UNIVERSITY OF ALBERTA

PADDY IRRIGATION WATER MANAGEMENT: Kenya case study

BY

©

TOM OWINO

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

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ABSTRACT

Irrigation remains a high priority in the development strategy of Kenya and several other countries particularly in south and southeast Asia. Unfortunately on several irrigation projects around the world, the potential for increased areas and yields has remained unrealized. Furthermore, most projects are plagued with large differences between potential and actual areas irrigated and between potential and actual yield levels. The central question then is what kinds of institutions and delivery systems and policies are needed to bring innovations to farmers so that they can benefit by higher production, income, more equity, and better levels of living.

This study aimed at identifying the main physical and organizational constraints that limit agricultural production of a government agency-managed irrigation system in Kenya. The physical constraints within the irrigation scheme were examined at the field, block and scheme level using a water balance model. Production per block compared with average scheme production for six consecutive crops formed the basis of the test on yield variation. Additional factors affecting production tested were distance from water intake to the blocks and seasonality. Concerning organizational constraints, participant observation was used to gather information on management constraints hindering the income level of the farmers.

Calculated and measured field water storage were similar using a water balance model. Inequity in water distribution results in excessive spill and high water levels in some fields while others remain dry. Consequently, the seasonal project application efficiency and yield are lowered considerably. Rice yields are also lowest in fields located furthest from water intake.

Overcoming the organizational constraints in the traditionally focused public service agency has no simple or quick answer. A major revolution in such rigid systems is in order. The system management must have an understanding of the physical interface between the farmer system and the main system to develop an effective two-way communication. Lasting changes can be achieved if the

farmers and personnel throughout the organization are exposed to and understand current paddy water management principles.

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ABBREVIATIONS OF MEASUREMENTS

Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer

Area

cm^2	=	square centimeter
m^2	=	square meter
km^2	=	square kilometer
ha	=	hectare

Volume

cm^3	=	cubic centimeter
L	=	liter
m^3	=	cubic meter

Weight

g	=	gram
kg	=	kilogram
tonne	=	metric tonne

Time

s	=	second
min	=	minute
hr	=	hour
yr	=	year

Other Measures

%	=	percent
°	=	degree
°C	=	degrees Celsius
mb	=	millibar

Derived Measures

mm/day	=	millimeter per day
L/s/ha	=	liters per second per hectare
m^3/sec	=	cubic meter per second meter
km/h	=	kilometer per hour
cal/cm^2/day	=	calorie per square meter per day
mmho/cm	=	millimhos per centimeter

NOTATIONS

Organization	Description	
AIS	Ahero Irrigation scheme	
FAO	Food and Agriculture Organization	
IRRI	International Rice Research Institute	
JICA	Japan International Cooperation Agency	
MOA	Ministry of Agriculture	
MOWD	Ministry of Water Development	
NCPB	National Cereal and Produce Board	
NIB	National Irrigation Board	
UCA	Unit Command Area	
US SCS	United States Soil Conservation Services	
Others		
DF	degree of freedom	
F	statistical F-test	
GDP	gross domestic product	
GNP	gross national product	
MS	mean square	
O & M	operation and maintenance	
P	probability	
R	correlation coefficient	
SS	sum of squares	
		Units
dS	change in subsurface and surface water storage	(cm)
D_n	run-off form uncultivated land	(mm)
D_p	horizontal percolation	(L/s/km)
D_r	reused drain water	(mm)
D_s	surface outflow	(mm)
EC	electrical conductivity	(mmhos/cm)
CEC	cation-exchange capacity	(meq/100 gm)

$E_{a.}$	field application efficiency	(%)
E_u	tertiary unit efficiency	(%)
E_p	project or overall efficiency	(%)
ET_c	crop evapotranspiration	(mm/day)
ET_n	evapotranspiration from non-Cropped Land	(mm/day)
ET_r	reference evapotranspiration	(mm/day)
ET_m	maximum or potential evapotranspiration	(mm/day)
I	amount of irrigation water	(mm)
P_i	seepage inflow	(mm)
P_o	deep percolation	(mm/day)
R_n	net solar radiation	(mm/day)
γ	psychrometric constant	(mb/°C)
E_a	aerodynamic term (function of e_{sa}, e_a, and u_2)	(mm/day)
e_{sa}	saturation vapor pressure at air	(mb)
e_a	actual vapor of the air	(mb)
u_2	mean day time wind velocity at 2 m height	(m/s)
P_a	atmospheric pressure	(mb)
h	elevation above sea level	(m)
RH	relative humidity	(%)
R_a	extraterrestrial solar radiation	(mm/day)
R_e	effective rainfall	(mm/day)
R_s	observed solar radiation	(mm/day)
T_a	average air temperature	(°C)
h_{do}	daytime hours at zero declination	(h)
r_{vc}	radius vector of the earth	(-)
h_s	sunrise to sunset hour angle	(°C)
Φ	location latitude (positive for north latitudes and negative for south latitudes)	(°C)
δ	declination of the sun	(°C)

θ	day of year expressed in degrees	(°)
J	days from January 1 (Julian day)	(day)

1.0 INTRODUCTION

1.1 Background

Kenya has a total land area of about 58 million hectares, of which only 20% is of medium to high agricultural potential (Jaetzold and Schmidt, 1982). The country's population is approximately 21.4 million (1990 census), and is projected to grow at an average rate of 3.3% per annum during this decade. Presently the density is 2.0 persons per hectare and is expected to increase to 2.5 persons per hectare by the year 2000 (MOA, 1990).

The agricultural sector plays a dominant role in Kenya's economy. Agricultural products contribute about 30% of the GDP, account for more than 70% of the country's employment, and provides the basis for about 65% of Kenya's exports. Agriculture also provides a means of livelihood for 85% of Kenya's population (Ngigi, 1990).

The Kenya government's long term strategies are set out in Sessional Paper Number One (1986). It targets an average agricultural production growth rate of 5.6% annually for 1984-2000. The Sessional Paper puts the most emphasis on development of rural sectors, as the only means of avoiding foreseeable social problems in the cities by the end of the century. The paper reports that the target is to be achieved through improved productivity and selective expansion of high value crops such as tea and coffee. It also says that the country will strive to reduce the import gap in three commodities that Kenya imports to meet her national demands: wheat, vegetable oils, and rice.

Over the past two decades, the country has been able to rely on the agricultural sector for most of her basic food requirements in most years. However, in recent years, serious problems have emerged. The rapid expansion of the population and unstable production of the basic foodstuff is now beginning to expose a potentially dangerous imbalance between national supply and demand for foods. Under such situations the Government of Kenya has formulated the Fifth National Development Plan (1984-1988). One of its main objectives was to increase domestic food supplies through intensified use of resources with an aim of attaining self sufficiency. The Government is emphasizing, among other strategies, rehabilitation of the existing irrigation systems and encouragement of small scale irrigation development.

Kenyan agricultural production levels fluctuate greatly year by year, mainly due to the present agricultural condition characterized by rainfed cultivation and extreme variations in annual rainfall patterns. In the country, approximately 51,400 ha, or less than 2% of the total farmland, is under irrigation (Osoro, 1990).

1.2 Irrigation Development in Kenya

The Ministry of Water Development (MOWD) identified that there exists an irrigation potential of 540,000 ha nationwide (MOWD, 1979). Existing irrigation area of 51,400 ha is equivalent to approximately 9.5% of the irrigation potential. Irrigated public land, totaling 28,177 ha, comprises NIB schemes (10,080 ha) and various small-holder schemes (18,097 ha). An additional 23,224 ha of private land is also under irrigation mainly for tea and coffee. Compared to the existing high and medium potential cultivatable land of an estimated 7.5 million ha, the irrigation potential of 0.54 million ha is limited and the existing irrigation area of 51,400 ha is insignificant.

Eventually, the government strives to develop the irrigation potential of the country through innovative improvement of planning and implementation process also of operation and maintenance after implementation.

1.3 Demand and Supply of Rice

Grain crops, such as rice, are marketed under the sole responsibility of the National Cereals and Produce Board (NCPB). The total marketed output that is sold to NCPB is approximately 40,000 tons of paddy (unmilled rice) per annum. About 98% of the total output is produced in the existing NIB irrigation schemes. The rest (2%) is produced in small, privately owned rainfed paddy fields (NIB, 1990). The average unit yield per ha in the NIB schemes has been decreasing gradually from 6.0

tonne level in the early 1970's to 5.0 tonne level presently. The worst case scenario is observed in the Ahero Irrigation Scheme (AIS), which produces approximately 2,800 tonnes per annum with an average unit yield of 3.5 tonnes per ha.

There is a tendency for the nation to move to rice as a basic food because of the considerable lower energy costs involved in preparing rice compared with the traditional crops, such as maize, in Kenya (MOA, 1989). The present consumption level of rice is estimated at approximately 6.0 kg in terms of paddy per capita per annum (CBS, 1990). The national demand for rice is therefore approximately 120,000 tonnes of paddy per annum. The present paddy production is, on the other hand, approximately 40,000 tonnes. The country makes up for the deficit in rice demand through commercial imports.

The quantity of imported milled rice is rapidly increasing, from 44,800 tonnes in 1988 to 96,200 tonnes in 1989 (CBS, 1990). With the present economic situations in Kenya, there is little foreign exchange to make up the deficit in rice supply by importing rice. Therefore, the domestic rice production must be increased using such techniques as expansion of irrigated area, improvement of present yield and introduction of double cropping (NIB, 1987).

The AIS is expected to improve the expected supply-demand imbalance of rice and to contribute toward the achievement of the Government's goal of self-sufficiency in foods.

1.4 Objectives

Niemeijer et al. (1985) conducted a study on the influence of rice growing on the nutritional condition of farming households, on the Kano Plain. They reported that the group with the smallest resource-base, the resident tenants of AIS, who almost wholly depend on irrigated rice production, showed the lowest food intake levels among children. Non-resident tenants, who depend on rain-fed cultivation, livestock-keeping and external remittance beside rice cultivation, showed the best nutritional conditions. The size of resource-base of the AIS farmers is directly proportional to how much paddy rice they can produce per unit of land.

There is a tendency toward decrease in the unit yield at the AIS. Large variation in unit yield between blocks is observed. Similar variations are also observed between tenant farmers. Reasons for the large variations have not been clearly identified yet. Therefore, a logical step toward the improvement of rice production at AIS is to conduct a study of the system.

Several irrigation schemes in Kenya have been evaluated on economic impact and performance and on technical performance. Molenaar (1986) observed that scheme performance, a few years after completion of the technical infrastructure, hardly improved. Operation (water management) and maintenance especially fell short of the expectations, and the blame was laid on the farmers. Bearing in mind that the design procedures hardly changed over the years, this criticism is one sided and unfair as evidenced in this case study.

This study aimed at identifying the main physical and organizational constraints to the government agency - managed irrigation system (AIS) which limits agricultural production. The purpose of the study was to provide an assessment of the existing pattern of water use in Ahero Irrigation Scheme and to figure out technical and management practices that may be undertaken to improve the scheme's general economic performance.

The overall objective of the study was to formulate an irrigation system improvement plan that will result in a recognizable increase in crop production and the improved well being of the farmer and his family. Three distinct objectives define the purpose of this study. These are:

- Understanding the AIS system as it actually operates with both its strong points as well as its constraints.
- Identifying the major physical, biological, economic and social organizational constraints to the system, and
- Listing the identified constraints, their causes and importance in an order of priority and based on stated criteria to assist the development and assessment of solutions.

1.5 Scope and Limitation of the Study

An irrigation system is a combination of diverse, yet related, parts that form a unified whole. The totality of this study demands that it cross disciplinary lines to accurately describe and understand the irrigation system in its entirety. This requires more than a superficial knowledge of the physical, cropping, economic, social-organizational and operating irrigation system.

This study combines the socio-economic and operational component of the system without the benefit of direct participation of an economist. The socio-economic component is therefore not as delineated but is included so that the total system can be seen as an interrelated, dynamic, functioning whole.

Valuation of application, operation, and conveyance efficiencies is necessary for the estimation of the overall system efficiency. Due to financial constraint, limited study period, and inadequate measuring structures, operation and conveyance efficiencies could not be assessed. Similar reasons were also responsible for the limited water balance trials done at the field level.

The study is aimed at providing paddy irrigation managers with an irrigation system improvement plan that they can adopt to attain better performance. The methodology developed can also be used to assess the pattern of water use in paddy irrigation at the field, block and scheme levels.

2.0 LITERATURE REVIEW

This chapter gives an overview, from the literature, of many aspects of paddy irrigation development. It first relates some insights into the history and irrigation practices in paddy rice cultivation. This is followed by a description of the general nature of irrigation. The next five sub-sections' present information on detailed aspects of paddy irrigation. The final sub-section discusses the views on the assessment of scheme performance.

2.1 Rice (paddy)

Rice (Oryza sativa) is believed to have originated from Southeast Asia, and as of 1980, about 345 million tonnes was produced world-wide annually from about 142 million ha (FAO, 1979). The total growing period normally varies between 90 and 150 days depending on variety, temperature and sensitivity to day length. Optimum daytime air and water temperatures for the growth of rice are between 28 to 35 °C.

A wide range of soils are suitable for rice cultivation but fine-textured soils are preferred due to low percolation losses. The crop has a high tolerance to acidity with optimum pH between 5.5 and 6.0, but moderately tolerant to salinity. Yield decreases for different salinity levels are: 0% at ECe 3.0 mmhos/cm, 10% at 3.8, 25% at 5.1, 50% at 7.2 and 100% at EC 11.5 mmhos/cm (FAO, 1979).

Seasonal water requirements of paddy rice for evapotranspiration are between 450 and 700 mm, depending on climate and length of the total growing period. For paddy rice, the maximum evapotranspiration (ETm) in relation to reference evapotranspiration (ETr) is given by the crop coefficient (kc) for the different months. The kc values ranges from 1.1 to 1.5 during the first and the second month, 1.1 to 1.3 in the mid-season and 0.95 to 1.05 in the last month (FAO, 1979). The root system of rice increases gradually from transplanting, reaching a maximum of 100 cm, at the time of heading, in the absence of a dense subsoil layer.

Tsutsui (1979) described "continuous submergence" with intermittent drainage as the most promising method of irrigation scheduling for paddy rice. This method involves maintaining a water level of 10 cm for about a week during and immediately after transplanting to secure a healthy growth for the seedling. In the following tillering period, submergence is kept at a maximum of 3 cm to maintain high soil temperatures. Adequate water supply during head development through flowering is essential. Continuous flow irrigation or drainage and renewal of water once or twice during this period is sometimes practised. Usually fields are completely drained to facilitate harvest operations 30 to 45 days after heading. Untimely drainage adversely affects yields.

Although rice is an aquatic plant and grows well under submerged conditions, deep and prolonged submersion of rice adversely affects plant growth. Seckler (1986) reported that high yielding varieties are more susceptible to flood damage than most traditional varieties. The most susceptible stages for whole plant submergence are head development and flowering (FAO, 1979). Tsuitsui (1979) reported that rice and fish production can take place simultaneously or alternately when the field layout and water control structures are adapted to suit both rice and fish production.

2.2 Irrigation

Campbell (1986) stated that irrigation projects simply take river flows, practically regulate them to the extent that storage is available, and convey them to the area to be irrigated. Keller (1985) described irrigation essentially as a "happening" performed by human enterprise and not merely a network of channels feeding prepared fields. Lowdermilk (1983) also focused on the human aspect when he defined irrigation water management as the process by which the irrigation system is manipulated and orchestrated by human resources for production of food and fibre.

Keller (1985) originated an evolutionary viewpoint when he stated that an irrigation system is organic in nature and evolves according to its environment, moving toward what attracts it. He summarized this idea by saying that irrigation is an organic happening, with capital as its nutrient and income its attraction, and human its nature. One would therefore expect the institutional frameworks, as well as the physical systems, to change as they mature and may not conform to some set of desired goals through regimentation.

