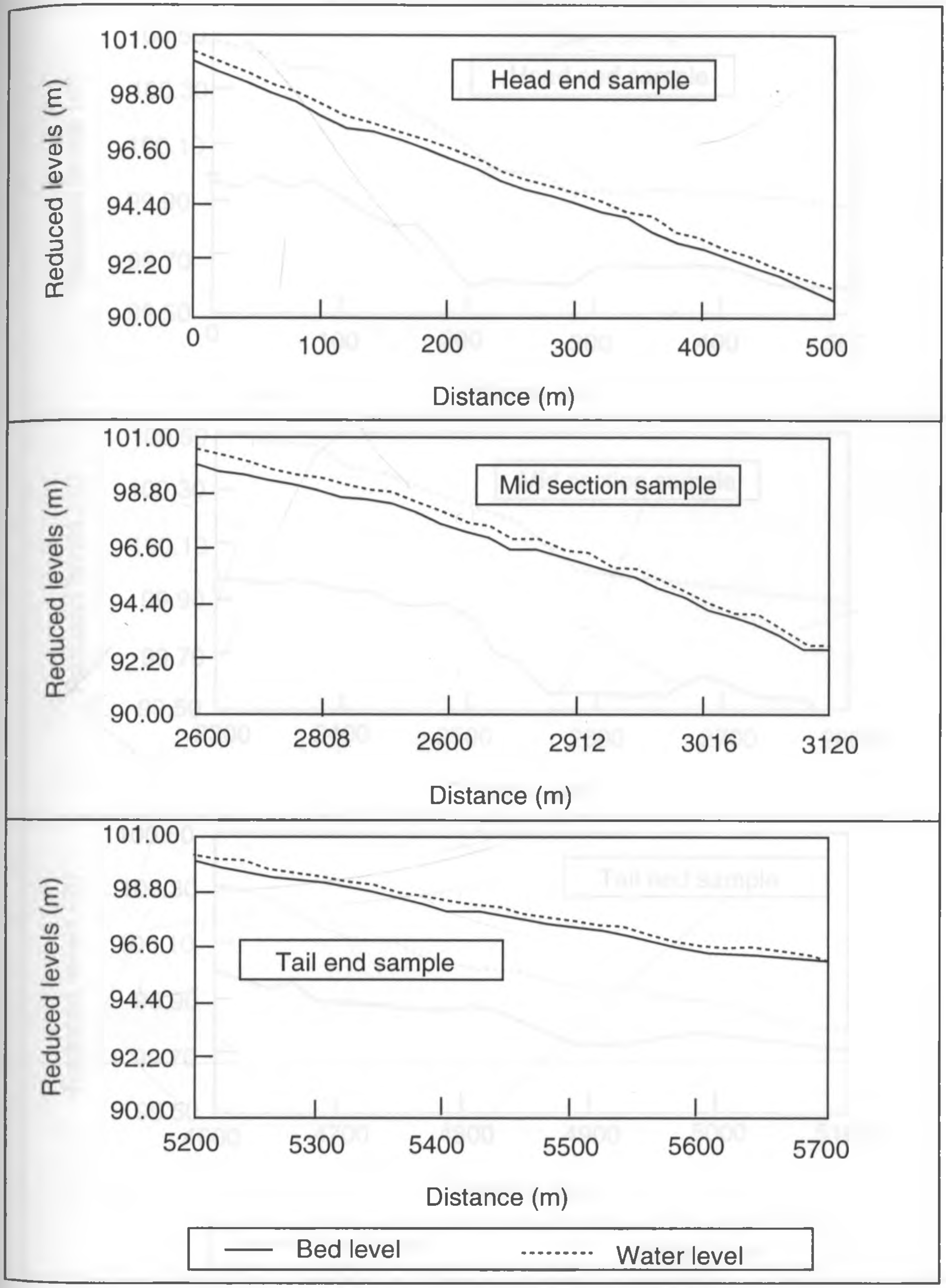


Figure 7: Canal bed level and Water level for Aguthi scheme samples

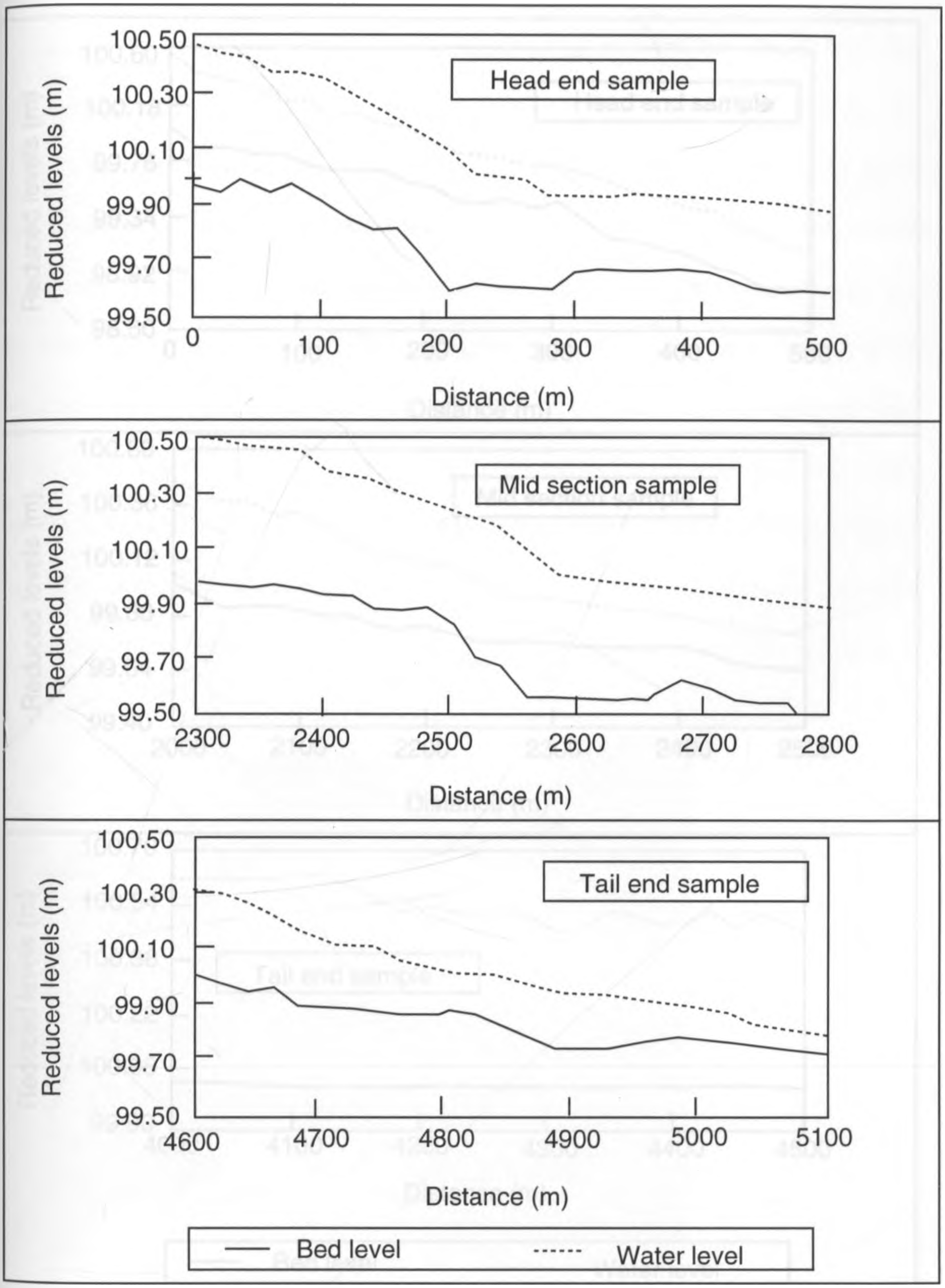


Figure 8: Canal bed level and Water level for Thome scheme samples

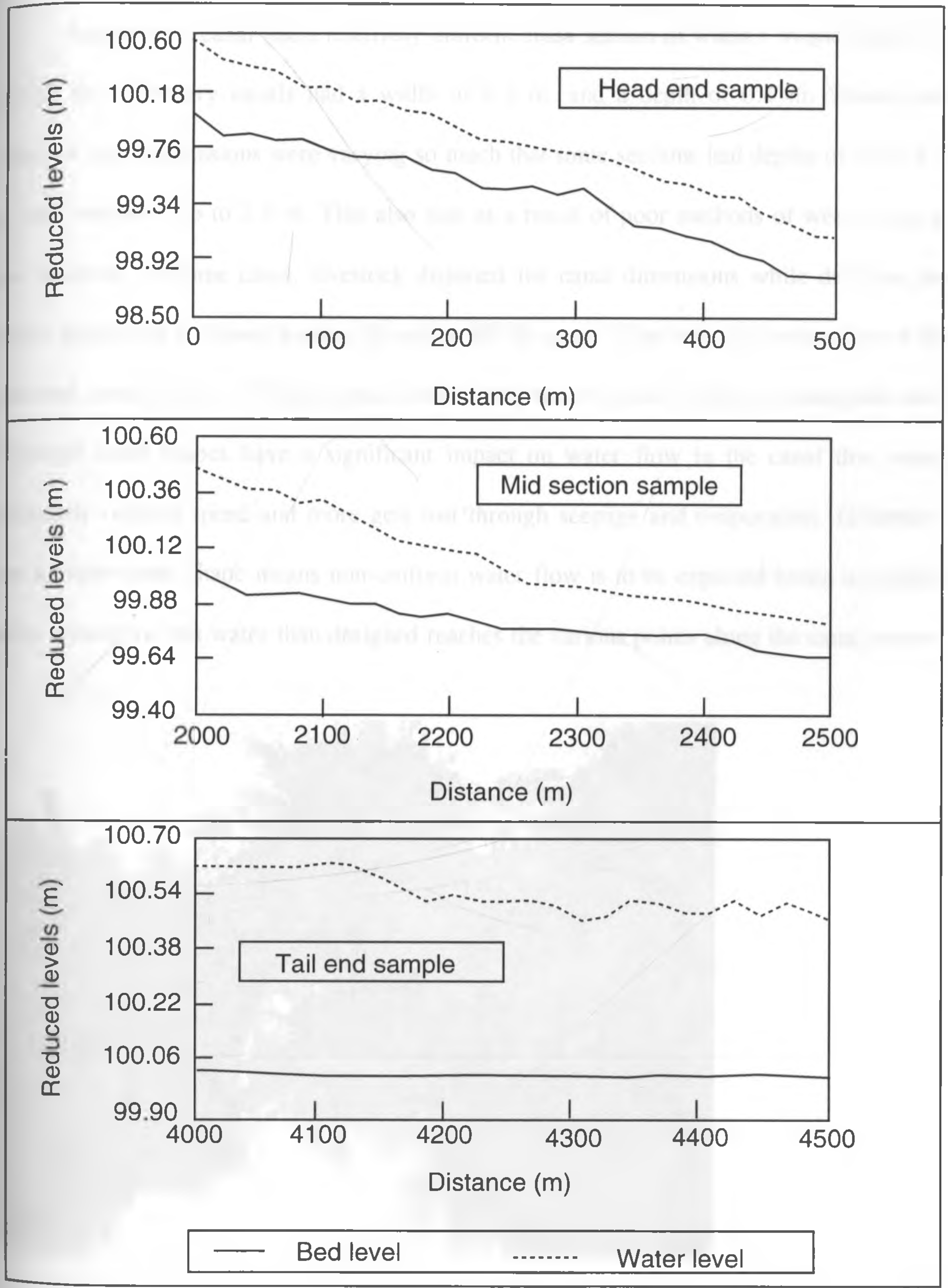


Figure 9: Canal bed level and Water level for Matanya scheme samples

4.3.5 Water Canal Dimensions

Aguthi main canal had a relatively uniform cross section of width 1 m and depth 0.7 m. All the secondary canals had a width of 0.5 m. and a depth of 0.4 m. Thome and Matanya canal dimensions were varying so much that some sections had depths of up to 1.5 m. and widths of up to 2.5 m. This also was as a result of poor methods of weed clearing and desilting. In some cases, livestock distorted the canal dimensions while drinking the water. Banks had collapsed leaving the soil to fill the canal. Plate 9 has an impression of the distorted canal shape of Thome canal contrary to the expected uniform rectangular one. Distorted canal shapes have a significant impact on water flow in the canal thus water eventually reduces speed and more gets lost through seepage and evaporation. Generally, non-uniform canal shape means non-uniform water flow is to be expected hence unreliable water volume or less water than designed reaches the various points along the canal course.

Plate 9: Acanal section with distorted shape in Thome

4.3.6 Conveyance Structures

A part from the intake concrete barriers, it is only Aguthi Canal that had division boxes for sub-furrow water diversion but all the three had culverts for crossing major roads otherwise other crossing structures were unavailable for sub furrows, a case that made water be misused as animals came to drink water along the paths leading to poor canal dimensions in those sections. Road and path crossing structures are very important for they reduce water which would have flowed downstream being lost by overflowing on the banks. See plate 10 for one of the division structures on Aguthi main canal, which is a very important structure in a water conveyance system. The water that was allowed to flow to the secondary canal was let to a PVC pipe of 4 inch diameter implying a water delivery surface area of 0.008 m^2 while that let to flow downward in the main canal had a surface area of 0.06 m^2. Taking the velocity of water at the division box to the same for the water in the main and that in the secondary canal, since the water is stilled in the box, then 13.3% of the total water at that point goes to the secondary canal. The entire network had five of such division boxes meaning water was divided in 6 sections; five to the secondaries and one of the final main, 79.8% of the water was therefore conveyed and the 20.2% could be the losses in the main canal as the water moved in the unlined canal downwards.

Plate 10: Aguthi Water Canal Division box

4.4 Potential Solutions to the Identified Constraints

4.4.1 Equal Water Distribution to Farmers

For head end, middle section and tail end farmers to be satisfied with the water they get, a well stipulated managerial component must be met. The delivery system network to the farmers must be such that all members receive equal amounts of water. This could be achieved by using a rotational based system whereby the contributors are divided in sections and each section allowed to draw water for a specific number of hours. Sagardoy *et al* 1982 (1982) discusses the several ways of allocating irrigation water to farmers in a scheme; on-demand, semi-demand, canal rotation and free demand, rotational system and continuous flow. He credits the rotational system by quoting that: 'In this system, all canals receive water by turns and farmers on the tertiary canals or watercourses receive water at a pre-set time and in the allowed quantity. This system is an improvement on the rotation and free demand one where the rotation is not only of the main canal receiving water but also to the farms. It is a highly efficient system from the operational point of view and socially fair since it gives an equal chance to everyone.'

Strictness could be developed such that no individual farmer could have the mandate to temper with the main canal water but instead maximize on water delivered in his/her own farm. Stern legal action should be taken for farmers found tempering with water delivery system.

4.4.2 Better Canal Maintenance

The factors noted that require maintenance attention are as listed below and are the same as those cited by Malik (1978).

(a) Siltation which are caused by;

1. excessive silt entry at the main canal intake
2. disproportionate withdrawal by branches
3. prolonged heading up at control points
4. drifting sand
5. inadequate transport capacity of channels
6. re-entry of excavated material by rain and wind action
7. malfunctioning of intakes
8. haphazard sediment excavation
9. excessive weed growth
10. wrong channel regulation

These causes indicate defective design (1-5), inefficient maintenance (6-9) or improper channel operation (10).

(b) Weed infestation which can seriously impede the flow of canal water.

(c) Water infiltration through canal banks caused by burrowing small crabs, ants and water rats or by rotting plants and roots.

(d) Erosion of banks caused by heavy rainfall or wind, improper canal operation, stock grazing or passage by drinking animals and transit of vehicles.

The above factors boil down to desilting and weed control as the others are interrelated. It was clear that the way the exercise of desilting and clearing off weeds was done with no knowledge of water flow factors thus gradient and dimensions. Ideally all the three schemes need regular maintenance but the badly hit cases were the Thome and Matanya canals. Silt clearing can be done manually provided that water levels can be lowered sufficiently or, even better, the canals dried for several days (Sagardoy *et al*, 1982). This method is quite effective, although the actual organization of the work could be a problem. There are four main methods of controlling canal vegetation: manual, mechanical, chemical and biological. The choice of method depends on the availability of labour, the predominant weed species, the environment and economic conditions. The manual method is ideal for these schemes as labour is available but only requires organization.

In the three schemes studied, the manual method was appropriate as the labour was available (scheme members). Weeds therefore could be removed by cutting, mowing or dredging. Emergent weeds and submerged weeds are best cut near the base of the stem, leaving roots and rhizomes undisturbed as this would affect the slopes. To be sure of having not tempered with this vital parameter in water flow (bed slope) during the maintenance exercise, a dumpy level could be used as a check. A tape measure should also be handy to confirm that the dimensions are according to the design.

It was observed that farmers were allocated sections to maintain and this was done at their own schedule, an exercise that was distorting the whole canal system in terms of shape and gradient. It was not logical to find some sections clean while others were very weedy. It would have been better to start cleaning the canal right from the intake to the end in order to maintain these two parameters (bed slope and dimensions) to their designed values.