Bromley (1982) called irrigation a technological innovation of unappreciated complexity as the irrigation system implies a physical linkage among farmers along a watercourse. He further remarked that the change from rainfed agriculture to irrigated agriculture replaces one form of technical uncertainty (rainfall) with a multitude of uncertainties resulting from human action or inaction. Bromley added that the essence of developing irrigated agriculture in a way that helps the farmer is to ensure that the institutional arrangements governing water allocation and system maintenance do not constraint the already uncertain economic environment of the farmer. He further added that the physical interdependence brought by irrigation requires an administrative system aware of this interdependence and structured so that the interests of the farmer are given protection.

These extensive and intricate implications of irrigated agriculture, compelled Siann (1983) to remark that irrigation is effective for raising agricultural productivity only where land scarcity has become a major constraint on future development. Planners should not think too easily of irrigation as a means of raising agricultural production. The complexity of irrigated agriculture demands a broad-minded view of the planners/designers.

Walker (1983) concluded that irrigation projects should be regarded as socio-technical systems that can only have the desired success when all persons and groups concerned cooperate effectively. Coward (1988) elaborated on the socio-technical approach and distinguished six essential elements of an irrigation system: three technical elements (the constructed facilities, the natural resources and the crops grown) and three social elements (system rules, organizational arrangements and individual behavior of users and management). These six elements are interactive. A change in one affect others, and one element cannot completely replace another. Successful irrigation development, therefore, requires attention to all these components and the interaction between them. Walker (1983) also said that there was often a bias to functioning of engineering infrastructure in project planning, with less attention to the other elements, resulting in non-optimal functioning of a scheme.

2.3 Socio-economic environment

The importance of economic aspects is best illustrated by Skold (1985) who asserted that the backbone of any economic activity are records and budgets. He adds that purposeful data collection via record keeping, sample surveys, and the compilation of available secondary statistics are essential to understanding farmer behavior and the complex environment in which farmers make decisions. Schwartz (1983) showed that an intimate knowledge of the community involved is a basic precondition for any project plan. The top-down approach in planning hardly considers the aims and ideas of the farming population, which is the target group of the project.

Siann (1983) lamented that many (identification) studies appear to lack the aspect of labor input requirements. Little consideration is given to what the farmer might perceive as an economic behavior in the light of his experiences of local conditions. Von Harder (1983) stated that for every innovation all subsequent stages of work should be reviewed, as innovation means, more often than not, an increase in labor demand.

Tiffen (1985) warned that different rights over land may be held at the level of community leadership, household and adults within the household. This is particularly so in cases where the project area is communally owned. A situation where the farmers are tenants poses a threat to improvement of irrigation.

2.4 Planning and group formation

Keller (1985) remarked that one reason for frequent project failure is that the process of decision making remained at a bureaucratic level. Lowdermilk (1985) stated that the planners and engineers must try to put themselves in the place of the farmers to appreciate the implications of their interventions. Kraatz (1984) expressed a similar view. Keller added that the best opportunity for eliminating the bureaucracy managing the main system is to induce the farmers within each unit command area (UCA) to organize a water user group to maintain the watercourses and distribute the water within the UCA. This would enable the main-system bureaucracy to control water deliveries to few headgates while giving the farmers within the UCA access to local management.

Bottral (1981) explained that to secure the farmers cooperation as a group the planning agency must devote substantial resources (time, labor) to consulting them closely, allowing them to participate directly in the decision-making process and keeping them well informed of all final decisions taken.

As Coward (1988) pointed out, farmers had to be organized and prepared for meeting the designers. Elsewhere, Coward (1984) stated that pre-construction group activities are useful for group formation and strengthening. In 1986, he suggested that the task of helping farmers to form new, or strengthen existing, irrigator groups is not an activity that can simply be added to the responsibilities of the agricultural extension staff or the field staff of the irrigation agency. In this role he stresses the catalyst role of community developers.

Catalysts (community developers, institutional organizers) who work with the traditional irrigation may establish an effective channel of communication between the farmers and implementing agency. They may act as liaison between the project and the irrigation planners. Mock (1985) suggested that this may reduce the undesirable developments in many irrigation projects that are due to undervaluation of the human resource in the technical system of irrigation.

Kanazawa (1976) reported that good results were obtained through the deployment of community workers before the design and implementation of new irrigation systems in Sri Lanka and Philippines. It is therefore essential that an institutional infrastructure (farmer groups, water users group) should exist before the system becomes operational. These institutional mechanisms should be initiated from the start of project activities.

2.5 Operation and maintenance

Coward (1986) stated that organizing efforts should start from below, with user groups at the lowest level of operation. Any system of organization will depend greatly on having strong base-level units of organization (groups of cultivators whose fields are served by a common source, ranging from 10-15 to 25-30 users). These kinds of small base-level groups have usually been able to fashion workable means of moving water so that fair shares are received. Uphoff (1985) observed that this lowest level of organization can carry out their tasks with minimum of formalization.

Bottrall (1981) added that emphasis should be on development of watercourse groups, before farmer organization at project level can take place. Genuinely representative farmers' organizations can be established at project level only, if effective water user groups have first been built up at the watercourse level. He adds that irrigation organization should be channel based and not village based.

Coward (1988) stated that the record of implementing agencies in establishing water user organizations is quite poor. He pointed out the following considerations:

- o local irrigation groups may already exist but are invisible to outsiders. They should not be replaced by "modern" organizations.
- o a unit of local government responsible for irrigation operation (e.g., village headman) is essential as catalysts.
- o in case no groups, or ineffective groups, exist the agency should initiate and assist such groups. But this is no simple task and considerable commitment in time, staff and budget must be made by the agency. Staff should be exclusively assigned to this task (not a part-time function of regular field staff).

Wensley (1985) stated that the level of involvement of farmers in the initial development phases will greatly affect later system management. In this respect Bromley (1982) remarked that the general conditions of systems operation (distribution and maintenance) must be specifically defined before water moves through the system. Such an agreement with the future users then provides a basis for enforcement, once the system is in operation.

An important aspect of scheme management is good communication among farmers. Keller (1985) remarked on this aspect and stated that without regular communication among farmers they cannot cooperate to use available water to best advantage. He added that besides farmer communication, there should also be a good functioning two-way information system between management and farmers.

Morss et al. (1976) asserted that the management of an irrigation system must be flexible. If the technology and farming practices are new or if the local constraints facing the farmers are not well known, flexibility is critical. Revisions in project planning and operation are desirable to meet changing requirements and can constitute attempts to increase the chances of project success.

Coward (1986) stated that active farmer involvement in operational processes of acquiring, allocating and distributing of water will improve resource mobilization and incentive to improve maintenance.

Uphoff (1985) observed that the intensity and quality of water management are better in those areas where catalysts were used at the outset. Kanazawa (1977) gave an example of this approach from Sri Lanka. The group (project) was divided into small units based on hydraulic boundaries (e.g. laterals) or on a common channel. These groups were guided by an institutional organizer (catalyst) who lived in the area. Their role was to convince farmer groups to organize themselves and work together; they were not advisers. This created awareness about the effectiveness of group work. Each farmer group would select a representative. Large channels were divided in sub-units (head, tail).

Bottral (1981) remarked that to encourage group responsibility for subsequent operation and maintenance, farmers should be required to contribute toward the cost of work agreed to. He listed five requirements for effective water management:

1. clear rules on water allocation based on cropping patterns and crop water requirement,
2. allocation rules understood by farmers and officials,
3. physical design of distribution system should be such that water allocation rules can be implemented,

4. motivated staff by system of reward/sanction and accountability to farmers (groups), and
5. effective legislation for punishment of breaking of rules.

2.6 Aspects of Irrigation Water Management in Paddy Production

Kanazawa (1977) stated that the first water problem in paddy production is how to acquire adequate quantities for irrigation. Takase (1969) introduced a very interesting model that shows the correlation between yield and rice production technology and classifies the development of rice production technology into four stages as follows:

Stage I - Land (Rainfed, Flooded)
Stage II - Water Control (Irrigation, Drainage, Flood control)
Stage III - Inputs (Varieties, Fertilizers, Pesticides)
Stage IV - Cultivation-Methods (Diversification, Mechanization)

The "green revolution" (new rice production technology) is found in Stage III. I concur with the Takase development model. Acquisition of enough water is a prerequisite to jumping from Stage I to Stage II in the model. The problem of infrastructure for acquiring adequate water is, therefore, the first aspect of irrigation water management.

An excellent illustration of the importance of adequate water supply in the management of paddy irrigation systems is given by Seckler (1986). He compared the paddy production function to a binary switch, either on, with no stress and high yield, or off, with water stress and drastically reduced yield. In other words, there are no benefits of rationing water from a farmer and relocating to another farmer if the system water use efficiency is at its maximum. The farmer on the one hand cannot afford to over irrigate his field because the crop is subject to excessive submergence losses, on the other hand inadequate water supply result in a tremendous reduction in yield. Seckler concluded that paddy irrigation systems have a self-regulating property that leads to a reasonably optimal allocation of water supply between farmers if supplies are adequate.

Rice plants can tolerate excess water up to certain levels, which change as the crop matures. Ghosh, Mitra, and Pande (1975) found that any depth of water that was 50% or more of the crop height was detrimental to crop growth and yield, at any stage from seedling establishment to flowering. Palada and Vergara (1972) found that longer duration of submergence, higher water temperature, greater turbidity, lower light intensity, higher soil nitrogen, and deeper submergence can decrease the plant's carbohydrate content.

Kanazawa (1977) added that the second aspect of paddy irrigation management is judicious water management control, particularly of the depth and duration of irrigation water. This he asserted was the secret to increasing paddy yields. The growth stages of the rice plant and the kind of cultivation practices determine the depth of water in the paddy. The greater the amount of fertilizer needed the greater is the need for intensive management. Control of the over-luxuriant growth of the rice plants be cause of intensive fertilizer application is the basic problem in rice production Stage III (development stage) of the Takase model. Therefore, Stage IV in the Takase model may also be considered as the water management stage.

2.6.1 Water Stress Effects

De Datta et al. (1975) observed that water stress slows cell division and cell enlargement in a rice plant, with cell division being less sensitive to water stress than cell enlargement. De Datta adds that water stress also decreases respiration and photosynthetic rates, by that depressing the production of dry matter.

Results of experiments conducted by IRRI, suggested that for the improved varieties, the length of time the plant is subjected to moisture stress is more important in determining the amount of yield reduction than the particular growth stage at which stress occurs (IRRI, 1971).

Boyer and McPherson (1975) concurred with the fact that moisture stress early in the growth of the rice plant reduces tillering. They suggested that this phase of growth is probably limited more by cell enlargement than by other factors unless drought is severe. Boyer (1975) adds that if stress is relieved before the reproduction phase begins, some recovery in grain yield occurs through the increase in the number of grains pernicle. But if the stress period extends into the reproductive phase, a reduction in the number of grains diminish grain yield further. This he suggests is largely because of the potential for disruption of the floral development, anthesis, and fertilization.

Sugimoto (1971) and Hsu (1970) reported that water is not necessary after the emergence of most of bearing tillers until check-node differentiation. A lack of water at this time apparently decreases the number of nonbearing tillers, which use nutrients but produce no grain. Moisture stress in the late vegetative and reproductive phases results in a decrease in the contribution of panicle weight to grain yield through a reduction in the number of grains per panicle, percentage of filled grains, and average grain weight. Moisture stress also frequently causes nonsynchronous flowering and maturing of tillers in high-tillering varieties (Krupp et al. 1972). Chow (1965) reported that in Taiwan drought occurring later than about 25 days after heading did not greatly influence yield.

Tsutsui (1979) reported that good yields under fully controlled irrigation with high inputs are 6 to 8 tonne/ha paddy, while under controlled flood irrigation 3 to 4 tonne/ha would be considered good. Tsutsui also added that water utilization efficiency for harvested yield for paddy containing about 15 to 20 percent moisture, is 0.7 to 1.1 kg/m^3 with a milling percentage of approximately 65 percent.

2.7 Scheme Performance

Wang and Hagan (1979) said that the designers and managers of an irrigated rice production system must integrate two measures, efficiency and stability, which can be used to define the quality of the system. The economic efficiency of the project is generally evaluated by the Internal Rate of Return of the project investment. The physical efficiency of the production system is generally evaluated by the estimated improvement in yield per hectare, yield per man-hour, or the ratio between the yield and some suitable production demand, such as water. These two aspects of physical efficiency form the focus of this study. The other, no less important to assess but much more difficult to define, is system stability (Wang and Hagan 1979).

Efficiency generally is the ratio of output over input. Israelsen (1932) defined irrigation efficiency as the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period over water diverted from a river or other natural source into the farm or project canal or canals during the same period.

Several definitions have been proposed by various authors to 'evaluate irrigation' or 'measure performance of irrigation'. The definitions can be divided into three main groups as follows:

1). Definitions based on volume of water.

2). Definitions based on measured depth of field application.

3). Definitions based on other criteria, mainly related to yield.

The first group has the advantage of being easy to use because the volume delivered to the soil, a field or distribution system can be measured. Volume of water "stored in the rootzone during the irrigation," or "evapotranspirated by the crop" can also be measured or calculated. One disadvantage of the first group definitions is that some efficiencies do not take into account uniformity or adequacy of application.

In the second group, if the depths are actual (not average) values measured at specific locations in the field, then these definitions can also take the uniformity of application into account after processing. The second group definitions have the disadvantage that they cannot be used for whole system since it is not practical to measure the depth of application in all fields of an irrigation system.

The third group definitions are not used frequently because crop yields are influenced by more factors than water supply alone, e.g. fertilizer and herbicide application. Crop yields are a measure for agricultural production in an area and not for irrigation, although management performance of irrigation systems is sometimes judged by yields.

The difficult point in irrigation efficiency is to determine the amount of water used for plant growth. Bos (1980) defined the water used for crop growth as the volume of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle. Consequently, a water application efficiency defined as water stored in the soil (rootzone) over water delivered to the root zone is not useful if not related to evapotranspiration.

The time period considered is important too. The efficiency of one application at field level, measured with either volume or depths, gives no information on an average application efficiency for a growing season or for an area other than the measured field.

While searching for relations between water charges and the efficiency of irrigation water use, Bos (1980) used three efficiencies that were closely connected with the users of water. These efficiencies were: the field application efficiency (Ea); tertiary unit efficiency (Eu); and project (scheme) overall efficiency (Ep).
These efficiencies are defined as (ICID 1978, Bos 1980):

$$Ea = V_m / V_f \qquad 2.1$$

$$Eu = V_m / V_d \qquad 2.2$$

$$Ep = V_m / V_c \qquad 2.3$$

with:

Ea = field application efficiency

Eu = tertiary unit efficiency

Ep = project or overall efficiency

V_m = Volume of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle (m^3)

V_f = Volume of water furnished to the fields (m^3)

V_d = Volume of water delivered to the distribution system (m^3)

V_c = Volume of water diverted or pumped from the river (m^3)

From the above, the average field application efficiency (Ea) for a growing season in a paddy rice field may be described by:

$$E_{seasonal}=\frac{ET_c-R_e+dS}{I} \qquad 2.4$$

with:

V_m = ET_c - R_e + dS

V_f = I

Where:

ETc = Seasonal crop evapotranspiration

R_e = Seasonal effective rainfall

dS = Seasonal storage changes in the rice field

I = Amount of irrigation water applied during the season

Dastane (1974) defined effective rainfall as that portion of the total rainfall that can be used for crop production at the site where it falls without pumping. Sen and Wickham (1977) observed that the use of effective rainfall can increase the benefit derived from either a pumping system or a reservoir-based system. Seasonal storage change in the rice field are the change in the sum of the water stored in the soil and the water stored on the soil surface.

Wang and Hagan (1979) suggested that from the point of view of system stability, simple management infrastructures will be more stable than complex ones. Coward (1977) pointed out that changes in existing rural social infrastructures introduce instability, which can prevent the continued viability of the system. The designer of an irrigated rice production system must figure out the level of system sophistication at which the demand for social changes and management resources does not overburden the investment requirement or cause system instability.