The benefit of maintaining water canals is to maintain water flow rates as designed making expected water available for use, but if weeds are left to utilise the water, less is received for intended purposes since the weeds develop unuseful biomass to mankind. If silt is left to accumulate, the flow rates are reduced as the slope is distorted.

4.4.3 Water Uses

The canal water was to be used for domestic, livestock and irrigation. It was noted that in Matanya and Thome, farmers were obtaining water continuously from the canals at their own digression and letting it flow to their fields without caring if there are other users down the canal. In Aguthi, the case was a little different since those who tapped the water through pipes could close them after irrigating. This could be avoided if there was organization on water delivery to each farmer. Also, the method of water delivery from the canal to individual farmer could be controlled as was exercised in Aguthi scheme where whoever takes the water for irrigation uses a pipe and uses a sprinkler to irrigate, a device that can be controlled. Otherwise the issue of just opening a furrow to a farm and letting the water to flow to a crop was leading to water wastage and unmeasurable application of water to a given crop. In fact it was like irrigating more of weeds than crops so it would have been better to plant crops like arrow roots or any other edible or useful biomass than just letting unuseful biomass to take up the water.

4.4.4 Water Allocation

According to water permits of water canals, at the design stage, only water to meet domestic and livestock needs is ranked first then irrigation comes later at the abstraction point. There was no partition as for the quantities of water to be allowed for irrigation, domestic and livestock needs. This was so because these canals were constructed by the white settlers whose aim was to utilise the water for their domestic and livestock. It was noted that livestock were being let to take the water at their own pleasure directly from the canals and any farmer with ability tapping any amount of water for irrigation. It would have been more sensible to invest in water tanks where the amount of water would be known to give to the animals implying no animals go to distort the canal dimensions; one would also be able to quantify the water consumed by the animals and be abe to recommend the water to be put into irrigation assuming that for domestic consumption can be averagely estimated.

4.4.5 Untimely Irrigation Scheduling

Irrigation water is least required during rainy seasons, and is most needed during dry spells. What was observed was that the canals were overflowing whenever it was raining and could be almost dry during dry seasons. To be able to achieve a continuous irrigation exercise, storage tanks could be installed by the irrigators to store water when it water in abundance to be used whenever it was required. If farmers could form groups and have a common goal of irrigating known crops at given times, they could construct tanks and hire a pump to fill them during rainy seasons and hence control the water by pipe system when irrigating. The size of the tanks to be constructed would depend on the types of crops to be grown, the duration of dry periods, the cost of constructing and the number of water users per group. Also farmers were observed irrigating even when it was raining an issue that showed lack of knowledge on crop water requirements. This could be avoided if farmers could be informed through extension service or irrigation experts on how to calculate or estimate crop water requirements on real-time basis for effective scheduling hence avoid water misuse.

4.4.6 Canal Gradients and Dimensions

Without consistent canal gradient, according to the Manning equation, water cannot flow at the required speed and volume. To ensure that this is maintained, the operation of canal clearing (maintenance) should be done with this in consideration. To effect it, when clearing, a dumpy level could be used and a tape measure handy to maintain the dimensions and the gradient of the canal for water to flow according to the design. Livestock should be prohibited from taking the water directly from the canal as they tend to distort the canal dimensions and gradient.

4.4.7 Conveyance Structures

For effective water distribution, water has to be divided to secondary and tertiary canals through division boxes. Whenever the canal is crossing a path or road, it should be conveyed in culverts. Another effective way of conveying canal water is by lining the canal although this is expensive and depends on the value of use of the water if cost effectiveness is to be considered. Piping the water is another expensive but viable way of conveying canal water and can effect better allocation of water to farmers if gates are incorporated, all these alternatives aim at reducing water loss and ensuring designed water volumes to reach the targeted water users.

Water diversion to individual farmers posed another problem especially for Aguthi scheme. Along the canal, a section of about 30 m could be identified and noted to have 10 pipe delivery points to serve the 10 farms. This was a common scenario for most sections in this scheme. Some financially able farmers could tap water from as far as 500 m to their fields thereby crossing many other farms, this made such farmers have more water delivered to their farms due to a larger water head than others. In fact there a tense network of pipes through some fields posing a danger to any possibility of using machinery like tractors in land preparation of the said fields. A sample layout presented in Figure 10 (a section of Aguthi canal) reveals the cost of installing such pipes and the inconvenience caused to the farms through which the pipes pass. This actually means more conveyance loss than if the farmers had a common delivery point as illustrated in Figure 11. The many individual abstractions in Figure 10 could be restructured to 5 main abstraction points as shown in Figure 11. Such a system would prompt an element of responsibility and social implication of common goal setting for the individual farmers. The cost of piping would be shared among the users and raise an element of better care and use of the water resource.

Even for earthen water conveyance systems, the re are critical points where installation of conveyance structures are inevitable. At road and path crossings where culverts are appropriate to minimize canal water flow interference with by-passing traffic, people or animals. Division boxes are to be installed whenever a major diversion of water is located while gated or lockable pipe fitting is required whenever an individual diversion point is located.

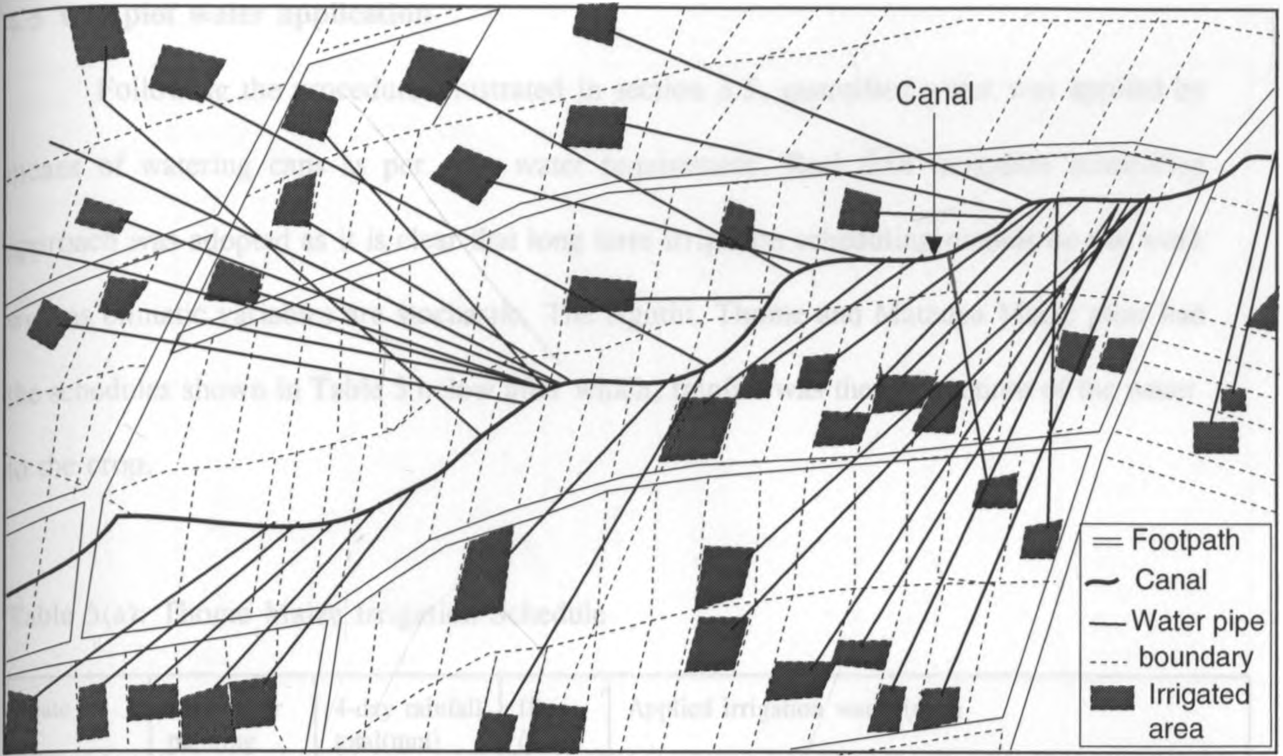


Figure 10: A section of multi point water delivery system as practised in Aguthi scheme

Figure 11: Alternative common point water delivery system for Aguthi Canal water users

4.5 Test plot water application

Following the procedure illustrated in section 3.5, quantified water was applied by means of watering cans as per crop water requirement. Real time irrigation scheduling approach was adopted as it is clear that long term irrigation scheduling models do not work well as climatic variables are stochastic. The Aguthi, Thome and Matanya Maize plots had the schedules shown in Table 5 below after which, rainfall was the only source of the water to the crop.

Table 5(a): Thome Maize Irrigation Schedule

Date	Days after planting	4-day rainfall total(mm)	IR (mm)	Applied irrigation water (mm)		
				Trt 1 (33IR)	Trt 2 (66IR)	Trt 3 (100 IR)
17/1/95	0	0.0	10.0	10.0	10.0	10.0
22/1/95	4	0.0	6.1	6.1	6.1	6.1
26/1/95	8	0.0	3.5	3.5	3.5	3.5
30/1/95	12	0.0	7.0	7.0	7.0	7.0
3/2/95	16	0.0	6.4	2.0	4.0	6.4
7/2/95	20	0.0	15.5	5.2	10.0	15.5
11/2/95	24	23.5	0.0	0.0	0.0	0.0
15/2/95	28	8.0	0.0	0.0	0.0	0.0
19/2/95	32	6.5	0.0	0.0	0.0	0.0
23/2/95	36	0.0	0.0	0.0	0.0	0.0
27/2/95	40	17.8	9.7	3.0	6.3	9.7
3/3/95	44	60.5	0.0	0.0	0.0	0.0
7/3/95	48	12.8	0.0	0.0	0.0	0.0
11/3/95	52	0.8	0.0	0.0	0.0	0.0
15/3/95	56	10.3	0.0	0.0	0.0	0.0
19/3/95	60	-	0.0	0.0	0.0	0.0
23/3/95	64	-	0.0	0.0	0.0	0.0
27/3/95	68	-	0.0	0.0	0.0	0.0

Table 5(b): Aguthi maize irrigation schedule

Date	Days after planting	4-day rainfall total(mm)	IR (mm)	Applied Irrigation Water (mm)		
				(33IR)	(66IR)	(100IR)
31/12/94	0	0.0	10.0	10.0	10.0	10.0
6/1/95	5	0.0	7.8	7.8	7.8	7.8
11/1/95	10	0.0	6.4	6.4	6.4	6.4
16/1/95	15	0.0	7.9	7.9	7.9	7.9
21/1/95	20	0.0	8.0	2.7	5.3	8.0
26/1/95	25	0.0	10.0	3.3	6.6	10.0
31/1/95	30	0.0	10.4	3.4	6.8	10.4
5/2/95	35	0.0	19.7	6.5	13.0	19.7
10/2/95	40	25.0	10.6	3.5	7.0	10.6
15/2/95	45	14.6	0.0	0.0	0.0	0.0
20/2/95	50	8.5	0.0	0.0	0.0	0.0
25/2/95	55	16.0	0.0	0.0	0.0	0.0
2/3/95	60	10.8	4.0	1.3	2.6	4.0
7/3/95	65	80.0	0.0	0.0	0.0	0.0
12/3/95	70	14.8	0.0	0.0	0.0	0.0

Table 5(c): Matanya maize irrigation schedule

Date	Days after planting	4-day rainfall total(mm)	IR (mm)	Applied irrigation water (mm)		
				(33IR)	(66IR)	(100IR)
2/1/95	0	0.0	10.0	10.0	10.0	10.0
6/1/95	4	0.0	6.9	6.9	6.9	6.9
10/1/95	8	0.0	5.6	5.6	5.6	5.6
14/1/95	12	0.0	4.9	4.9	4.9	4.9
18/1/95	16	0.0	5.6	1.8	3.6	5.6
22/1/95	20	0.0	6.1	2.0	4.0	6.1
26/1/95	24	0.0	3.5	1.2	2.3	3.5
30/1/95	28	0.0	7.0	2.4	4.8	7.0
3/2/95	32	0.0	6.4	2.2	4.2	6.4
7/2/95	36	0.0	15.5	5.2	10.2	15.5
11/2/95	40	23.5	0.0	0.0	0.0	0.0
15/2/95	44	8.0	0.0	0.0	0.0	0.0
19/2/95	48	6.5	0.0	0.0	0.0	0.0
23/2/95	52	0.0	0.0	0.0	0.0	0.0
27/2/95	56	17.8	9.7	3.2	6.3	9.7
3/3/95	60	60.5	0.0	0.0	0.0	0.0
7/3/95	64	12.8	0.0	0.0	0.0	0.0
11/3/95	68	0.8	0.0	0.0	0.0	0.0
15/3/95	72	10.3	0.0	0.0	0.0	0.0

From the time of planting, the treatments were the same as this was the establishment stage of the maize. After applying only three real treatments in accordance to the experimental design, rainfall was in excess of the crop water requirement and therefore the treatment practice ceased. Rainfall data on daily basis was therefore obtained for the season the maize grew and compared with the crop water requirement to be able to see when irrigation was necessary.

4.6 Maize Yield Analysis

The maize crop was harvested and the shelled grain weighed and recorded as shown in Table 6. It was clear that the yield depended on the water application of the crop water requirement thus the 33% irrigation requirement treatment yielding least while the 66% irrigation requirement yielding most. This in essence implied that applying the 100% irrigation requirement in the three schemes was ineffectively using the water as maybe most of it was just percolating down the soil profile and not effectively utilised by the crop.

Table 6: Maize Yield Results (g/plot)

Scheme	Matanya				Thome				Aguthi			
Trt	a	b	c	Mean	a	b	c	Mean	a	b	c	Mean
1	810	830	765	801.7 1336*	875	850	795	840 1400*	675	830	865	790 1317*
2	1490	2260	1840	1863 3105*	1760	1535	1945	1747 2912*	1630	1575	2045	1750 2917*
3	1375	1790	2135	1767 2945*	2110	1475	1645	1645 2742*	1850	1635	1965	1817 3028*

* (kg/ha)

The mean treatment yields were analyzed for variance and were found significantly different at the 5% level of significance in all the three schemes (Appendix 5, 6 and 7). Duncan's Multiple Range Test ranked yields from plots under treatment 1 lowest.

Linear regression of yield on irrigation water supply gave a strong linear correlation between the two (Table 7). The results agree with findings by Barret and Skogerboe (1978) that although water applied versus grain yield curve is concave upwards, the relationship is close to linear when the water application efficiency is high. In a study of water-yield response of a maize-bean intercrop Lenga and Stewart also found that maize yield and ET_a were strongly correlated with r =0.95.

Table 7: Regression analysis of yield on irrigation water supply

Scheme	Constant term (A)	Regression Coeff.(B)	Correlation Coeff.(r)
Matanya	878.63	2386.99	0.817
Thome	1031.06	1990.35	0.805
Aguthi	735.15	2542.48	0.889

Yield response factor (K_y) was computed according to Doorenbos and Kassam (1986). The K_y values in treatment 1 relative to treatment 3 were high and ranged from 0.73 to 1.23. This shows that in treatment 1 the plants were severely stressed resulting in high yield depression whereas in treatment 2 the stress was mild with negligible effect on yields relative to treatment 3 (Table 8). The negative values of K_y are a result of higher mean yields recorded in treatment 2 than treatment 3 and are attributable to experimental inadequacies hence can be taken to be zero. The computation assumes that evapotranspiration during the vegetative phase and yields at 100IR were maximum (ET_m and Y_m respectively).

Table 8: Yield Response Factor (K_y)

Scheme	ET_a /ET_m	Y_a /Y_m	K_y
Matanya	0.33	0.454	0.815
	0.66	1.054	-0.0159*
Thome	0.33	0.511	0.730
	0.66	1.062	-0.182*
Aguthi	0.33	0.435	0.844
	0.66	0.963	0.108

* yield at 66IR > yield at 100IR; ET_a is the actual evapotranspiration, ET_m is the maximum evapotranspiration, Y_a and Y_m are the actual and maximum yield respectively.

4.7 Site Maize Yield Analysis

Another factor considered was if the yields for the different sites was any different. Analysis of variance test was carried out, site of the scheme being the main factor, yield being the variable and the replicates being the irrigation requirement treatments. A summary of the ANOVA test and the Duncan's Multiple Range Test are as presented in Appendix 8.

This showed that the yields were highly dependant on the site regardless of the same treatments, a fact that could be attributed to the soil conditions of a given site. However the Duncan's Range Test showed that for the 33% and 66% crop water irrigation requirement application was not significant on the obtained yield on Matanya and Thome plots but was on the Aguthi scheme experimental plots.

4.8 Water-Yield Relationship

The source of water to the crop was rainfall and irrigation. Table 9 presents the yield per unit volume of water extrapolated on per hectare basis. The yield considered in this case was only the dried grain. It could be deduced that just like the yields/ha were highest for the 66% Irrigation requirement, so was the yield/m^3/ha was. This vividly implied that the extra amount of water applied at the 100% IR was unproductive hence the scheme members can adopt the 66% IR dose of water hence make maximum use of the available water.