Wickham and Takasse (1976) concluded that in the final analysis careful management complements sound structural facilities. Rarely, however, are the specifics of the management program spelled out when facilities installed. Proper management of structures is usually simply assumed when new structures are built.

But good management is a necessary condition of good irrigation performance, and cannot be taken for granted.

Water management can be simple if there is no limit on water availability. However, it can become socially difficult during periods of water shortage. It is quite impossible to use water efficiently on a systemwide basis and yet remain impartial to all farmers in the project area during periods of water shortages. The formulation of a socially acceptable management policy for periods of water shortage is difficult and requires time. Morss et al. (1976) observed that the physical system should be designed with sufficient flexibility so that the level of management sophistication can be increased in step with the development of social infrastructures.

Mellor (1969), in discussing farmer innovation and change, observed that a failure that drives a farmer under the margin of subsistence or into debt in a system of high interest rates may be disastrous and thus eliminate the possibility of playing probabilities that would pay well over the long term. In other words, it just slows the transition from low-input-low-yield agriculture to a high-input-high-yield agriculture using improved varieties.

Roumasset (1976) suggested that the government can speed the diffusion of innovation by subsidizing the change. Certain other government policies, such as the availability of long-term farm credit at reasonable interest rates and crop insurance programs to partially offset crop losses induced by natural causes, can increase the farmers' confidence in the stability of the planned production system and encourage them to make the changes necessary to increase yields and profits.

Wang and Hagan (1979) concluded that in the design of an irrigated paddy-rice production system, the consideration of efficient utilization of a limited and variable water supply, typified by a stream diversion system, requires examination of some "soft" social factors. The selection of optimal project size, the length of implementation period and implementation strategy, and the formulation of socially acceptable uncertainty levels are related. Economic and engineering analyses can be used to help guide these tasks, but they alone are seldom adequate.

The performance of any given activity, in this case government-agency managed, irrigation scheme, was judged against the narrowed set of criteria under physical efficiency. Lenton (1986) used the term "irrigation performance" to mean the extent to which an irrigation system achieves established objectives, often defined in terms of meeting equitable water delivery schedules in time and space, increasing agricultural productivity, and minimizing adverse effects.

Bottrall (1981) stated that the performance of an irrigation system should not be judged by absolute standards, but against the potential level of performance that a project might be reasonably be expected to achieve under conditions of adequate design and good management. This potential level will vary with time (scheme development). Furthermore the background of the scheme should be considered (e.g. settlement of pastoralists as in the case study). Chambers (1983) listed four criteria for project performance: productivity (per unit water), equity of water distribution, environmental stability and low costs. The first criterion is influenced by many other factors, crops grown, pests, soil, fertility, inputs etc. and has therefore to be handled with care as pointed out by Abernethy (1984).

Swendsen (1983) introduced the idea of relative water supply (RWS) also referred to as water density Keller (1985). It is the ratio of the amount of water the crops can beneficially use to the average amount of water which would be available at each farm turnout if the total supply was uniformly delivered throughout the system.

The use of flow measurements to assess the performance of irrigation schemes was discussed by Pearce (1952). Flow measurements will identify various water distribution problems as seepage, water theft, sedimentation and design faults. The magnitude of water wastage given by poor application efficiency is however only a quantitative indicator of problems in a project. Eggers (1983) pointed out those reasons behind low application efficiencies may include, beside design flaws, inefficient or lacking education, information and assistance to farmers.

Abernethy (1984) stated that efficiency is too technical, ignores crops and farmers. He stressed the study of equity of distribution and gave a list of parameters for this study. One of his most visible parameters is the maintenance of the canal system and farmers fields which Botrall also noted as paramount for high quality water distribution.

Coward (1984) rightfully observed that the success of an irrigation scheme should be measured as the number of functionally irrigated hectares and not the implemented command area. Bottrall (1981) warned that partial analysis of performance of irrigation schemes tends to be either management or technically biased.

3.0 CASE STUDY (AHERO IRRIGATION SCHEME: AIS)

This chapter presents a general description of the AIS. It includes the historical, physical, operational, and climatological attributes of the project area. Details of the water balance model used concludes the chapter.

3.1 History

The Ahero Irrigation Scheme (AIS) forms part of the Kano Plain, an area of about 650 square km located in Kisumu district, Nyanza Province, Kenya. The Kano plain is bordered by a steep escarpment to the North and the South, and by the foothills of the Tinderet Highlands in the East. In the West, it borders on Lake Victoria. The altitude of the plain varies from less than 1140 m near the shores of Lake Victoria to more than 1200 m inland. The climate of the Kano Plain is relatively dry with high average temperatures during the day. The soil is black cotton (section 3.3.2) and rather fertile. It is however difficult to drain. Seasonal flooding and water logging limit the agricultural potential.

AIS is situated in the middle of the Kano Plain, 25 km southeast of Kisumu town. The southern end of the scheme borders on the road from Kisumu to Kericho (Fig. 3.1). The total surface of the scheme covers some 1540 ha, of which 1147 ha is used for irrigated agriculture. The remaining area is mainly occupied by tenant estates (Villages). Water for irrigation is pumped from the Nyando River, at the eastern corner of the scheme, and is led through the scheme by gravity.

The AIS project started in 1966 as a response to the mounting pressure on resources in the Kano Plain caused by the high population growth rate ,3.5%, especially land. The aim was to improve agricultural production by improved water management. Land was expropriated from farming families. Plots of 1.6 ha were redistributed among the dispossessed families. Rice, the only permitted crop on the scheme, was first produced in 1969. The "Ahero Pilot Scheme", as the scheme was first called, was supposed to stimulate other large scale rice projects in the region. To date only one rice irrigation project, West Kano scheme, 15 km southwest of AIS, has been established.

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Figure 3.1: KANO Plain - Location Map

Source: NIB Annual Report, 1989. (No copyright involved)

3.2 Cultural Setting

The density of the population on the Kano Plain is 177 persons per square km (Niemeijer, 1988). The population is concentrated on the high spots, which do not flood under normal circumstances. The people are mainly members of the *Luo* tribe. Over 80 percent of the active population of the Kano Plain are smallholders. Crop production is mainly geared towards the subsistence of the farm family. Maize and sorghum are the main food crops, in some cases supplemented by sweet potatoes and cassava. Agricultural techniques are traditional and on the whole less advanced, than those used in other parts of Kenya. Consequently, yields are low. Cotton, rice, and sugar-cane are the most important cash crops in the area. Crop production is usually accompanied by livestock-keeping which formerly used to be the main economic activity among the *Luo*.

The most simple household structure in the *Luo* society is that with a compound in which one man and one woman live together with their children. This entity is extended when a man has more wives. Each wife has her own house in which she and her children live. Married sons initially stay at their father's compound, where they start raising their children. The eldest son is supposed to marry first, and to be also the first to establish his own compound.

Agricultural activities are supplemented with off-farm wage labour activities, for example in the sugar-estates to the north of the plain, in Ahero trade centre or in Kisumu town. Even with these commercial activities, the Kano plain with its high natural population increase, offers only limited economic possibilities, resulting in continuous out-migration, which started in the 1950's.

The living condition of the tenants vary widely. Some live in the villages originally constructed for them in 1969 by the scheme authorities. Others, over 30%, live in houses outside the scheme. Originally, every tenant got one house irrespective of his marital status or the composition of his household. However, if a man is polygamously married, all his wives are supposed to have their own houses. According to *Luo* traditions, the married sons also need their own houses on their father's compound. The housing provided by the scheme was therefore not suitable.

Further the material used was poor and construction of the houses inadequate, which caused many houses to deteriorate rapidly. The crowded condition of the villages made people eager to move outside the scheme, where they did not have to worry about NIB regulations.

In the scheme villages as well as outside the scheme, hardly any provisions for clean water or electricity exist. Only two villages have an improved water source (protected wells). People in other villages are totally dependent on water from a nearby river or stagnant water. For light during evening hours, people use paraffin lamps. There is no sewage system, but every compound has a pit latrine.

3.3 Physical System

3.3.1 Study Area

The AIS, situated near Kisumu, Nyanza Province (Kenya), covers a gross area of some 1540 ha which comprises:

a. Rice fields	b. Levees
c. Canals	d. Drains
e. Field roads	f. Office Buildings
g. Experimental Station	h. Staff Houses
i. Villages (tenant housing)	

3.3.2 Soils of the AIS

1. <u>Soil classification</u>

Soils of the study area are broadly divided into the following three soil groups (D'Costa and Ominde, 1973):

a) Black Cotton Soils

b) Lithosols

c) Swampy peat soils

Major soils of the study area are typical types of black cotton soils. These soils are mostly suitable for irrigation. Other soils are not suitable for irrigation development due to poor soil nature and undulating topography. A profile description of a typical black cotton soil pit in the study area is given in Appendix B. Major characteristics of each soil group are summarised as follows:

Black cotton soils are black coloured clayey soils which are characterized by deep cracks at the surface when they are dried. They generally swell when wet and shrink when dry. These soils are commonly planted with rice under irrigation. Non-irrigated black cotton soils are generally left uncultivated or utilized for cattle grazing.

Lithosols (very shallow soils) are observed in some parts the study area. The surface of the soil is almost bare with very little plant cover. The soils are not suitable for agricultural purposes. The distribution of these soils is however, negligible small.

Swampy peat soils are also found in some parts of the study area. The soils are poorly drained, having deep, grey coloured organic layer, and are not suitable for agricultural purpose. The distribution of these soils is also negligible.

2. Soil physical and chemical properties

Soil texture is classified into clay, silty clay, silty clay loam and sandy clay loam. Most of the black cotton soils are classified into clay. Soil pH ranges from 6.30 to 8.40 (Dijk et al. 1978), and the black cotton soils have a relatively high pH. The cation exchange capacity (CEC) of the soils is generally high, ranging from 25.2 to 132.0 meq/100 gm. The black cotton soils have higher CEC than the other soil groups.

3.3.3 Main irrigation system

A main irrigation canal and secondary canals convey the water from the river Nyando to the different blocks within the scheme (Fig. 3.2). There is continuous water flow in these canals. Outside the rice growing season, a limited supply of water is maintained for domestic purpose and for irrigation in the research fields. The canals may be closed during maintenance work and heavy rains for short periods not exceeding one week.

The water level in the main and secondary canals are controlled by duck-bill weirs. These provide stable water levels in the canals when well maintained. Turn-outs to the blocks are constant head orifices.

3.3.4 Layout of fields in a block

The locations of all the blocks is presented in Fig. 3.2. A typical lay-out of a block is shown in Fig. 3.3. AIS is divided into 13 blocks, of which one block (block E) is reserved for Ahero Irrigation Research Station. From the diversion box in the main or secondary canal, the water runs through the main feeder (irrigation canal) to the different feeders. These convey water to the individual fields. The control structures in the main feeders are rectangular weirs placed at regular intervals whose nappes are regulated by movable wooden planks. Flow diversion structures on the open channel network use movable steel gates as weirs to control discharge. The off-take to the field inlets are prefabricated concrete structures also regulated by planks. The flow in the main feeder may be continuous or intermittent. The flow is equally divided among the feeders in the former and rotated in the latter arrangement.

The layout of rice fields is shown in Fig. 3.4. Each measures about 40 x 100 m, approximately 1 acre (0.4 ha). Each tenant has four such 1.0 acre fields. In one of the fields, on the drain side, an area is kept apart as nursery. There are a total of 519 tenant farmers at AIS.

Along one of the short sides of the field runs the feeder; in most cases there is one inlet for each field. A drainage canal runs along the other short side. Each field has its own outlet to the drainage canal. The fields border each other on the long sides. In between the fields there are bunds on which one can walk in most cases.

The feeders sustain fields on both sides. The drainage canal runs along the road. On the other side of the road runs the drain of another series of fields. Outlets

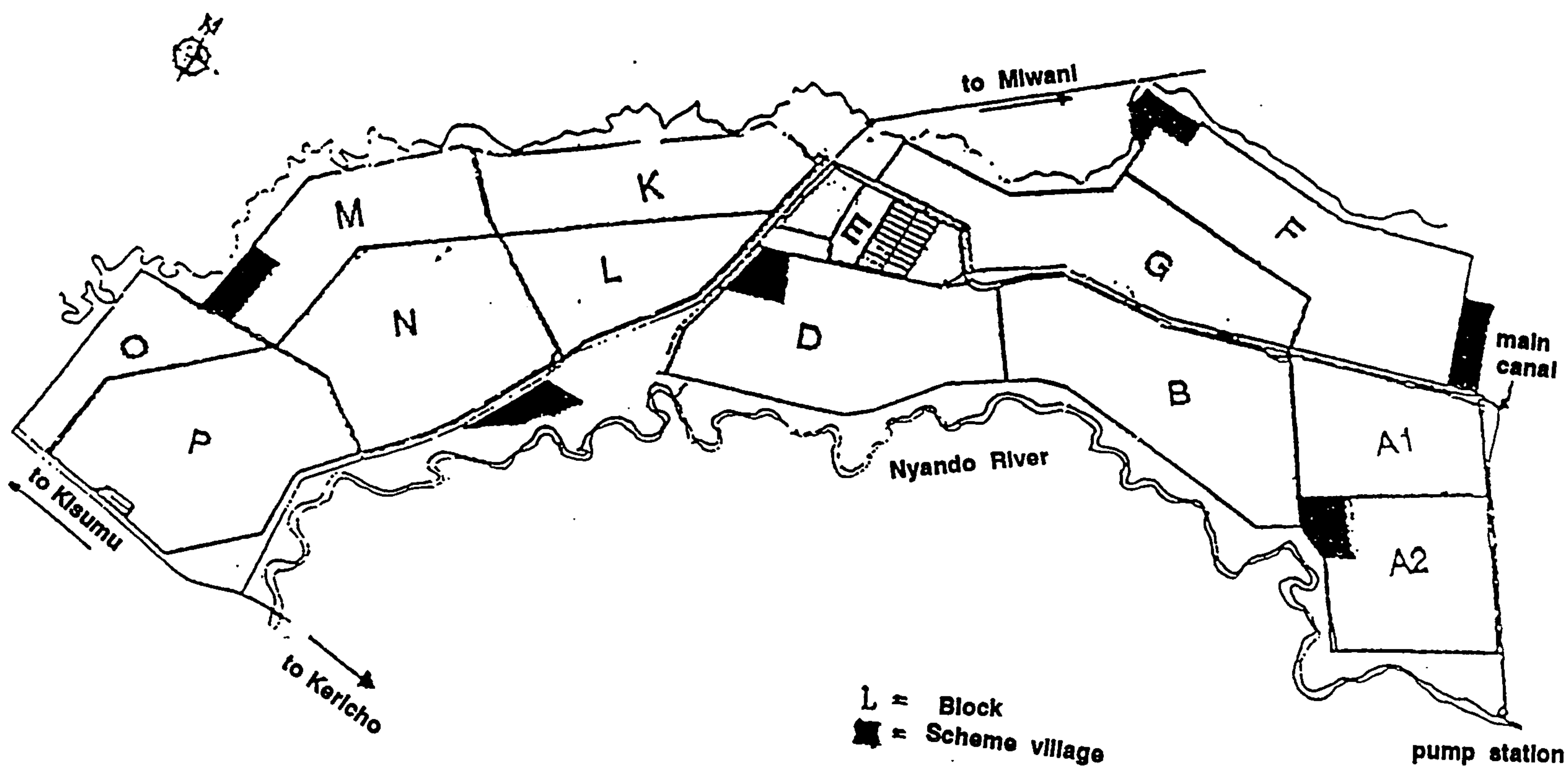

Figure 3.2: Map of The Ahero Irrigation Scheme

Source: NIB Annual Report, 1989
(No copyright involved)