Table 9: Maize grain yield-water analysis

Scheme	Trt (% IR)	Rainfall (mm)	IR (mm)	Yield (Kg/ha)	Total water (l)	Yield response to water Kg/m^3
Thome	33	1974.6	223	1400	3662.67	0.38
	66	1974.6	284	2912	3764.33	0.77
	100	1974.6	349	2742	3872.67	0.71
Matanya	33	1950.8	271	1336	3703.00	0.36
	66	1950.8	376	3105	3878.00	0.80
	100	1950.8	487	2945	4063.00	0.72
Aguthi	33	1726.8	317.1	1317	3406.50	0.39
	66	1726.8	441.6	2917	3614.00	0.81
	100	1726.8	569.1	3028	3826.50	0.81

The yield response to water that was realised in the three schemes under treatments 1 and 2 are within the range of water utilization efficiency for harvested yield of 0.8 to 1.6 kg/m^3 as recorded by Doorenbos and Kassam (1986).

4.9 Soil Characterization

4.9.1 Soil Basic Infiltration Rates

The results of the infiltration rate tests carried out are as shown in Table 10. This data was fitted in the Horton's infiltration rate equation which according to Sharma (1994) is the simplest infiltration rate equation since the variables involved can easily be determined in the field. The equation states that

$$f = f_c + (f_c - f_o)\, e^{-kt}$$

Where f = infiltration rate (mm/hr)

f_c = final infiltration rate (mm/hr)

f_o = initial infiltration rate (mm/hr)

k = decay constant

t = time (hr)

Table 10: Soil Infiltration Rates for Thome Matanya and Aguthi Schemes

	Aguthi	Matanya	Thome
Time (hr)	Infil. rate (mm/hr)	Infil. rate (mm/hr)	Infil. rate (mm/hr)
0.08	15.8	14.5	16.6
0.17	13.8	13.6	14.5
0.25	11.6	10.8	10.3
0.33	12.8	12.0	11.8
0.50	7.9	7.5	8.3
0.67	8.4	7.2	7.9
0.83	7.8	7.4	7.4
1.00	7.4	7.0	7.2
1033	6.8	7.6	7.7
1.67	6.5	6.8	7.3
2.00	7.2	6.5	7.5
2.50	5.6	6.3	6.8
3.00	5.4	6.3	6.8
3.50	5.4	6.3	6.8

It was found that the infiltration rates at the three sites were high and this signified that most of the water applied initially to the crops percolated down the soil profile. This may have been because of the large cracks at the sites during the time of experimentation. Generally basic infiltration rates have a bearing on how water moves down the soil profile hence would be an indicator of water holding capacity at steady state infiltration and assist in determining how much water to apply to a crop when irrigating.

4.9.2 Soil Textural Class

The soils were sampled depthwise at an interval of 20 cm. The samples were five for each scheme plot and for each of the samples, its textural class was determined using the hydrometer method. For the length of 1 m sampled, it was found that the soils were uniform, thus Matanya and Aguthi could be classified as Sandy clay loam While the Thome soil could be classified as Loam soil. The results were tabulated as in Table 11 below

Table 11(a): Matanya plot Soil Textural class

Sample Length (cm)	%Sand	%clay	%silt	Textural class
0-20	53.3	22.0	24.7	Sandy clay loam
20-40	53.3	26.7	18.0	Sandy clay loam
40-60	53.3	28.7	18.0	Sandy clay loam
60-80	53.3	30.7	16.0	Sandy clay loam
80-100	53.3	22.0	24.7	Sandy clay loam

Table 11(b): Aguthi plot Soil Textural class

Sample Length (cm)	%Sand	%clay	%silt	Textural class
0-20	49.55	30.2	20.3	Sandy clay loam
20-40	52.0	28.5	19.5	Sandy clay loam
40-60	53.6	28.0	18.4	Sandy clay loam
60-80	53.8	29.2	17.0	Sandy clay loam
80-100	56.0	28.4	15.6	Sandy clay loam

Table 11(c): Thome plot Soil Textural class

Sample Length (cm)	%Sand	%clay	%silt	Textural class
0-20	39.0	23.0	38.0	loam
20-40	42.3	21.5	36.2	loam
40-60	48.3	18.5	33.7	loam
60-80	47.9	20.0	32.1	loam
80-100	49.4	19.6	31.0	loam

Thome had more silt due to flooding during rainy seasons since the experimental plot was at the water canal intake where whenever it rains heavily, the river and canal banks overflow. Similarly as for the case of Matanya and Aguthi soils, Thome soils were uniform within the 100 cm depth sampled. This uniformity verified that there was no ambiguity in water flow down the soil profile when irrigating.

5.0 CONCLUSIONS

It was established that the actual irrigated area is far less than the potential irrigable area in terms of acreage. For instance, Aguthi, Thome and Matanya irrigation schemes were only irrigating below 50% of the potential. This verified that there are hindrances in full irrigation potential exploitation.

The factors leading to this under-irrigation were; lack of proper water canal maintenance leading to poor water flow hence water unreliability supply, unequal water distribution creating a situation whereby head end farmers misuse water while tail end farmers hardly get irrigation water, lack of knowledge on irrigation water scheduling and planting times, lack of designed road and path crossing structures leading to water losses, not maintaining water canal gradients hence water stagnation and poor management and organization on water allocation distribution and application by the farmers in question.

Proposed solutions to these constraints were that the farmers organise among themselves on how to ration the water among themselves preferably on time basis other than on demand basis for all to benefit. Water conveyance structures like culverts are inevitable at road and path crossing sections to avoid unnecessary water losses. Livestock should be restricted to drink water at homesteads instead of going to destroy water canal dimensions. Clearing of the canal should be organized such that weed removal and desilting start at the intake to the end to maintain canal bed levels and dimensions for effective water flow. To ensure consistent irrigation water availability, farmers are advised to construct water storage tanks such that when water is abundant in the canals it can be stored and used when dry spells come. This will in effect prompt farmers to consult irrigation professionals on crop water requirement principles, irrigation technologies and cropping systems to maximise on the utility of the available water.

There was the tendency of just crying that water is scarce yet other farmers had water crossing their farms but not utilised at all for irrigation, while other farmers divert more water than they require, this resulting in wastage of the so called scarce resource. In fact what came out vividly from the research findings is that there is poor water governance at both community level and institutional level. This was established from the fact that there is no monitoring unit from the concerned government ministry on the water use as per the issued water permits if any while at community level, there is no streamlined water governance principles, if they are, they are not followed.

If the levels of canal water management for the three schemes were to be compared, the ranking would be; Aguthi, Thome and Matanya. This was because In Aguthi, the water intake from the river was well constructed of a weir and a control gate to a lined canal where the permitted flow could be controlled. The water users were strictly to use 2 inch pipes to divert water to their farms and homesteads and at the same time, the canal had division boxes to divide water to secondary canals, the canal bed levels were hydraulically acceptable, the canals were generally clean. These factors which portrayed a fairly good water management system were missing in Thome and Matanya schemes.

Basically the cost implication to the remedial solutions proposed is labour oriented though this can be availed by the scheme members if educated on the anticipated benefits. With careful implementation of these solutions, the whole array of irrigation benefits can be realised thus: creation of employment in the rural set up, increased yields, diversified crop production for food and commercial, and farm production being achieved throughout a calendar year.

6.O SUGGESTIONS FOR FURTHER WORK

For irrigation schemes to be effective, a multi-displinary team of professionals or researchers are required to look into and enforce the following:

1. modern canal design and water conveyance systems command area and permissible flows in mind
2. Water allocation network to the farmers
3. Soil-water-and crop yield production analysis and results (to give an impression of irrigation demand)
4. Scheme water management organization
5. Design of sustainable water storage facilities to avail water throughout a calender year
6. Persistent extension services and evaluation of the viability of the schemes' productivity and the agro-economic performance
7. An account of the socio-economic implications of the schemes

The role of governance should be studied at both community and institutional levels to highlight water management aspects for an effective system utilising the scarce resource, water in line with social and economic respects.