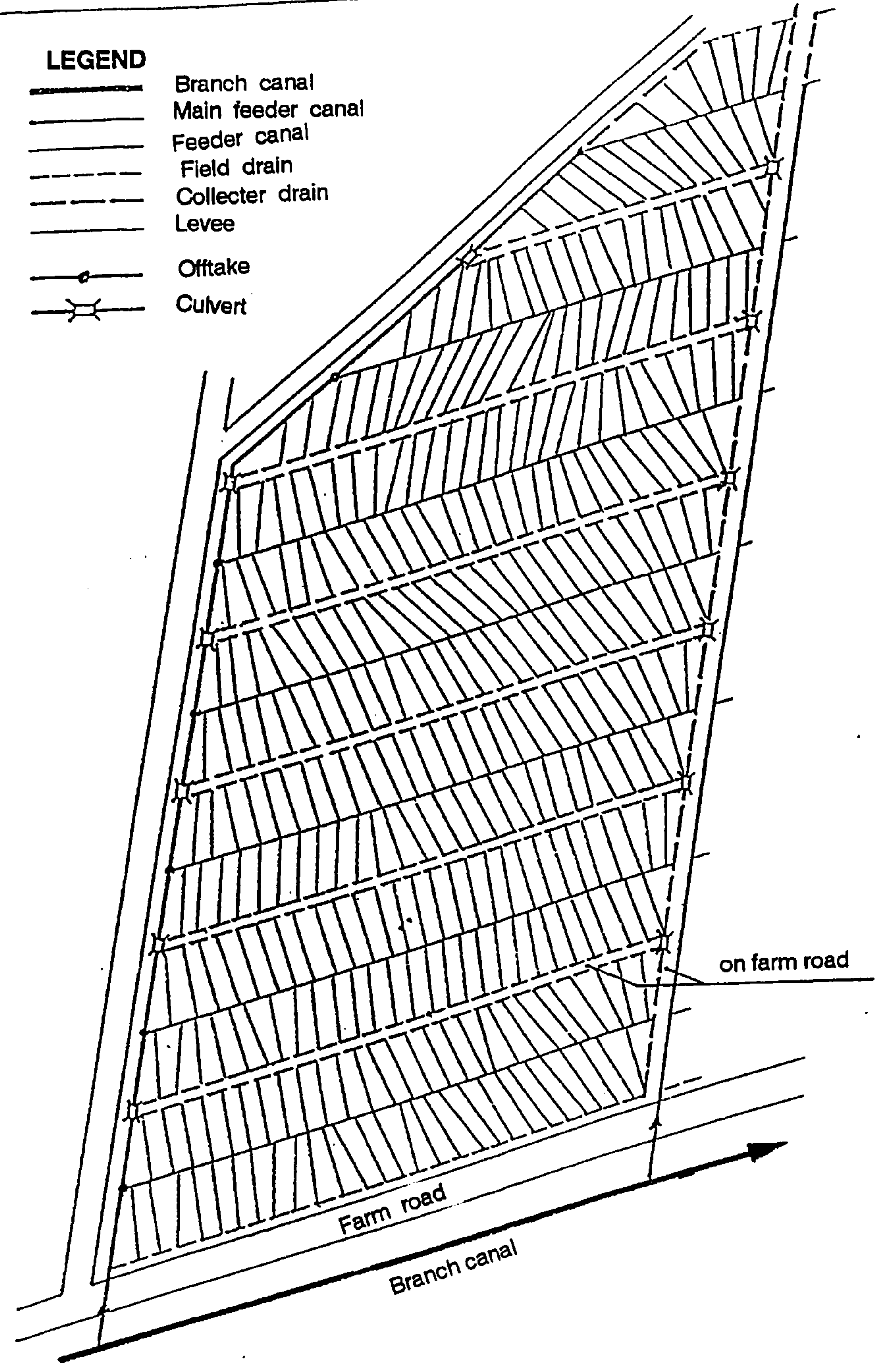

Figure 3.3: A typical layout of a block

Source: NIB Field staff manual (1989)
(No copyright involved)

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Figure 3.4: Layout of rice fields

Source: NIB Annual Report, 1989. (No copyright invovled) to the drains are pre-fabricated concrete checks operated by wooden planks. The drain water is collected in a collector drain and evacuated from the block. Blocks which are located along the river have their fields drains draining into the river. Field drains and collector drains are designed for a capacity of 3.5 $Ls^{-1}ha^{-1}$ at a water level of 0.30 and 0.06 m below ground level respectively. Main drains collect water from two or more blocks and convey the water to the river. 90° V-notch weirs are used as flow measuring structure along the main drains which have a design capacity of 7 $L\ s^{-1}\ ha^{-1}$ at a water level of 0.90 m below ground level.

Each field has, in principle, its own inlet and outlet. This has been arranged in view of the limited transplanting capacity of the tenant. Thus if transplanting in one field has been completed, irrigation need not wait until the other fields have been completed.

The feeders are supplied by the block feeders (main feeders) which are, in turn, supplied by the main canal. The road network, if in good condition, makes all the fields readily accessible.

3.4 Rice Irrigation at AIS

3.4.1 Rice irrigation

Paddy rice is grown under conditions of near soil saturation and submersion at AIS. The various irrigation stages in paddy rice with "continuous submergence" is shown in Fig. 3.5. First, the fields are flooded with a layer of water. Next, a dense subsoil layer is obtained by puddling the wet soil (rotavation).

Following rotavation, the water levels in the fields are increased. Almost simultaneously with rotavation, the nurseries are sown with pregerminated seeds, which are to remain in the nurseries for three to four weeks. Two weeks after flooding, the water is topped up to compensate for evaporation losses. After about four weeks, the fields are drained and the crops transplanted. This being completed, the water level is slowly raised depending on the growth-stage of the rice plants. About four weeks after transplanting, the water level is maintained at 12 to 20 cm until ripening period. During the ripening period, fields are gradually drained to

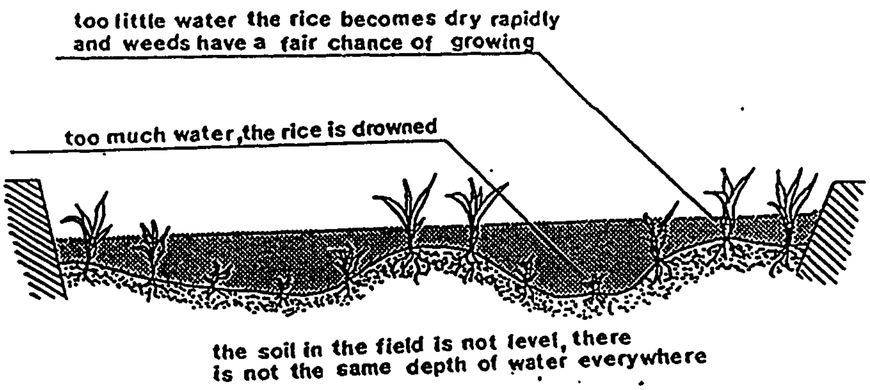

Figure 3.5: Unlevelled Fields

Source: NIB Field staff manual (1989)
(No copyright involved)

facilitate harvest operations. Finally, approximately two weeks before harvesting, the fields are completely drained to allow ripening of the crop.

3.4.2 Required water depth in fields

Under the system of rice cultivation as used in AIS, the plant is partly submerged. It should, however, never be drowned. Depending on the height of the plant it can stand a water depth between 0 and 20 cm before submersion adversely affects plant growth.

The plant itself does not require more than just a saturated soil. The thicker layer of water offers the advantages that the water is stored and consequently irrigations do not have to frequent. A water layer of approximately 10 cm suppresses most of the weeds in a field.

From the results and observations in chapter five, it seems in practice that fields are not completely level; even the most properly levelled fields have high and low spots. Therefore, a certain layer of water is required to assure complete submergence of the fields (Fig. 3.5)

3.4.3 Water Losses in the AIS Fields

Three major categories of water losses in the fields are identified. These are as follows:

1) Evapotranspiration represents the water loss from a combined surface of vegetation and soil. For a paddy field this would be the evaporation of the open water surface and transpiration of the rice plants. The amount of water required daily for this purpose varies between 5 and 7 mm.

2) Percolation is the downward movement of water to the subsoil. Under the AIS conditions this only occurs in exceptional cases (more sandy areas). The black cotton soils allow very little percolation loss in the puddled fields (less than 1 mm/day, see chapter five) and are mostly sealed off below the rootzone.

3) Seepage refers to the lateral movement of water through the bunds. Its magnitude depends hydraulic conductivity of the material through which the flow

occurs. This occurs more often in many bunds, especially if fields have been dry for a long period. Part of the water leaks to the neighbouring fields and could be considerable but tends to diminish over time.

3.4.4 Irrigation Stages

There are five irrigation stages (Fig. 3.6) in the scheme's irrigation schedule. These are:

1). Flooding stage and land preparation stage. This is the period between the first irrigation in a given season and drainage before transplanting. The length of the flooding period at AIS is determined by the time during which the rice is to remain in the nurseries, which ranges from 21 to 28 days. During the first few days the field is rotovated, and the nurseries are sown.

During flooding period, a proper water level should be maintained to suppress the weeds. If this is not done, weed growth will be considerable resulting in extra work for the tenant. After the flooding period, the water should be drained off to allow for transplanting.

2). Transplanting stage. Immediately after drainage of the field, preparation for transplanting (removal of weeds) should commence. In order to prevent the soil from drying out, the tenant should have the field ready for irrigation again not later than 7 days after drainage. At that moment a limited amount of water (40 mm) should be applied to ensure a saturated soil in the next period (Irrigation I).

3). Increasing water level stage (Irrigation II). About one week after Irrigation I, water should be applied again, this time not only to replace evapotranspiration losses but also to start building up the water level in the fields. The maximum water level should follow the growth of the rice plant.

Once every 7 days an irrigation of approximately 80 mm should be applied. Of this amount, 40 mm is to increase the water level and 42 mm to compensate for evapotranspiration. After 3 weeks of such irrigation rounds,

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Figure 3.6: Irrigation stages in rice growing

Source: NIB Annual Report, 1989. (No copyright involved) or 5 weeks after transplanting, the water level will have reached its required level.

4). Evaporation replacement stage (Irrigation III). During this period, a water level of 10 to 17 cm should be maintained. This can be achieved by an irrigation of approximately 60 mm once every 10 days. Normally, 5 to 6 of such irrigation rotations are needed.

5). Ripening stage. At least two weeks before harvesting, the field should be drained to allow ripening of the rice. This can be achieved either by draining an amount of about 100 mm of water, 14 days before harvesting, or by skipping the last irrigation 24 days before harvesting and having the water evaporate.

3.5. Operational System

3.5.1. Present organizational set-up for water management.

The official regulations governing the water management in the NIB schemes are "The Irrigation Regulations 1977". No other regulations has been issued so far. All NIB schemes, located over the country in different places under different conditions, are operated under this unified regulation. No internal regulations and/or guidelines are in operation other than "The Irrigation Regulations 1977".

The AIS farmers are called as "tenant farmers" under the present regulations. The farmers are granted the licences from NIB to stay within the AIS area and cultivate the irrigated paddy of 4 acres (1.6 ha), provided that they follow the instructions from the NIB management. Individual farmers are not allowed to cultivate, by their own ideas, the allocated paddy fields. Water management decisions are therefore made by the AIS staff, and not the farmers.

AIS has 204 staff in total, comprised of 20 senior staff, 71 intermediate and 113 subordinates, out of which the staff for water management is limited to only 30 as of 1991 (Fig. 3.7).

The Department of Works is responsible for the allocation and distribution of water and maintenance of irrigation facilities. The scheme has an Irrigation