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8.0 APPENDICES

Appendix 1(a): Irrigation Potential for Aguthi scheme based on varied planting dates

Planting date	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January 1	permitted flow (l/s)	90	67	52	115	132	117	91	102	97	92	89	96
	ET_o/month (mm)	6.1	5.8	4.5	4.2	5.0	4.8	5.3	5.0	4.6	4.5	4.0	5.0
	K_c	0.4	0.78	1.05	0.8	0.76	0.58						
	ET_c (mm)	2.4	4.5	4.73	3.7	3.8	2.8						
	R_{eff} (mm)	0.0	64.1	105.8	45.4	52.3	39.6						
	$IR_{(daily)}$ (l/s/ha)	12.51	10.35	6.74	10.85	10.84	7.35						
	Irr.area (ha)	7.20	6.47*	7.72	10.59	12.17	15.92						
February 1	K_c		0.4	0.78	1.05	0.8	0.76	0.58					
	ET_c		2.32	3.51	4.41	4.0	3.65	3.07					
	IR		0.14	0.50	14.37	11.87	11.57	14.64					
	IA		468.53	103.5	7.97	11.12	10.11	6.22*					
March 1	K_c			0.4	0.78	1.05	0.8	0.76	0.58				
	ET_c			1.8	3.28	5.25	3.84	4.03	2.9				
	IR			NIR	0.50	18.28	12.51	19.56	14.29				
	IA			Inf.	231.61	7.22	9.35	4.65*	7.14				

*: Irrigation potential NIR: No irrigation requirement Inf.: maximum available area

Appendix 1(a) continuation

April 1	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	K^c				0.4	0.78	1.05	0.8	0.76	0.56			
	ET_c				1.68	3.9	5.04	4.24	3.8	2.67			
	IR				0.83	11.35	18.48	20.65	18.19	11.34			
	IA				138.95	11.63	6.34	4.41*	5.40	8.55			
May 1	K_c					0.4	0.78	1.05	0.8	0.76	0.58		
	ET_c					2.0	3.74	5.56	4.0	3.50	2.61		
	IR					1.6	12.01	27.41	19.93	15.46	1.59		
	IA					82.17	973.4	3.32*	5.12	6.27	57.8		
June 1	K_c						0.4	0.78	1.05	0.8	0.76	0.58	
	ET_c						1.92	4.13	5.25	3.68	3.42	2.32	
	IR						2.97	20.08	26.34	16.36	5.75	NIR	
	IA						39.27	4.53	3.87*	5.93	16.01	Inf.	
July 1	K_c							0.4	0.78	1.05	0.8	0.76	0.58
	ET_c							2.12	3.9	4.83	3.6	3.04	2.9
	IR							9.77	19.42	22.87	6.66	NIR	NIR
	IA							9.31	5.25	4.24*	13.79	Inf.	Inf.

Appendix 1(a) continuation

August 1	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	K_c	0.58							0.4	0.78	1.05	0.8	0.76
	ET_c	3.54							2.0	3.59	4.73	3.04	3.8
	IR	18.16							9.67	15.90	12.47	NIR	7.38
	IA	4.96*							10.55	6.10	7.38	Inf.	7.41
September 1	K_c	0.76	0.58							0.4	0.78	1.05	0.8
	ET_c	4.64	3.36							1.84	3.51	4.2	4.0
	IR	23.81	4.98							7.22	6.21	0.99	3.65
	IA	3.78*	13.45							13.44	14.82	89.65	26.36
October 1	K_c	0.8	0.76	0.58							0.4	0.78	1.05
	ET_c	4.88	4.41	2.61							1.8	3.12	5.25
	IR	25.04	9.82	NIR							NIR	NIR	16.99
	IA	3.59*	6.82	Inf.							Inf.	Inf.	5.65
November 1	K_c	1.05	0.8	0.76	0.58							0.4	0.78
	ET_c	6.41	4.64	3.51	2.44							1.6	3.9
	IR	32.89	10.90	0.50	4.60							NIR	15.04
	IA	2.73*	6.15	104.4	24.99							Inf.	6.38
December 1	K_c	0.78	1.05	0.8	0.76	0.58							0.4
	ET_c	4.76	6.09	3.6	3.12	2.9							2.0
	IR	31.05	17.62	0.96	7.98	5.75							NIR
	IA	2.90*	5.51	54.17	14.41	22.99							Inf.

Appendix 1(b): Irrigation Potential for Matanya scheme based on varied planting dates

Planting date	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January 1	permitted flow (l/s)	98	103	110	63	119	70	58	50	30	50	60	98
	ET_o/month (mm)	5.5	5.1	4.6	3.9	4.8	5.3	4.3	4.7	5.3	3.6	2.8	2.6
	R_{eff}/month (mm)	22.0	55.8	84.4	90.0	32.3	66.6	46.6	30.0	34.6	77.1	14.5	93.2
	K_c	0.4	0.78	1.05	0.8	0.76	0.58						
	ET_c (mm)	2.2	3.98	4.83	3.12	3.65	3.07						
	$IR_{(daily)}$ (l/s/ha)	7.65	9.21	10.81	0.60	13.38	3.90						
	Irr.area (ha)	12.82	11.18	10.17	105.73	8.89*	17.90						
February 1	K_c		0.4	0.78	1.05	0.8	0.76	0.58					
	ET_c		2.04	3.59	4.1	3.84	4.03	2.49					
	IR		0.21	4.45	5.46	14.36	8.98	5.06					
	IA		471.71	24.71	11.53	8.29	7.79*	11.45					
March 1	K_c			0.4	0.78	1.05	0.8	0.76	0.58				
	ET_c			1.84	3.04	5.04	4.24	3.27	2.73				
	IR			NIR	0.2	20.51	10.02	8.52	9.04				
	IA			Inf.	317.20	5.80*	6.98	6.80	5.53				

Appendix 1(b) continuation

	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
April 1	K_c				0.4	0.78	1.05	0.8	0.76	0.58			
	ET_c (mm)				1.56	3.74	5.57	3.44	3.57	3.07			
	IR				NIR	6.69	16.63	9.94	13.36	9.52			
	IA				Inf.	17.76	4.21	5.84	3.75	3.15*			
May 1	K_c					0.4	0.78	1.05	0.8	0.76	0.58		
	ET_c					1.92	4.13	4.52	3.76	4.03	2.09		
	IR					4.50	9.48	15.47	14.33	14.29	NIR		
	IA					26.41	7.38	3.75	3.49	2.10*	Inf.		
June 1	K_c						0.4	0.78	1.05	0.8	0.76	0.58	
	ET_c						2.12	3.35	4.94	4.24	2.74	1.62	
	IR						NIR	9.48	20.38	15.33	1.30	5.65	
	IA						Inf.	6.12	2.45	1.96*	38.53	10.63	
July 1	K_c							0.4	0.78	1.05	0.8	0.76	0.58
	ET_c							1.72	3.67	5.57	2.88	2.13	1.51
	IR							1.12	13.87	21.92	2.02	8.18	NIR
	IA							52.15	3.61	1.37*	24.80	7.34	Inf.

Appendix 1(b) continuation

	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
August 1	K_c	0.58							0.4	0.78	1.05	0.8	0.76
	ET_c	3.19							1.88	4.13	3.78	2.24	1.98
	IR	7.46							4.68	14.79	6.64	8.72	NIR
	IA	7.55							10.68	2.04*	7.54	6.88	Inf.
September 1	K_c	0.76								0.4	0.78	1.05	0.8
	ET_c	4.18	2.96							2.12	2.81	2.94	2.08
	IR	13.06	4.48							4.80	1.66	12.20	NIR
	IA	7.50	22.98							6.24	30.18	4.92*	Inf.
October 1	K_c	0.8	0.76	0.58							0.4	0.78	1.05
	ET_c	4.4	3.88	2.67							1.44	2.18	2.73
	IR	17.52	8.75	NIR							NIR	3.05	NIR
	IA	5.59*	11.47	Inf.							Inf.	19.65	Inf.
November 1	K_c	1.05	0.8	0.76	0.58							0.4	0.78
	ET_c	5.78	4.08	3.5	2.26							1.12	2.03
	IR	21.01	9.67	3.99	NIR							3.16	NIR
	IA	4.66*	10.65	27.58	Inf.							18.98	Inf.
December 1	K_c	0.78	1.05	0.8	0.76	0.58							0.4
	ET_c	4.29	5.36	3.68	2.96	2.78							1.04
	IR	8.28	15.60	4.92	NIR	8.72							NIR
	IA	11.83	6.60*	22.39	Inf.	13.65							Inf.

Appendix 1(c): Irrigation Potential for Thome scheme based on varied planting dates

Planting date	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
January 1	permitted flow (l/s)	126	118	121	82	112	75	62	93	51	55	65	115
	ET_o/month (mm)	5.5	5.1	4.6	3.9	4.8	5.3	4.3	4.7	5.3	3.6	2.8	2.6
	R_{eff}/month (mm)	22.0	55.8	84.4	90.0	32.3	66.6	46.6	30	34.6	77.1	14.5	93.2
	Kc	0.4	0.78	1.05	0.8	0.76	0.58						
	ET_c/month (mm)	2.2	3.98	4.83	3.12	3.65	3.07						
	$I^R_{(daily)}$ (l/s/ha)	7.65	9.21	10.81	0.06	13.38	4.22						
	Irr.area (ha)	16.48	12.81	11.19	137.62	8.37*	17.77						
February 1	K_c		0.4	0.78	1.05	0.8	0.76	0.58					
	ET_c		2.04	3.59	4.10	3.84	4.03	2.49					
	IR		0.21	4.45	5.46	14.36	8.98	5.06					
	IA		540.14	26.80	15.01	7.80*	8.34	12.24					
March 1	K_c			0.4	0.78	1.05	0.8	0.76	0.58				
	ET_c			1.84	3.04	5.04	4.24	3.27	2.73				
	IR			NIR	NIR	16.19	10.02	9.37	9.04				
	IA			Inf.	Inf.	6.92	7.48	6.84*	10.29				

Appendix 1(c) continuation

	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
April 1	K_c				0.4	0.78	1.05	0.8	0.76	0.58			
	ET_c				1.56	3.74	5.57	3.44	3.57	3.07			
	IR				NIR	6.69	16.63	9.94	13.36	9.52			
	IA				Inf.	16.73	4.51*	6.24	6.97	5.36			
May 1	K_c					0.4	0.78	1.05	0.8	0.76	0.58		
	ET_c					1.92	4.13	4.52	3.76	4.03	2.09		
	IR					4.50	9.48	15.47	14.31	14.29	NIR		
	IA					24.86	7.91	4.01	6.49	3.57*	Inf.		
June 1	K_c						0.4	0.78	1.05	0.8	0.76	0.58	
	ET_c						2.12	3.35	4.94	4.24	2.74	1.62	
	IR						NIR	8.98	20.38	15.33	1.30	5.66	
	IA						Inf.	6.90	4.57	3.33*	42.38	11.47	
July 1	K_c							0.4	0.78	1.05	0.8	0.76	0.58
	ET_c							1.72	3.67	5.57	2.88	2.13	1.51
	IR							1.12	13.87	21.94	2.02	8.17	NIR
	IA							55.74	6.71	2.33*	27.28	7.94	Inf.

Appendix 1(c) continuation

	Variable\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
August 1	K_c	0.58							0.4	0.78	1.05	0.8	0.76
	ET_c	3.19							1.88	4.13	3.78	2.24	1.98
	IR	7.46							4.68	14.79	6.64	8.72	NIR
	IA	16.89							19.87	3.45*	8.29	7.45	Inf.
September 1	K_c	0.76	0.58							0.4	0.78	1.05	0.8
	ET_c	4.18	2.96							2.12	2.81	2.94	2.08
	IR	13.06	4.48							4.80	1.66	12.20	NIR
	IA	9.65	26.33							10.62	33.20	5.33*	Inf.
October 1	K_c	0.8	0.76	0.58							0.4	0.78	1.05
	ET_c	4.4	3.88	2.67							1.44	2.18	2.73
	IR	17.52	8.75	NIR							NIR	3.06	NIR
	IA	7.20*	13.43	Inf.							Inf.	14.31	Inf.
November 1	K_c	1.05	0.8	0.76	0.58							0.4	0.78
	ET_c	5.78	4.08	3.50	2.26							1.12	2.03
	IR	21.01	9.67	3.86	NIR							3.16	NIR
	IA	6.00*	12.20	3.34	Inf.							20.56	Inf.
December 1	K_c	0.78	1.05	0.8	0.76	0.58							0.4
	ET_c	4.29	5.36	3.68	2.96	2.78							1.04
	IR	8.28	15.60	4.92	NIR	8.72							NIR
	IA	15.22	7.56*	24.63	Inf.	12.85							Inf.

* the irrigation potential

Calculation for January

$ET_o \times K_c = ET_c$

$= 6.1 \times 0.4$

$= 2.44$ mm (mm per day)

For 31 days,

$ET_c = 75.64$ mm

$IR = ET_c$ - Rainfall

$= 75.64 - 0$

$= 75.64$ mm

IR (l/s/ha) $= (IR \times 10000/86400) \times 1.43$

$= [(75.64 \text{ X } 10000)/86400] \times 1.43$

Permitted flow = 90 l/s

Irrigable area = 90/12.51

= 7.19 ha

Appendix 2: Land use data recording Sheet extract

Date	Name of farmer	Scheme	Farm No.	Farm size (ha)	Water source	Section of canal	Proximity to water source (m)	Irrigated area (ha)	Crop(s) under irrigation
7.2.95	M. Nderitu	Aguthi	1	80	Main canal	Head end	50	0.1	cabbage, irish potatoes
8.2.95	R. Njoroge	Aguthi	26	2	main canal	mid -section	200	0.03	snowpeas
9.2.95	F. Mwangi	Aguthi	1	1	Lenana s.c	head end	150	0.04	snowpeas
11.2.95	Everest Project	Aguthi	87	1	Lenana s.c	tail end	125	0.4	cabbage snowpeas
12.2.95	T. Muriithi	Aguthi	1	2.5	Rongai s.c	head end	290	0.24	snowpeas, irish potatoes, cabbage
14.2.95	S. Mungai	Aguthi	32	0.6	Kabendera s.c	mid - section	0	0.08	cabbage tomatoes
16.2.95	J. Mwangi	Aguthi	56	1.6	Kabendera s.c	tail end	500	0.35	snowpeas, tomatoes, onions
17.2.95	D. Karanja	Aguthi	72	26	Kahuho s.c	tail end	350	0.15	snowpeas, cabbage
5.3.95	Mathenge	Thome	1	2	main canal	head end	0	0.8	maize, tomatoes, cabbage
5.3.95	P. Maina	Thome	8	2.5	Main canal	head end	0	0.06	nappier grass, maize, beans
7.3.95	S. Wainaina	Thome	32	2.8	Main canal	mid - section	100	0.5	maize, cabbage, irish potatoes
8.3.95	W. Mwaura	Thome	67	3	main canal	tail end	150	0.2	tomatoes, irish potatoes
9.3.95	S. Mwangi	Matanya	1	2.2	main canal	head end	50	0.3	irish potatoes
10.3.95	D. Gichuki	Matanya	16	2.5	main canal	head end	0	0.05	irish potatoes, tomatoes
10.3.95	J. Waweru	Matanya	37	1.8	main canal	mid - section	0	0.08	tomatoes, cabbage, maize
11.3.95	J. Kimani	Matanya	91	1.2	main canal	tail end	60	0.07	cabbage, maize

Appendix 3: Rise and Fall Recording Sheet for Relative Canal bed Levels (Thome Scheme sample)

Point	BS	IS	FS	CD	Rise	Fall	RL	Remarks
1	1.90			0			0	
2		1.950		20		0.050	99.95	Weedy
3		1.945		40	0.005		99.955	"
4		1.950		60		0.005	99.950	"
5		2.020		80		0.070	99.880	"
6		1.945		100	0.075		99.955	"
7		2.050		120		0.105	99.850	"
8		1.970		140	0.080		99.930	"
9		2.010		160		0.040	99.890	"
10		2.055		180		0.045	99.845	"
11		2.050		200	0.005		99.850	"
12			2.000.	220	0.050		99.900	"

Appendix 4: Sample calculation for Crop Water Requirement

If Eo = 5 mm/day, Kp = 0.8, Kc = 0.7, then ETo = Kp X Eo = 4 mm/day This then gives ETc of 2.8. If it never rains for a period of say six days, cumulative ETc values are found, say

day 1, ETc = 2,8

day 2, ETc = 3.0

day 3, ETc = 4.2

day 4, ETc = 5.0

day 5, ETc = 3.5

day 6, ETc = 2.5

Total ETc =21 mm

Appendix 5: Analysis of variance on maize yield (Matanya)

Source	SS	df	MS	F	P	
Blocks	289538.889	2	144769.44	1.933	0.359	ns
Main Effects	2067705.556	2	1033852.78	13.80	0.016	*
Error	299561.111	4	74890.27			
Total	2656805.556	8				

Duncan's multiple Range Test

Error mean square = 74890.278

Degrees of freedom = 4

Significance level = 5%

$LSD_{0.05}$ = 620.377

Rank	Treatment No.	Mean	n Non-significant ranges
1	2	1863.33	3a
2	3	1766.67	3a
3	1	801.67	3b

Appendix 6: Analysis of variance on maize yield (Thome)