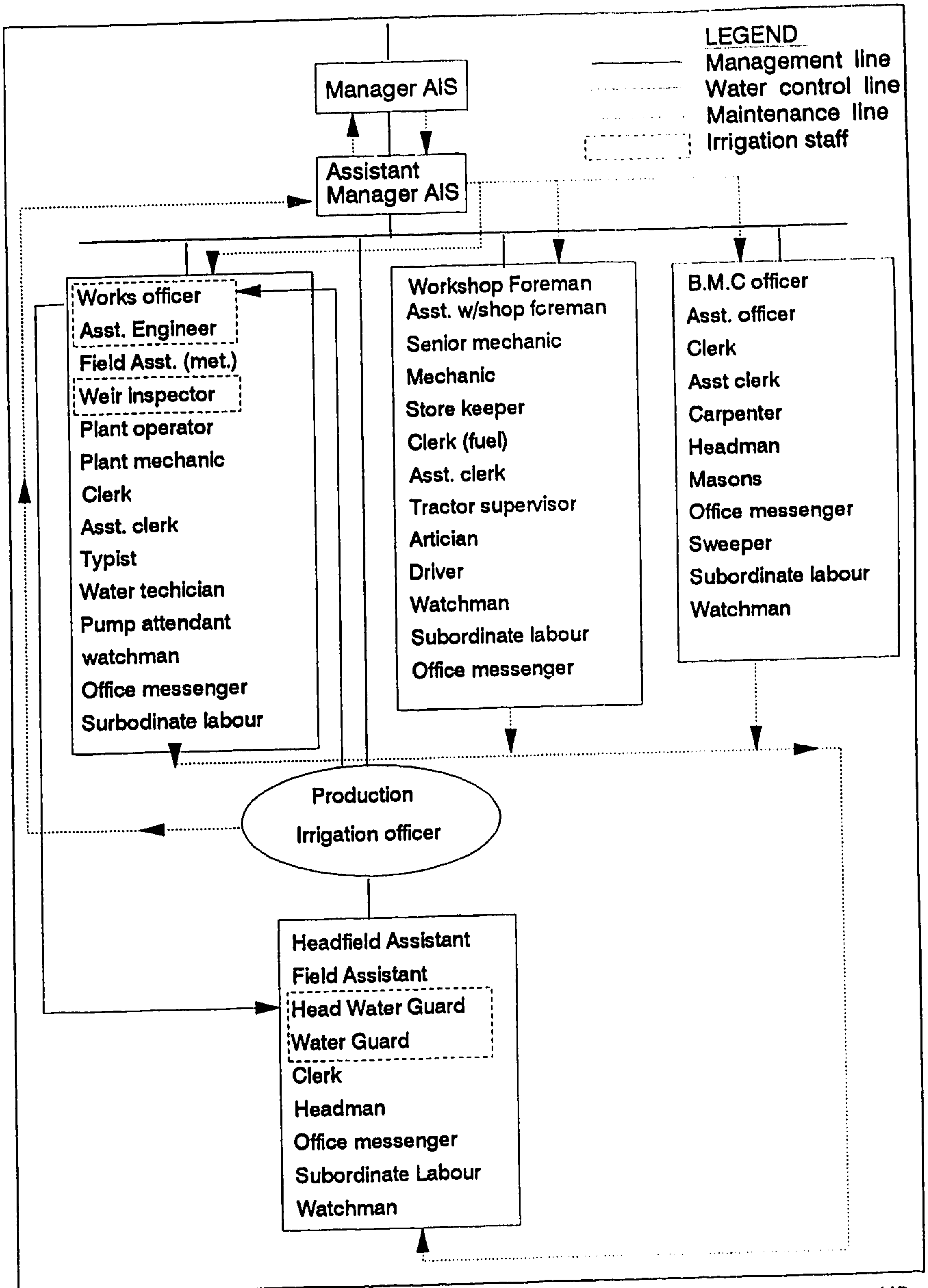


Figure 3.7: Present organization of operation and maintenance in AIS

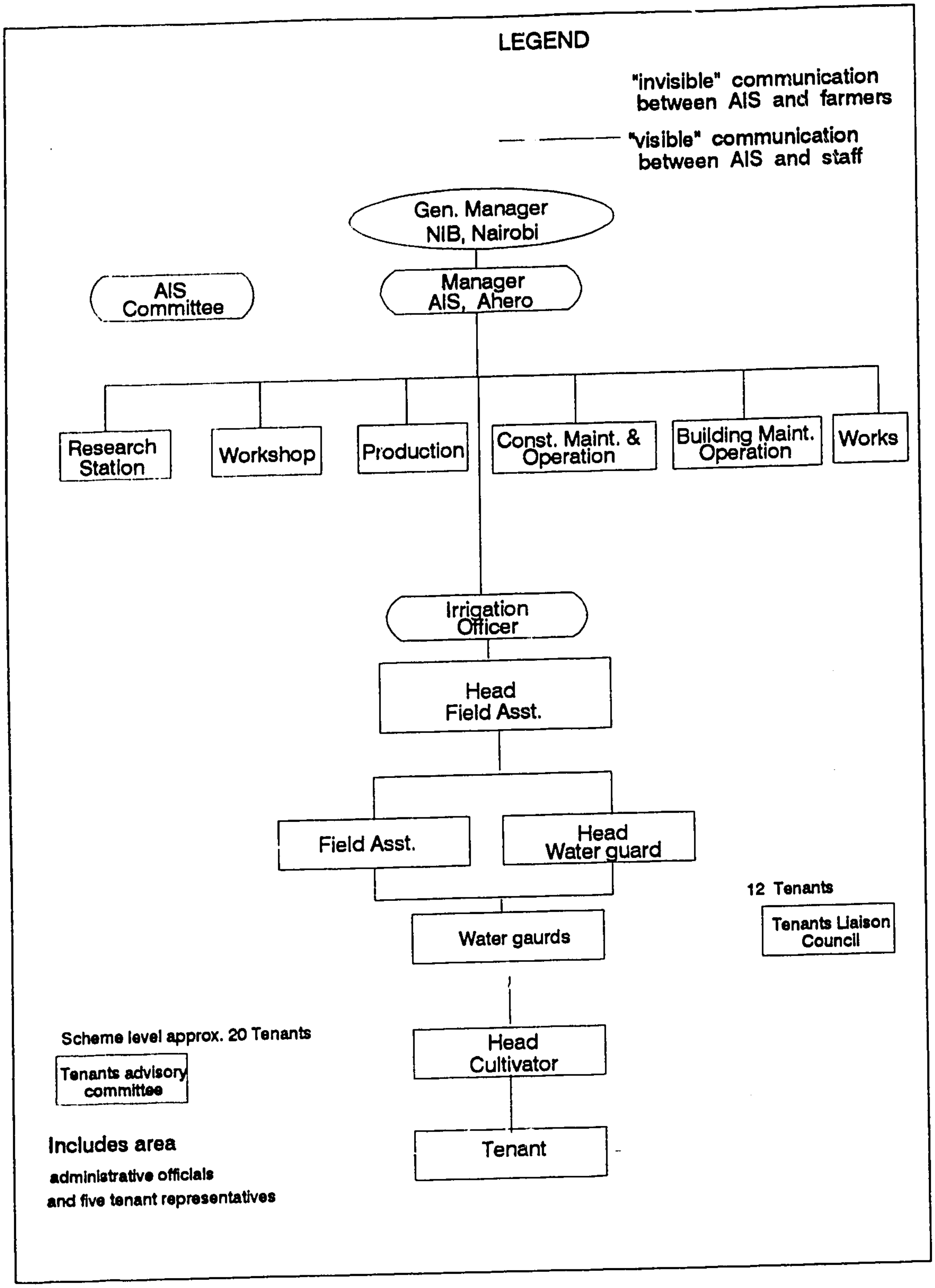


Figure 3.8: AIS organization chart

Officer in charge of production operations. He is assisted by a 3 head field assistants, 21 field assistants, a head water guard, 19 water guards and other intermediate and subordinates. The liaison with the tenant farmers is maintained via the head cultivator who represents the farmers (Fig. 3.8).

The tenant farmers communicate with AIS office and NIB management through the AIS Committee, Tenants' Advisory Committee, and Tenants' Liaison Council. In the meetings of the above, major operational issues are discussed.

The irrigation officer is a senior staff under the Production Department and is responsible for the preparation of cropping schedule in the scheme. He asks the Scheme Manager to allocate the irrigation water based on his cropping schedule. The Scheme Manager then informs the Works Engineer of his water allocation decision.

The Works Engineer prepares, in accordance with the directive from the Scheme Manager, the irrigation schedule on the basis of his experiences and makes gate operations at the pump station by himself accordingly and gives the necessary instructions to the head water guard for the operations of all the gates in the scheme.

The head water guard is responsible for the gate operations in the main canal. The water guard is allocated his respective irrigation fields/blocks in charge and is responsible for the application of irrigation water to the fields according to a stipulated schedule. However, in practice he bases his water distribution decisions on visual appraisal of the discharges to the different blocks.

3.5.2 Maintenance

The AIS management puts more emphasis on the operation works and rice production, while maintenance works for irrigation and drainage facilities are hardly taken care of. The maintenance works for irrigation and drainage facilities are composed of repairing, desilting and removal of weeds. The removal of weeds on feeder canals and levee of paddy fields are conducted periodically by farmers. The desilting and removal of weeds on the main and secondary canals are conducted sporadically by the scheme management. However, the other works, such as related water distribution structures and drainage canals, are inadequately or not maintained at all. This state of affairs is a result of a limited maintenance budget (Annual report 1990).

3.5.3 Present AIS Operational Activities (Operational regulation)

Activities of AIS and tenant farmers are regulated under the Irrigation Act (Cap. 347). Major regulations concerned with farming practices are as follows:

1) Regulations for the AIS office

a. AIS office supplies the following services to the tenant farmers:
   - rotavate the paddy field for tenant farmers by tractors,
   - provide the tenant farmers with farm inputs such as fertilizer and insecticides.

b. AIS office purchases necessary farm inputs through NIB head office and distributes them to each tenant farmer.

c. AIS office is responsible for collection of the harvested paddy, drying, re-bagging and sales to the National Cereals and Produce Board (NCPB, government parastatal). AIS office collects the payments for the sales of paddy on behalf of the farmers and makes payments to each farmer, deducting the service charge and costs of farm inputs that the farmer had used for production of his paddy.

2) Regulation for Tenant Farmers

a. Tenant farmers follow Irrigation Regulations (1977) and all instructions given by AIS.

b. Tenant farmers deliver all paddy harvested to AIS reception centre. The farmers are, however, allowed to keep some bags of paddy for their own consumption with permission from the office.

c. Tenant farmers maintain at all times for his holding, all field feeders and drainage channels to the satisfaction of the AIS office.

d. Tenant farmers are not allowed to hire or employ stock/machinery for cultural operations. The farmers are requested to accept all the services offered by AIS office.

3.5.4 Farming practices

Farming practices are conducted according to the cropping programme prepared by AIS office.

a. Land Preparation

Mechanical rotavation is carried out with 6 - 10 tractors. The fields are supposed to be given a pre-rotavation flooding of about 10 cm of water and rotavated within three days of the flooding. Pre-rotavation flooding for longer periods is likely to result in bogging down of tractors.

After rotavation, paddy fields are kept flooded with a layer of water approximately 10 cm in depth. Generally, rotavation begins in March. The farmers are normally organised into four groups (e.g. Group I = block A2, A1, and F). Group I rotavates first in the beginning of March and Group IV rotavates last (July/August). The farmers rotate through the groups with time. Sowing in the nurseries is done according to the rotavation groups and begins in mid-July. Transplanting is usually done four weeks later. Again the farmers in Group I plant first and farmers in Group IV plant last.

b. Nursery Preparation

Each tenant farmer seeds their own nursery to cater for his holding paddy field. The nursery measures about one-sixteenth of the holding. The nursery is usually prepared manually. The seeds are broadcasted at the rate of 18 kg/per each quarter of the nursery, a total of 72 kg of seed per 4.0 acre holding. Nitrogen is also broadcasted at the sowing time at the rate of 25 kg in each holding's nursery.

After sowing the water level in the nursery is increased gradually following the growth of the seedlings up to a depth of about 5 cm.

c. Transplanting

It is recommended by AIS that transplanting be made at a spacing of 10 cm x 10 cm with one seedling per hill. Transplanting is usually done during the school holidays in August (availability of school-going family labour), and with hired labour transplanting a holding (1.6 ha) takes 4-5 days. It takes a man and his wife up to 5 days to complete transplanting 0.4 ha.

d. Fertilizer Application

Nitrogen is applied before transplanting by broadcasting, in the form of sulphate of ammonia at the rate of one bag of 50 kg per acre (26 kg N/ha). Triple superphosphate is also applied before transplanting at the rate of one bag of 50 kg per acre. Top dressing with nitrogen is recommended at 42 days after transplanting.

e. Field Maintenance

After transplanting, the water level in the fields is increased as required, but normally should not exceed 10 cm in depth. The water stands in the fields throughout the growing period.

Besides the water control in the fields, other operations such as bird scaring, top dressing and weeding are conducted by the farmer from time to time when required. Minor cases of damage by insect such as leaf minor, stem borer, leaf eating caterpillars are occasionally noticed and effectively controlled by spraying with pesticide.

f. Pre-harvesting Drainage

After transplanting, the water level is maintained up to the ripening stage of the rice plant. Before harvesting the fields are drained and dried for three to four weeks.

g. Harvesting

Casual labour is usually employed for harvesting. This involves cutting, threshing by beating, wind-winnowing and bagging of the paddy. The paddy is then collected and transported by AIS office to the reception centre at the scheme.

After harvesting it has been recommended that the paddy straw be evenly spread over the fields and burned. Most farmers have not yet adopted this practice. Majority of the farmers leave the unburned straw in the feilds.

3.5.5 Processing and marketing of rice

At the reception centre, the paddy is dried on concrete floors to a moisture content of 14 percent. The paddy is then re-bagged to a standard weight of 75 kg and stored until it is milled at the Ahero Rice Mill located within the AIS area. Finally, the milled rice is marketed under the sole responsibility of the NCPB. The marketing flow of paddy from the farm to the consumer is depicted in Fig. 3.9.

3.6 Meteorological data

A summary of monthly meteorological record for the 1991 season is presented in Table 3.1 (also Appendix C). The data are from Ahero Meteorological Station located at the AIS and are used to calculate Reference Evapotranspiration (ET_r) with the modified Penman Method. The calculations and seasonal values of evapotranspiration using the Modified Penman Method are shown in Appendix D.

The number of sunshine hours was measured with Campbell-Stokes sunshine recorder. Mean daily sunshine hours is lowest in July (3.7 hrs/day) and highest in January (9.1 hrs/day). Variation in monthly temperature is small (Table 3.1) with a mean temperature of about 22 °C over the year. The Relative Humidity (RH) monthly averages range between 52 and 67%, and usually varies from approximately 70% in the morning hours to approximately 45% in the afternoon (not shown in Table 3.1).

The mean monthly daytime wind speeds, at 2 m height, varied from 3.2 to 6.8 km per hour. Evaporation (E_{pan}) was measured with a class "A" pan covered with a wire mesh. E_{pan} averaged approximately 6 mm/day over the year. Calculated reference evapotranspiration (ET_r) does not differ much from class "A" values with the ratio between ET_r and E_{pan} varying between 0.8 and 1 over the growth period (Fig. 3.10).

The average monthly rainfall varied from 17 to 298 mm between 1986 - 1990. From mean averages per month, 1975 - 1990 period (Fig. 3.11), distinct wet periods can be seen during February to May (Long rains) and October to December (Short rains). However, the monthly averages conceal the great fluctuations that can occur yearly for the same month. Even in the rainy season, daily rainfall varies considerably and drought periods of two weeks with less than 10 mm of rain can occur. The total rainfall during the rainy periods at the end of the year does not allow cropping under rain-fed conditions. Due to the limited discharge capacity of rivers and the low permeability of the black cotton soil in the region, floods occur frequently during the long rains.

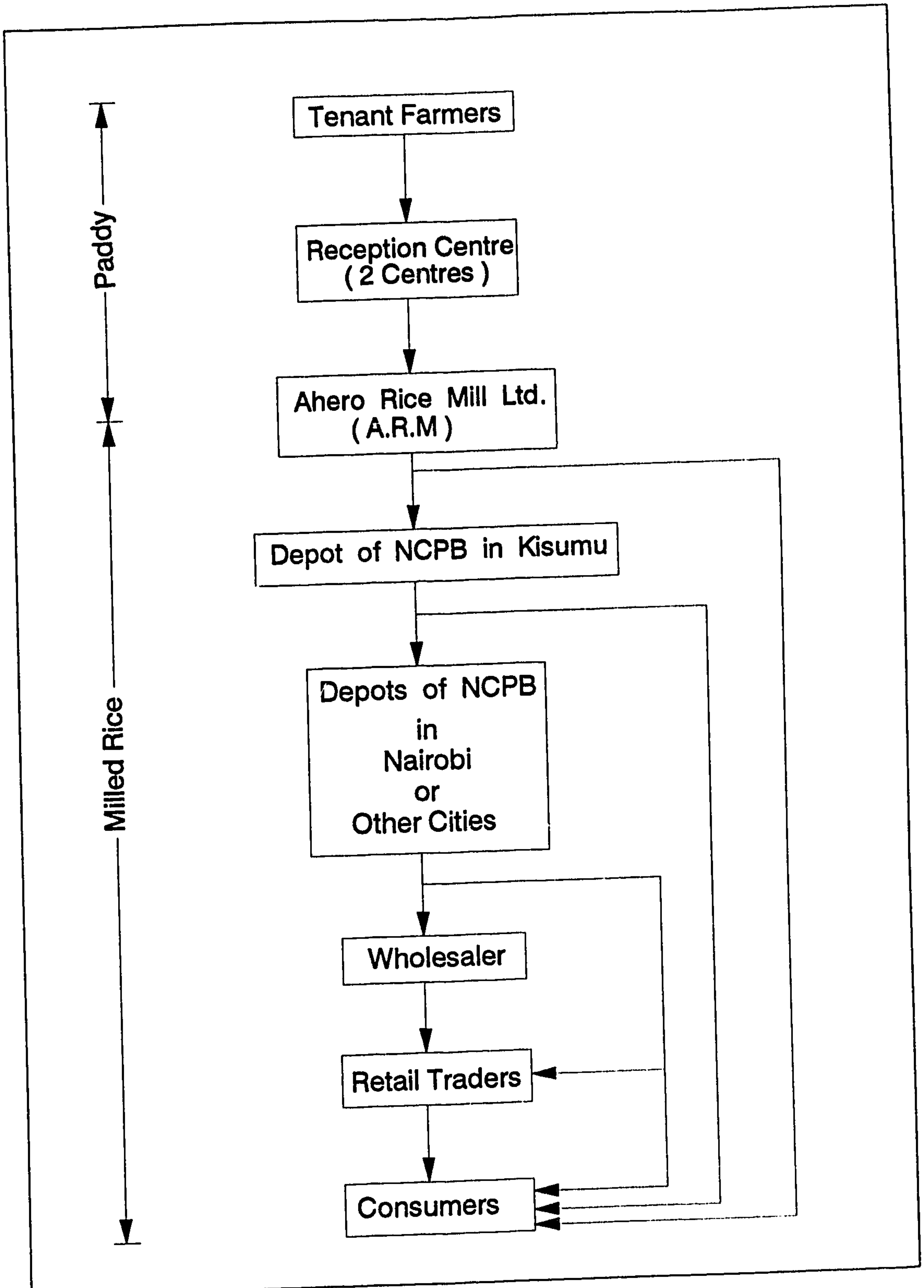


Figure 3.9: Marketing Flow of Paddy

Table 3.1 Monthly average meteorological record for the 1991 season.

AIS	T	R.H	n	W	E_{pan}	ET_r	R
JAN	21.6	66	6.7	5.0	6.4	5.3	103
FEB	22.6	28	8.3	5.3	7.5	5.9	5
MAR	22.8	56	8.6	5.1	7.3	5.9	159
APR	23.1	64	6.6	4.5	5.9	5.2	334
MAY	22.4	64	6.2	4.3	4.7	4.6	109
JUN	21.1	62	5.3	4.3	4.2	4.1	27
JUL	20.0	64	3.9	4.0	3.9	3.9	13
AUG	21.0	60	4.7	5.1	4.8	4.2	4
SEP	22.7	54	7.0	6.8	6.2	5.3	4
OCT	23.9	53	7.8	3.9	6.8	5.6	41
NOV	21.9	66	6.8	4.5	5.3	5.1	221
DEC	21.7	62	7.8	5.6	5.7	5.3	58
AVG	22.1	58.3	6.6	4.8	5.7	5.0	89.8

T — Mean Temperature (° C)
R.H — Mean Relative Humidity (%)
n — Actual Sunshine Hours (hours/day)
W — Mean Daily Windspeed (km/h)
E_{pan} — Average daily open water evaporation (mm/day)
Et_r — Reference evapotranspiration (mm/day)
R — Rainfall (mm/month)

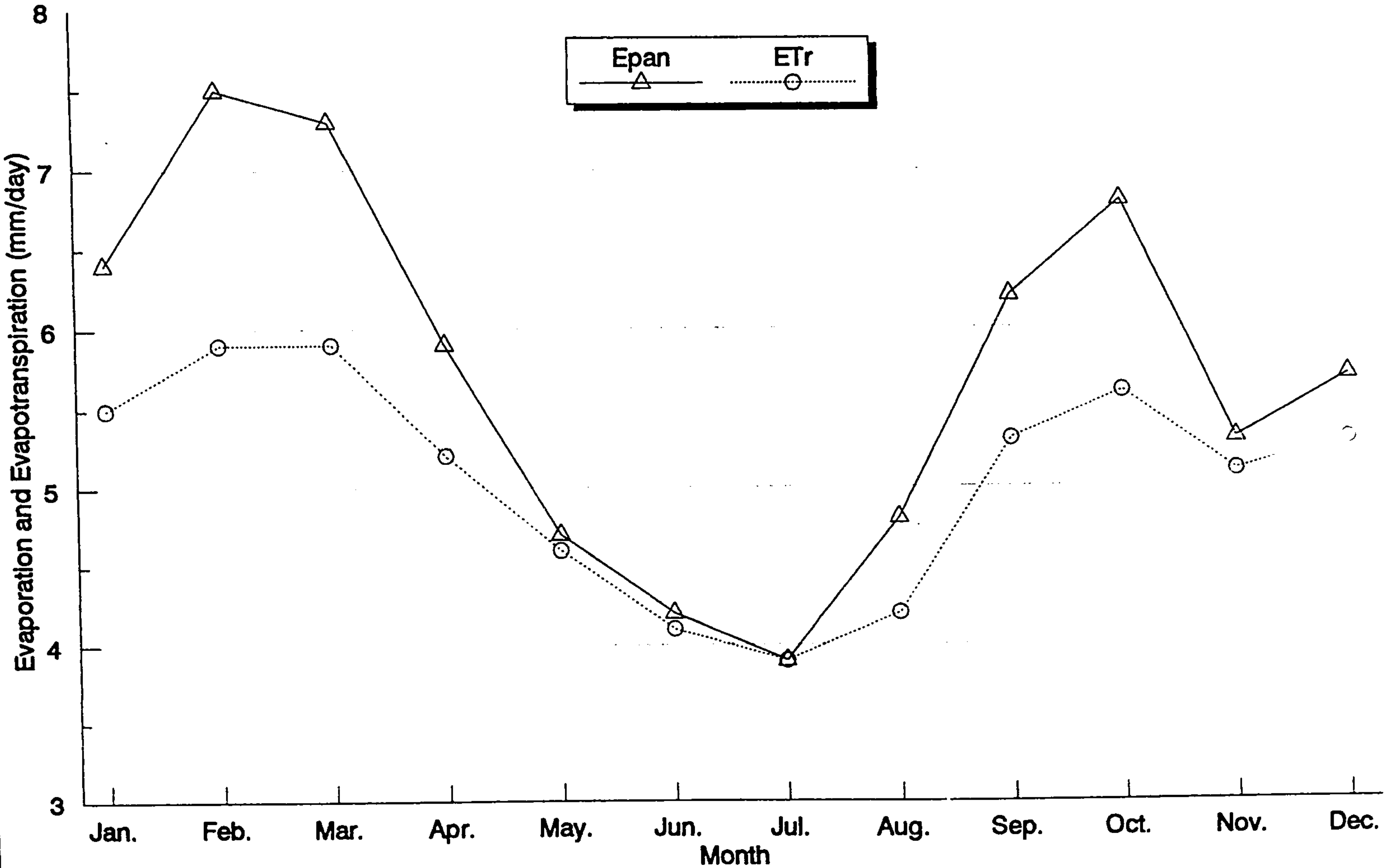


Figure 3.10: Variation of ETr and Epan (1991).

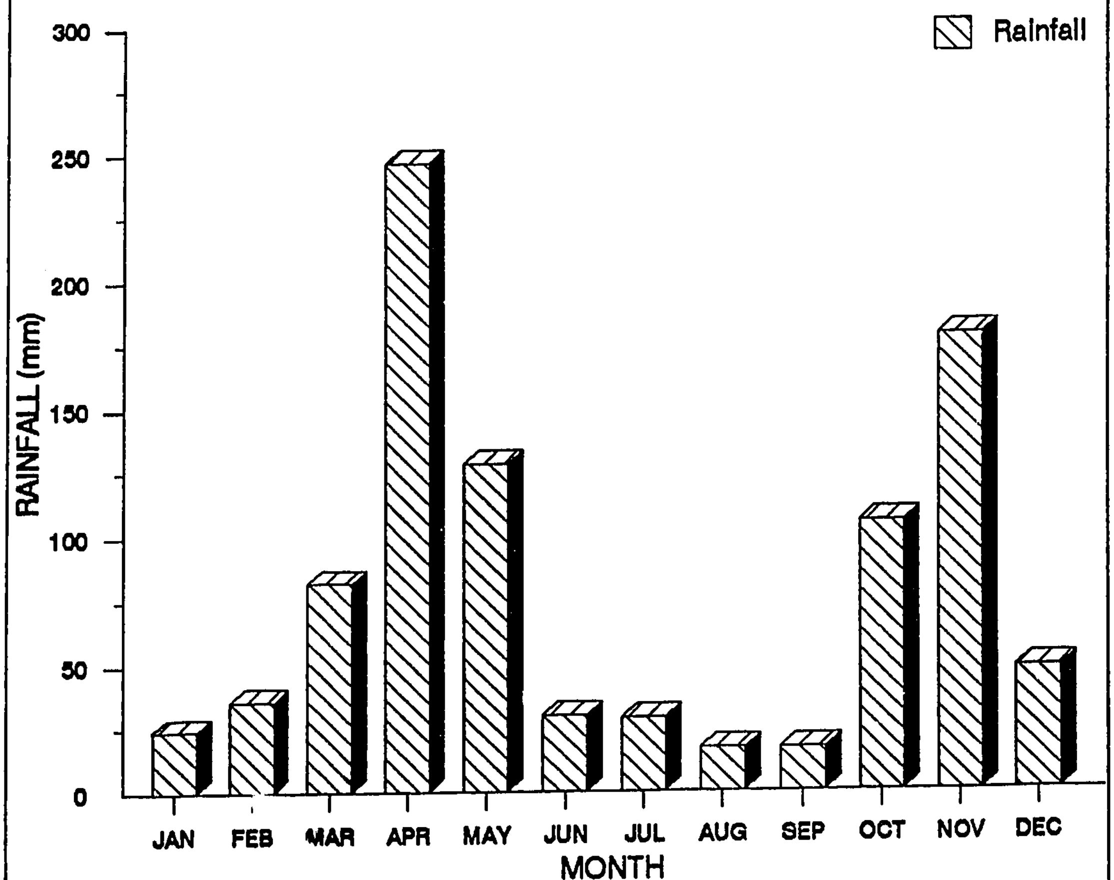


Figure 3.11: Mear Average Monthly Rainfall for the 1975 - 1990 Period

3.7 Water Balance - Definitions

The water balance is a statement of the law of conservation of matter, i.e. matter can neither be created or destroyed but can only change from one state or location to another. It is used to estimate the incoming and outgoing fluxes of a soil profile. If the outgoing fluxes exceed the incoming fluxes, a water deficit may occur in the soil to the point where growth is constrained and, in extreme cases ceases. Van den Broek (1992) described the water balance equation in its simplest form in a given volume of soil over a certain period as:

$$\Delta V = V_i - V_o \qquad 3.0$$

where: ΔV = change in soil water storage in profile (cm),
V_i = amount of water added (cm), and
V_o = amount of water withdrawn (cm).

For this study of the AIS, water balances conducted at field, block and scheme levels were formulated according to Nasu et al. (1985). In establishing the water balances, the relationship between the irrigated and non-irrigated areas was described by overland flow and lateral seepage.

3.7.1 Water balance at the field level

The water balance of a rice field shown in Fig. 3.12 can be stated by the following equation:

$$I + R + D_r + P_i = ET_c + ET_n + D_s + D_p + P_o + dS \qquad 3.1$$

Where: I = the amount of irrigation water
R = rainfall
D_r = reused drain water
P_i = seepage inflow (subsurface inflow)
ET_c = evapotranspiration (or evaporation)
ET_n = evapotranspiration from uncultivated area in the irrigated field
D_s = overland flow (surface outflow)
D_p = percolation through topsoil and levees

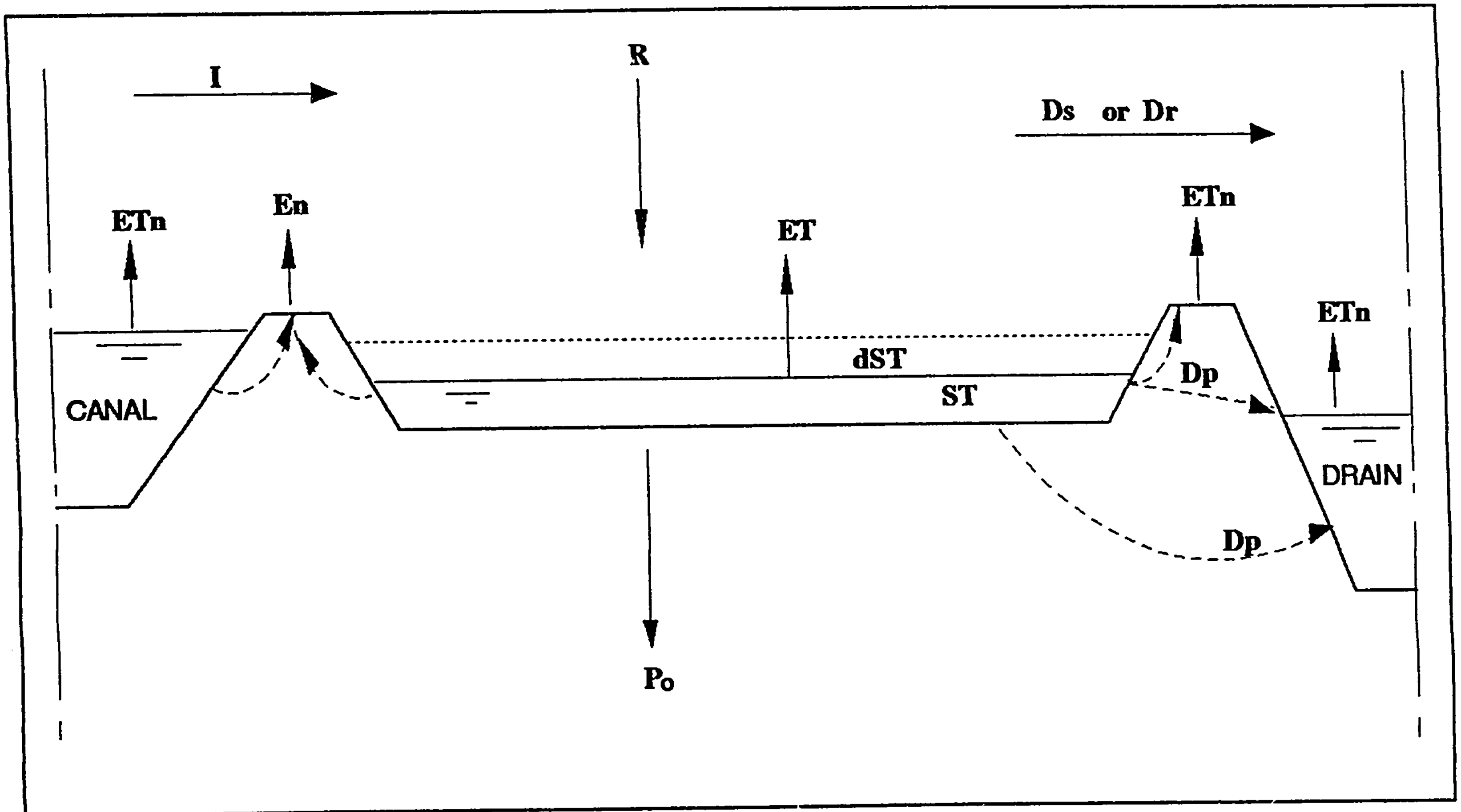


Figure 3.12: The components in the water balance equation for a paddy rice field

P_o = deep percolation, and
dS = changes in the amount of moisture stored in and on the soil.

All terms, unless otherwise indicated, are expressed in mm. ET_n refers to the evaporation from the open water surfaces of canals and drains. It also includes evapotranspiration from levees and canal banks where irrigation water contributes, by seepage and capillary rise, to the water consumption of grass in the dry season. The intervals for the calculations may vary but have to be equal for each term.

3.7.2 Water balance at the block level

The water balance equation of a block has been written as follows:

$$I + R = ET_c + D + P + ET_n + dS \qquad 3.2$$

$$\text{With: } P = P_o - P_i \qquad 3.3$$

$$D = D_s + D_p - D_n \qquad 3.4$$

Where D_n = runoff from uncultivated area

Runoff in this study is that portion of the precipitation that makes its way toward stream channels and paddy fields as surface flow. Factors affecting runoff are those associated the precipitation (e.g. rainfall duration and intensity) and thoseassociated with the watershed (e.g. size, shape, surface culture etc.) The contribution of runoff from uncultivated land (D_n), in the blocks' catchment area that may enter the drainage system must be subtracted from the total amount of drain water to find the amount of drain water from the rice field area (D).

Drain water from one block reused in another block has to be entered in the water balance equation at block level. In general, this drain water has discharged into the main or secondary canal before the water enters the section and can be considered as part of the irrigation water (I_r). Reuse within a block may be reflected in the efficiency of the block's water use.

3.7.3 Water balance at the scheme level

At the scheme level, all the different blocks are considered to have one irrigation inlet (pump station). The total amount of irrigation water (I) was the water diverted from the River Nyando. The amount of drain water could not be measured because of the numerous outlets. However, it was calculated by inserting into equation 3.1 the estimated values of ET_c obtained from the calculations made at block level. Runoff from the non-irrigated land is considered built into (I) or an internal water movement estimated at block level and the term D_n is absent. The equation can thus be written as follows:

$$I_d + R = ET_c + D + P + E_n + dS \qquad 3.5$$

$$\text{With } D = D_s + D_p \qquad 3.6$$

4.0 METHODOLOGY

This chapter first outlines the framework of the study, followed by procedures of data acquisition and monitoring. The methodology used in determining the irrigation application efficiency is presented last.

4.1 Framework

Diagnosis of the strengths and constraints of the AIS irrigation system is accomplished using the framework of interdisciplinary diagnostic analysis. The structure and strategy for the diagnostic analysis of the system follows the same sequence as that recommended for interdisciplinary diagnostic analysis (Lowdermilk et al., 1983) These, in order, include 1) setting preliminary objectives, 2) reconnaissance, 3) revising objectives, 4) detailed studies, and 5) analysis and synthesis. To achieve a more holistic type diagnosis, agro-economic information of the system is studied and incorporated in the report.

The present study focuses on the variability in water control and rice production within the scheme. In searching for relations between seasonal water availability and the efficiency of irrigation water use, seasonal field application efficiencies (Bos, 1980) were determined and used as a performance parameter.

4.1.1 Work Schedule

The outline for the research methodology was developed at the University of Alberta prior to initiating the field work in Kenya in May 1991. The field study component was scheduled for a period of 8 months beginning May 1991. This study is broadly divided into three stages:

1) The first stage of the study was carried out in Ahero, Kenya, during the period from May 1991 to August 1991, with a view to clarifying the present condition of the study area and also identifying constraints.