Source	SS	df	MS	F	P	
Blocks	132050	2	66025	1.537	0.3538	ns
Main Effects	1638066.67	2	819033.33	19.0778	0.0090	**
Error	171733.33	4	42933.33			
Total		8				

Duncan's multiple Range Test

Error mean square = 42933.33

Degrees of freedom = 4

Significance level = 5%

$LSD_{0.05}$ = 469.72

Rank	Treatment No.	Mean	n Non-significant ranges
1	2	1746.67	3a
2	3	1743.33	3a
3	1	840	3b

Appendix 7: Analysis of variance on maize yield (Aguthi)

Source	SS	df	MS	F	P	
Blocks	136538.89	2	68269.44	3.788	0.1194	ns
Main Effects	1980088.89	2	990044.44	54.943	0.0012	**
Error	72077.78	4	18019.44			
Total		8				

Duncan's multiple Range Test

Error mean square = 18019.54

Degrees of freedom = 4

Significance level = 5%

$LSD_{0.05}$ = 314.31

Rank	Treatment No.	Mean	n Non-significant ranges
1	3	1816.67	3a
2	2	1750	3a
3	1	790	3b

Appendix 8: Analysis of Variance for Maize Yield for the Three Schemes

Source	SS	df	MS	F	P
Main effects (Site)	5067374	2	2533687	213.255	**0.0***
Error	71286	6	11881		
Total	5138660	8			

* yield is highly Significant

Duncan's Multiple Range Test

Factor: site

Error mean square = 11881

Degrees of freedom = 6

Significance level = 5%

LSD 0.05 = 217.77

Rank	Trt Number	Mean	n Non-significant
1	2	2978	3a
2	3	2905	3a
3	1	1351	3b

Appendix 9(a): Aguthi water canal bed and water levels

Head end sample			Mid section sample			Tail end sample		
Distance (m)	Bed level (m)	Water level (m)	Distance (m)	Bed level (m)	Water level (m)	Distance (m)	Bed level (m)	Water level (m)
0	100.0	100.40	2600	100.0	100.60	5200	100.0	100.40
20	99.59	99.99	2620	99.80	100.36	5220	99.89	100.18
40	99.19	99.59	2640	99.55	100.15	5240	99.72	100.12
60	98.77	99.19	2680	99.37	99.96	5260	99.51	99.80
80	98.42	99.81	2700	99.15	99.65	5280	99.31	99.69
100	97.98	98.38	2720	98.95	99.50	5300	99.29	99.58
120	97.47	97.87	2740	98.72	99.22	5320	99.10	99.40
140	97.28	97.66	2760	98.65	99.11	5340	98.93	99.25
160	96.96	97.36	2780	98.44	98.87	5360	98.73	99.04
180	96.67	97.06	2800	98.15	98.55	5380	98.51	98.81
200	96.31	96.70	2820	97.34	98.18	5400	98.19	98.58
220	95.91	96.31	2840	97.38	97.79	5420	98.21	98.49
240	95.46	95.86	2860	97.06	97.50	5440	98.05	98.33
260	95.06	95.44	2880	96.63	97.03	5460	97.89	98.18
280	94.85	95.24	2900	96.69	97.08	5480	97.73	98.01
300	94.53	94.92	2920	96.36	96.71	5500	97.45	97.90
320	94.21	94.61	2940	96.16	96.51	5520	97.45	97.74
340	93.83	94.23	2960	95.75	96.11	5540	97.35	97.63
360	93.45	93.95	2980	95.59	95.93	5560	97.12	97.39
380	93.03	93.43	3000	95.19	95.54	5580	96.90	97.17
400	92.72	93.12	3020	94.79	95.12	5600	96.72	96.99
420	92.34	92.72	3040	94.34	94.56	5620	96.55	96.92
440	92.00	92.40	3060	93.95	94.25	5640	96.55	96.88
460	91.60	92.00	3080	93.65	94.05	5660	96.45	96.63
480	91.21	91.61	3100	93.23	93.52	5680	96.35	96.51
500	9081	91.21	3120	92.77	93.06	5700	96.29	96.45

Appendix 9(b): Thome water canal bed and water levels

Head end sample			Mid section sample			Tail end sample		
Distance (m)	Bed level (m)	Water level (m)	Distance (m)	Bed level (m)	Water level (m)	Distance (m)	Bed level (m)	Water level (m)
0	100.0	100.48	2300	100.00	100.52	4600	100.0	100.32
20	99.95	100.45	2320	99.98	100.50	4620	99.98	100.30
40	99.99	100.42	2340	99.97	100.48	4640	99.95	100.27
60	99.94	100.38	2360	99.98	100.47	4660	99.96	100.23
80	99.98	100.38	2380	99.96	100.46	4680	99.91	100.16
100	99.91	100.36	2400	99.95	100.4	4700	99.89	100.14
120	99.86	100.31	2420	99.94	100.36	4720	99.88	100.11
140	99.81	100.26	2440	99.89	100.37	4740	99.87	100.10
160	99.81	100.20	2460	99.89	100.30	4760	99.86	100.05
180	99.71	100.16	2480	99.89	100.28	4780	99.85	100.02
200	99.60	100.10	2500	99.85	100.25	4800	99.86	100.01
220	99.62	100.02	2520	99.71	100.21	4820	99.85	100.00
240	99.61	99.99	2540	99.70	100.20	4840	99.81	100.00
260	99.61	99.98	2560	99.57	100.11	4860	99.76	99.97
280	99.60	99.94	2580	99.57	100.02	4880	99.72	99.95
300	99.67	99.94	2600	99.57	99.99	4900	99.71	99.93
320	99.66	99.93	2620	99.56	99.99	4920	99.71	99.93
340	99.67	99.94	2640	99.57	99.98	4940	99.73	99.91
360	99.67	99.94	2660	99.57	99.98	4960	99.76	99.90
380	99.67	99.94	2680	99.65	99.97	4980	99.75	99.89
400	99.66	99.93	2700	99.61	99.954	5000	99.75	99.86
420	99.64	99.92	2720	99.56	99.93	5020	99.73	99.85
440	99.61	99.92	2740	99.55	99.93	5040	99.72	99.81
460	99.60	99.91	2760	99.55	99.92	5060	99.71	99.80
480	99.59	99.89	2780	99.45	99.91	5080	99.70	99.78
500	99.58	99.88	2800	99.45	99.90	5100	99.69	99.77

Appendix 9(c): Matanya water canal bed and water levels

Head end sample			Mid section sample			Tail end sample		
Distance (m)	Bed level (m)	Water level (m)	Distance (m)	Bed level (m)	Water level (m)	Distance (m)	Bed level (m)	Water level (m)
0	100.0	100.55	2000	100.0	100.45	4000	100.0	
20	99.85	100.40	2020	99.95	100.40	4020	100.0	
40	99.85	100.35	2040	99.91	100.36	4040	100.0	
60	99.81	100.32	2060	99.90	100.35	4060	100.0	100.60
80	99.82	100.21	2080	99.90	100.30	4080	100.0	100.60
100	99.74	100.20	2100	99.89	100.30	4100	100.0	100.60
120	99.68	100.10	2120	99.87	100.26	4120	100.0	100.60
140	99.68	100.09	2140	99.86	100.20	4140	100.0	100.60
160	99.67	100.03	2160	99.82	100.13	4160	99.99	100.60
180	99.59	100.00	2180	99.80	100.11	4180	100.0	100.50
200	99.56	99.90	2200	99.81	100.09	4200	100.0	100.50
220	99.44	99.80	2220	99.78	100.07	4220	100.0	100.50
240	99.43	99.78	2240	99.75	100.02	4240	100.0	100.50
260	99.46	99.75	2260	99.76	99.95	4260	100.0	100.50
280	99.38	99.72	2280	99.75	99.93	4280	100.0	100.50
300	99.44	99.70	2300	99.75	99.93	4300	100.0	100.50
320	99.30	99.65	2320	99.73	99.92	4320	99.99	100.50
340	99.15	99.59	2340	99.74	99.90	4340	99.99	100.50
360	99.13	99.50	2360	99.73	99.88	4360	99.99	100.50
380	99.09	99.46	2380	99.73	99.88	4380	100.0	100.50
400	99.04	99.40	2400	99.72	99.86	4400	99.99	100.50
420	98.94	99.36	2420	99.70	99.83	4420	100.0	100.50
440	98.89	99.25	2440	99.66	99.83	4440	100.0	100.50
460	98.78	99.18	2460	99.64	99.81	4460	100.0	100.50
480	98.77	99.11	2480	99.64	99.79	4480	100.0	100.50
500	98.76	99.05	3500	99.64	99.78	5000	100.0	100.50