2) The second stage followed immediately after completion of the first stage and was completed in December 1991. It aimed at completing all the field, block and scheme level experiments.

3) The third and final stage commenced at the beginning of 1992 and was directed at formulating an overall AIS system improvement plan.

4.1.2 Review of first, second and third stage study

Major activities made during the stages of the study are as follows:

First stage

1) Field reconnaissance
2) Data collection in various technical and economic fields
3) Review of available reports concerning scheme.
4) Review of AIS annual reports (1978/79-1989/90)
5) Field investigation comprising:
    a) Inventory survey of existing irrigation and drainage facilities
    b) Inspection of major structural sites
    c) Installation of gauging sites and measurements of discharge
    d) Paddy field inspection at representative paddy plots.
    e) Farm economic survey
    f) Field measurements of hydraulic conductivities
    g) Field measurements of water storage on paddy fields.
6) Preliminary study on current constraints for irrigation system improvement.

The following three issues were recognised as major constraints currently encountered in the irrigation system improvement of the AIS.

i) deterioration of the existing irrigation and drainage facilities in the AIS with decreasing production level of rice
ii) technical and managerial difficulties involved in double cropping of rice, and
iii) poor distribution of water between blocks.

Second Stage

1) Preliminary study on AIS system improvement plan.
2) Additional field investigation and preparation of interim report, and

3) Field investigation concerning water management.

Third Stage

1) Formulation of AIS system improvement plan preparation of draft report.
2) Submission of first draft of final report, and
3) Final report.

4.2 Data Acquisition and Monitoring

Data collected at the study sites were used in the water balance models (field, block, and scheme) to simulate the soil water balance and to estimate the various seasonal field application efficiencies. Data measured at the sites included parameters related to water requirement of rice e.g. irrigation and drainage, rainfall, percolation, storage, spill, and evapotranspiration.

Other data collected/measured at the sites included parameters related to growth and production. Twenty five households were selected at random, maintaining the geographical distribution over the three scheme villages. Data were gathered on rice production, available family labour, distance from water intake to field, how the farmer irrigates, and how much water he applies.

Statistical information about rice yields from rice production and net incomes was obtained from the scheme administration in Ahero. This information seemed accurate when compared with the farmers' records. Data on rice production were collected for all crops between 1971 and 1991. For the period between 1981 to 1991 information on harvest dates per block was included as well. Finally data and other relevant information were obtained from annual reports of the scheme from 1970 until 1990.

4.2.1 Establishment of individual components of the water balance

The water balance equation (3.1) is relatively simple but solving for one unknown may in practice prove rather difficult as some components are not easily measured. For instance, the term P for the percolation of water below the rootzone and subsequent movement to lower lying areas. Methods used in determining the individual components of the water balance are discussed below.

Irrigation and Drainage in canals and drains have been measured with calibrated weirs and flumes.

Rainfall was measured at the AIS meteorological station with raingauges which were read at 0900h (local time) everyday. Raingauges were also installed in the centre of Blocks D and N, and records taken daily. Isohyets developed from this data were employed to determine the amount of rainfall in different blocks.

During the short rain season (1991) from 25th October to 15th November, the effective rainfall in Block D was calculated by subtracting the estimated drainage base flow from the total amount of drain water. A water level recorder registered the upstream head of the weir in the drain of Block D. Rainfall figures have been obtained from the raingauge installed in Block D.

Deep Percolation in rice fields was estimated with the help of piezometers. Two sets of piezometers were installed in Block D. The installation of two piezometers at different depths gives the hydraulic head difference in the ground water at the open end of the shallow and deep piezometer. When the water level in the shallow piezometer is higher than that in the deeper one, downward seepage takes place. When the water level in the shallow piezometer is lower, seepage in an upward direction takes place. The flow of water through the layer of soil between the piezometer pipe ends is described by Darcys' law (Hillel, 1982);

$$Q=K\frac{\Delta H}{L}A \qquad 4.1$$

Q = the amount of water flowing through the soil, m^3/day

K = hydraulic conductivity of the soil, m/day

L = the thickness of the soil layer, m.

ΔH = the hydraulic head difference measured over the soil layer in question, m

A = cross sectional area of the soil layer, m^2

The two sets of piezometers were installed at depths of 0.6 m and 1.5 m in Blocks D and O. The thickness of the soil layer over which the seepage was measured was 0.9 m. In the same blocks the hydraulic conductivity of the soil was measured using the auger hole method. The results obtained are presented in Table 4.1. These results led to the acceptance of a rate of deep percolation of approximately 0.05-0.1 mm/day.

Table 4.1: Deep percolation in the rice fields of Blocks D and O.

	Block D	Block O
ΔH (m)	0.13	0.3 (Avg. of three readings)
L (m)	0.9	0.9
K (m/day)	0.6×10^{-3}	1.6×10^{-3} (Avg. of six measurements)
Q (mm/day)	**0.09 mm/day**	**0.05 mm/day**

Deep percolation in canals was measured in the main canal having an average wetted perimeter of 3.5 m by means of infiltrometers. The average infiltration approximated to 75 mm d^{-1}. Thus percolation losses were in the order of 3 L/s/km canal.

Besides the above method, seepage was also estimated by using the static seepage method. This was done by measuring the change in flow between two drop structures along the canal. The main flow of the canal was reduced to a small flow of 5 - 10 L/s. The discharge measurements were taken at the drop structures with the use of bucket and stop watch. Seepage losses were approximately 2 L/s over a length of canal of about 1.5 kilometres. Possible error in the experiment could have been caused by some water seeping under the drop structure or hidden crevices.

Storage The amount of water stored in a rice field is the sum of the water stored in the soil and the water stored on the soil surface. The amount of water in the soil and changes in the soil moisture have been measured by soil sampling (Appendix E).

The amount of water stored on the field was measured by measuring the water level using staff gauges. This storage for the blocks was determined by measuring the water levels in several fields within the block every second or third day. For this purpose, 15 gauges have been placed at random in Blocks A1, K, D, O, N, L, and P. It appeared that the difference in water levels of the individual fields was large because the fields were irrigated in rotation. Consequently, the water balance for the individual blocks was solved for a time interval of at least two weeks so that the influence of the error made in the storage calculation could be neglected.

For periods shorter than two weeks, the storage can be calculated by inserting the calculated amount of evapotranspiration in the water balance equation at the block level. Measured and calculated storage were then compared.

Runoff from uncultivated land (D_n) could not be measured and was estimated with the empirical method of the United States, Soil Conservation Services, US SCS (Appendix F). By subtracting the runoff from the uncultivated area from total drainage, the drainage from the rice area was determined.

Evapotranspiration from rice fields can be determined directly or calculated from crop and climate data. Most direct measurement techniques involve isolating a part of the crop from its surroundings to determine actual evapotranspiration, as described by James (1988). The complexities of estimating crop evapotranspiration, ET_c, have led to the development of the concept of reference evapotranspiration, ET_r (Hatfield, 1990). ET_c from a well-watered rice crop is calculated by solving the water balance equation (3.2) at block level. ET_c was also estimated as the product of reference evapotranspiration, ET_r, from a standard surface and an appropriate empirical crop coefficient, k_c. This is stated in the following equation:

$$ET_c = k_c \, ET_r \qquad 4.2$$

where:

ET_c = evapotranspiration for the rice crop (mm/day)

K_c = crop coefficient, and

ET_r = reference evapotranspiration (mm/day)

Crop coefficients, k_c, are often determined experimentally with lysimeter studies, and reflect the physiology of the crop, the degree of crop cover, the location where data were collected, and the method used to calculate ET_r (James, 1988). In this study seasonal k_c values were estimated by the ratio of ET_c and ET_r (ET_c / ET_r). These k_c values could then be applied to other blocks and periods.

The selection of methods for calculating evapotranspiration often depends on available data and level of accuracy required. This study employs the 'combination method' involving the solution of the energy balance (Penman, 1948. Appendix D). Other methods using routinely measured meteorological data such as radiation and temperature are also commonly used in irrigation studies.

Evapotranspiration from uncultivated area (ET_n) is assumed equal to reference evapotranspiration as calculated by the Penman equation. ET_n recalculated over the net cropped area amounted to about 0.3 mm/day. In the dry season this may not be neglected but during the rainy season most of ET_n is met by rainfall and the contribution of irrigation water to ET_n is negligible.

4.3 Methods

4.3.1 Field Level

A water balance was calculated for two adjacent fields in Block D to establish the pattern of water use at the field level for the period during deep flooding (saturation), flooding and maintenance of flood. Block D was chosen for this experiment because it was one of the two blocks receiving water at the time. Due to the limited number of pre-fabricated flow measuring structures which had to be installed in the fields, similar experiments on other fields in different blocks could not be done. These two fields, having a total area of approximately 7900 m^2, were chosen at random within the block. The amount of water in the main feeder was controlled by the water guard while the farmer controlled the flow through the field inlets and outlets. A sketch of the field is shown in Fig. 4.1.

The irrigation inlet was located in Field 1, while the drain outlet was located in Field 2. Irrigation water passes from Field 1 to Field 2 via an overflow in the levee between the two fields. A flow chart depicting the flow of water in the field is shown in Fig. 4.2.

The water balance equation used is Equation 3.1, with Dr = 0 because the fields are located at the boundary of Block D, where no drainage water is reused. The inflow was measured with a 15-cm Parshall flume. Rainfall was taken as the average of the rainfall measured at the Ahero Reception centre.

The amount of water which was stored in the soil before and after flooding differed by 75 mm (Appendix E). The amount of water stored on the field was measured with staff gauges which had been installed in both fields. A Topographical survey was used to obtain their mean elevation. The evapotranspiration from both fields was assumed as being equal to the calculated evapotranspiration according to the Penman equation (Cuenca, 1989). It appeared from the water balance calculations at the block level (section 5.2) that this is acceptable. The other data which were not measurable are calculated from the water balance equation as the combined losses. They are as follows:

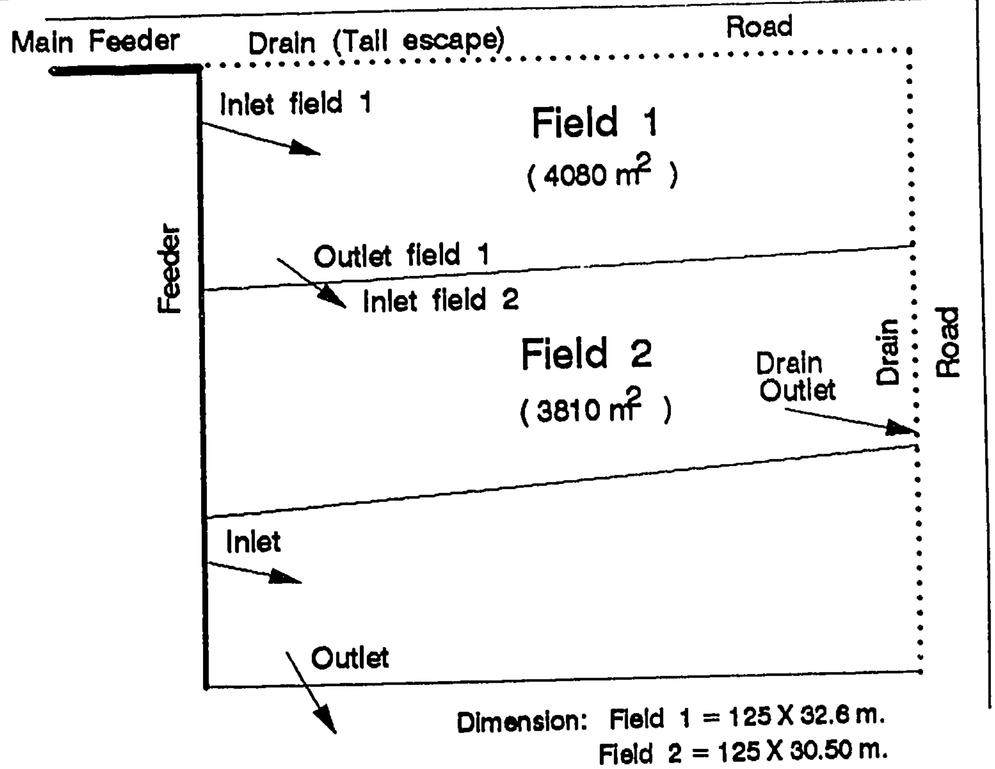


Figure 4.1. Sketch of Block D fields where field experiment was conducted

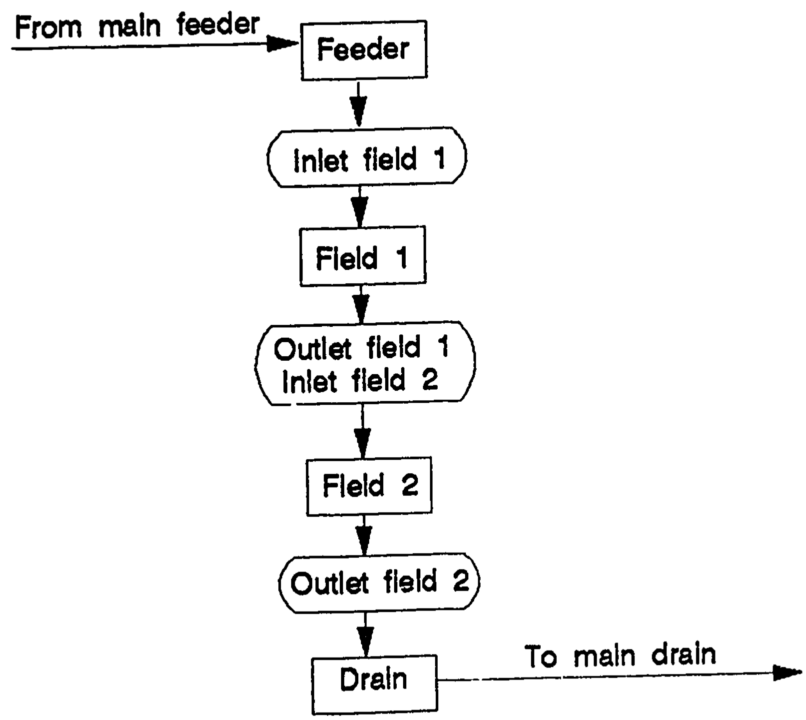


Figure 4.2. Flow of water in the experimental fields

$$D_s + D_p + ET_n + P_o - P_i \qquad 4.3$$

The water balance calculations were carried out for the period 3 July - 26 July 1991. At the beginning of July the fields were saturated and flooded, and the flood was maintained for the rest of the period. Rotavation (puddling) was conducted on the fields on the 8th of July.

4.3.2 Block Level

The basis of the calculation at the block level was the water balance Equation 3.2. The amount of irrigation water, rainfall, drainage outflow and the water stored was measured in several blocks while deep percolation and the evapotranspiration from the uncultivated area was estimated as indicated in Section 4.2.1. The amount of measured drainage outflow was corrected for runoff from uncultivated area. With these results, the evapotranspiration from rice fields (ET_c) and seasonal field application efficiency (E_a) could be calculated.

The amount of irrigation water which was applied was measured in Blocks G, A1, B, K, D, L, N, M, P and O. Discharges were measured twice daily. Drainage outflows were obtained from Blocks G and B, A1 and K, and D. The outflow of Blocks G and B combined was measured twice or three times a day. The amount of water stored on the soil surface was measured in Blocks A1 and K, D, O, N, P, and L at intervals of two to three days.

From the water balance equation it was possible to calculate the evapotranspiration from rice fields in different blocks. The data obtained on the storage change of water in the soil were not sufficiently accurate to warrant the calculation of evapotranspiration for periods shorter than two weeks. In order to verify the water balance model, it was necessary to work out the water balance equation for five-day periods to calculate the apparent storage in the fields for time steps other than two weeks. A five-day time step was possible because ET_c could be calculated reasonably accurately for other periods of time by multiplying ET_r by the obtained K_c. Comparisons were then made between the measured and calculated storage in the blocks.

5.0 RESULTS AND DISCUSSIONS

The first three sections of this chapter present an asses   nt of the variability in water application at the field, block and scheme levels using the seasonal water balance. Management practices within the scheme with particular emphasis on water distribution have been included. Statistical analysis is used to access the variability of rice production in the blocks. Possibilities to save water and improve the economic setting of the farmer are finally presented as a synthesis of the analysis.

5.1 Variability in water application at field level

<u>Observations</u>

Irrigation, rainfall and storage depths are graphically presented in Fig. 5.1, while the irrigation schedule and the quantities applied are presented in Table 5.1. The results from the water balance calculations are shown in Table 5.2. From the data it appeared that the losses, which are mainly drainage losses, in the period before rotavation were considerably higher than in the period after rotavation. Before rotavation the losses amounted to 12.0 mm/day against 5.0 mm/day after rotavation. The water loss before rotavation, although, higher on a daily basis, is, as a percentage, much lower. This is due to large amount of water applied for the saturation and to establish a layer of water on the soil. After the establishment of the water layer, the losses are quite high.

For the saturation and establishment of the flood 211 mm of water was required for the two fields. The field application efficiency during this period was about 80%. After rotavation, the water losses were quite high and the efficiency obtained was in the order of 40%.

<u>Conclusion</u>

- Prior to rotavation, the rate of D_p and P_o terms in equation 4.3 which are influenced by the soil texture are generally high but decreases with time. These together with spill (D_s) make the daily water losses significant. After rotavation the water retention ability of the paddy is increased as D_p and P_o decrease and most of the losses are caused by D_s.

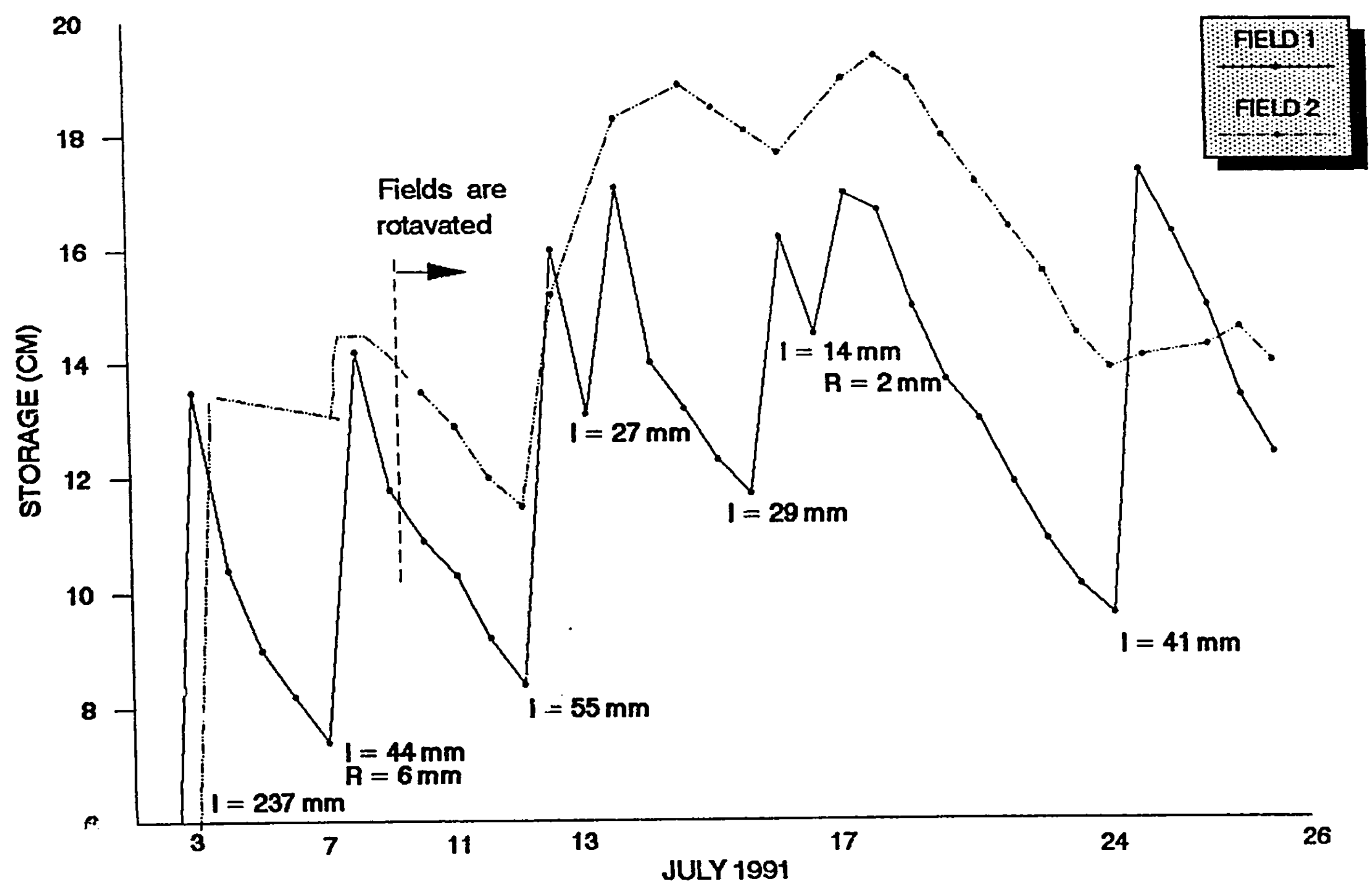


Figure 5.1. Water storage on the soil surface during, saturation, flooding and maintenance of the flood in Block D fields

Table 5.1. Irrigation schedule and water applied from July 3 - July 26, 1991. (Two fields in Block D)

Date	Irrigation Duration (hrs)	Irrigation Amount applied (mm)
July 3 - 4	24	237
July 7	3	44
July 12 - 13	9	82
July 16 - 17	4	43
July 24	4	41

Table 5.2. Results of water balance calculation at field level (1991).

Period	3 July - 8 July	3 July - 26 July	8 July - 26 July
I (mm)	281	447	166
R (mm)	6	8	2
dS (mm)	211	207	-4
ET_r (mm)	17	92	75
Losses (mm)	59	156	97
Efficiency (E_a)	79%	65%	42%

- It is not possible to draw a conclusion about the application efficiency of the scheme water management at the field level from this one experiment. However, it is evident that the peak water requirements falls in the period during rotavation. Thus, a diligent management strategy is necessary for equitable water delivery schedules in time and space.

5.2 Variability in water application at block level

1) Evapotranspiration

The crop evapotranspiration in the different Blocks has been calculated for periods of two weeks for Block D (Table 5.3). Similar calculations made for the other blocks are shown in Appendix H. Block D evapotranspiration rates (Fig. 5.2) indicate that the evapotranspiration from rice fields calculated using the water balance equation before and just after transplanting is about equal to the reference evapotranspiration according to Penman. The crop evapotranspiration (ET_c) surpasses reference evapotranspiration (ET_r) as the crop develops and the peak water use exceeds ET_r by 25%. ET_c value ranged from a maximum 6.6 mm/day in the latter half of October, 1991 to a minimum of 3.5 mm/day in the first half of July in Block D (Fig. 5.2).

The values of K_c found for the different blocks are presented in Fig. 5.3. The maximum value obtained was 1.24 in the first half of November 1991, in Block D. The K_c found for Block N was lower than those of Blocks D and P during part of the season and only increased when the rains started in the beginning of November.

2) Storage on the soil surface

The water balance equation for five day periods is worked out and used for calculating the amount of storage on the soil surface. This amount is then compared with the measured storage. An example of the calculation made for Block D has been presented in Table 5.4.

The calculations which have been made for the other blocks have been presented in Appendix H. The comparisons of the calculated and measured storage in Blocks D, P, and L are shown in Fig. 5.4, 5.5, and 5.6 respectively. The average

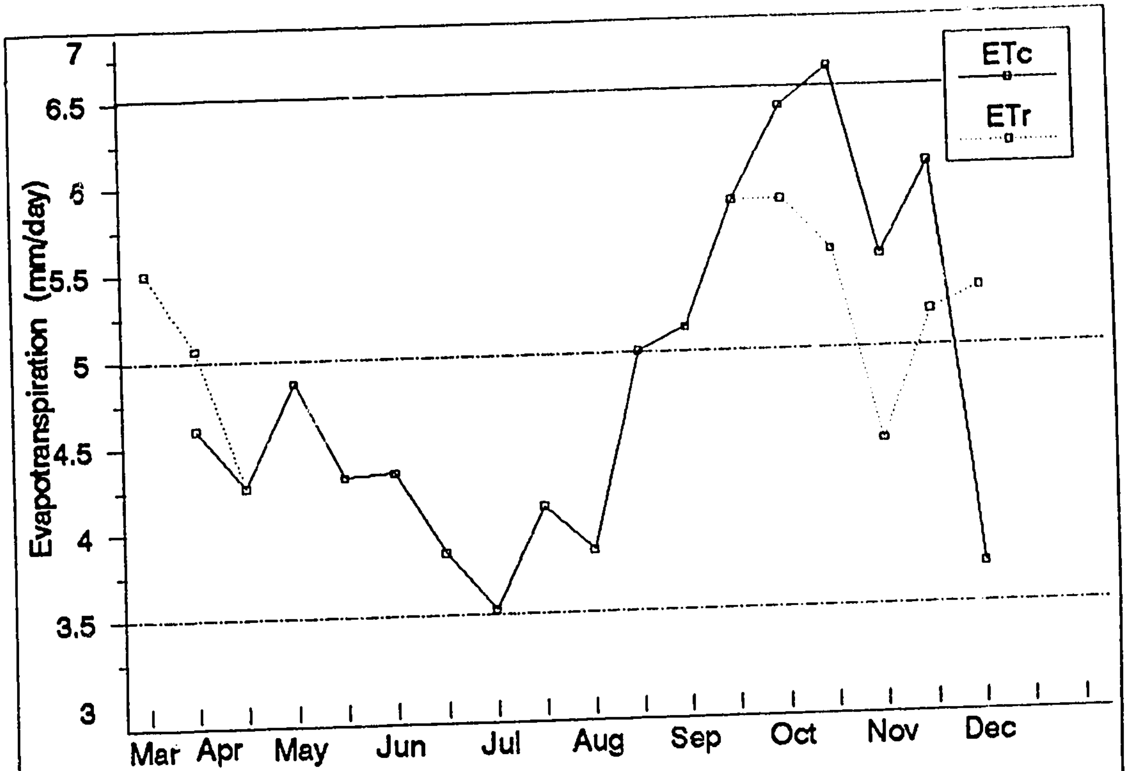


Figure 5.2: Variation of ETc and ETr during 1991 season

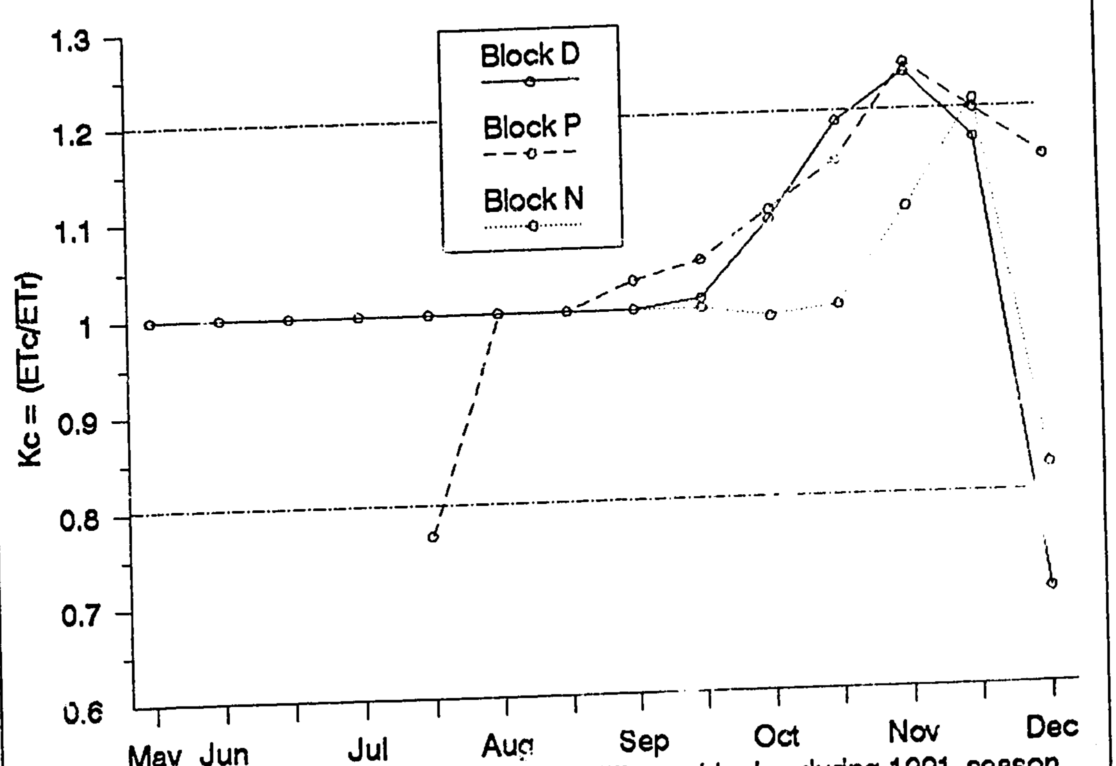


Figure 5.3: Variation of crop coefficient for different blocks during 1991 season

Table 5.3. Water balance of Block D for two week periods.

Month	Date	I mm	R mm	D^1 mm	ET_n+P mm	dSTO mm	STO mm	ET_c mm	ET_r mm	K_c
Mar	28-31	66	0	11	-	45	4.5	5	22	0.25
Apr	1-15	139	207	129	1	137	18.2	69	76	0.9
	16-30	54	74	105	1	-47	14.0	64	64	1.0
May	1-15	150	57	81	1	52	19.2	73	73	1.0
	16-31	79	80	79	1	10	20.2	69	69	1.0
Jun	1-15	115	24	53	4	17	21.9	65	65	1.0
	16-30	60	0	33	5	-36	18.3	58	58	1.0
Jul	1-15	131	2	86	5	-11	17.2	53	53	1.0
	16-31	85	2	42	5	-26	14.6	66	66	1.0
Aug	1-15	98	2	83	5	-46	10.0	58	58	1.0
	16-31	97	2	79	5	-65	3.5	80	80	1.0
Sep	1-15	137	2	32	5	25	6.0	77	77	1.0
	16-30	149	0	26	5	30	9.0	88	88	1.0
Oct	1-15	128	5	27	5	5	9.5	96	88	1.09
	16-31	128	32	44	3	7	10.2	106	89	1.19
Nov	1-15	97	225	208	1	30	13.2	83	67	1.24
	16-30	54	4	96	1	-130	0.2	91	78	1.17
Dec	1-15	12	6	25	3	66	-	56	80	0.

Table 5.4. Water balance of Block D for five-day periods.

Month	Day	I mm	R mm	D[1] mm	ET_n+P mm	ET_c	dSTO mm	STO[2] cm
SEP	1-5	38	0	13	2	27	-4	3.1
	6-10	56	1	12	2	24	19	5.0
	11-15	43	1	7	1	26	10	6.0
	16-20	56	0	18	2	30	16	7.6
	21-25	48	0	12	2	30	4	8.0
	26-30	45	0	6	1	27	11	9.1
OCT	1-5	44	5	9	2	31	7	9.8
	6-10	40	0	11	2	33	-6	9.2
	11-15	44	0	7	1	33	3	9.5
	16-20	42	0	9	2	33	-2	9.3
	21-25	35	32	14	1	32	20	11.3
	26-31	51	0	21	0	41	-11	10.2
NOV	1-5	30	67	29	0	31	37	13.9
	6-10	55	100	100	1	24	30	16.9
	11-15	12	58	79	0	29	-38	13.1
	16-20	40	4	30	0	29	-15	11.6
	21-25	10	0	41	1	31	-63	5.3
	26-30	4	0	25	0	31	-52	0.1

1. D = Corrected outflow

2. STO on 31 August = 3.5 cm

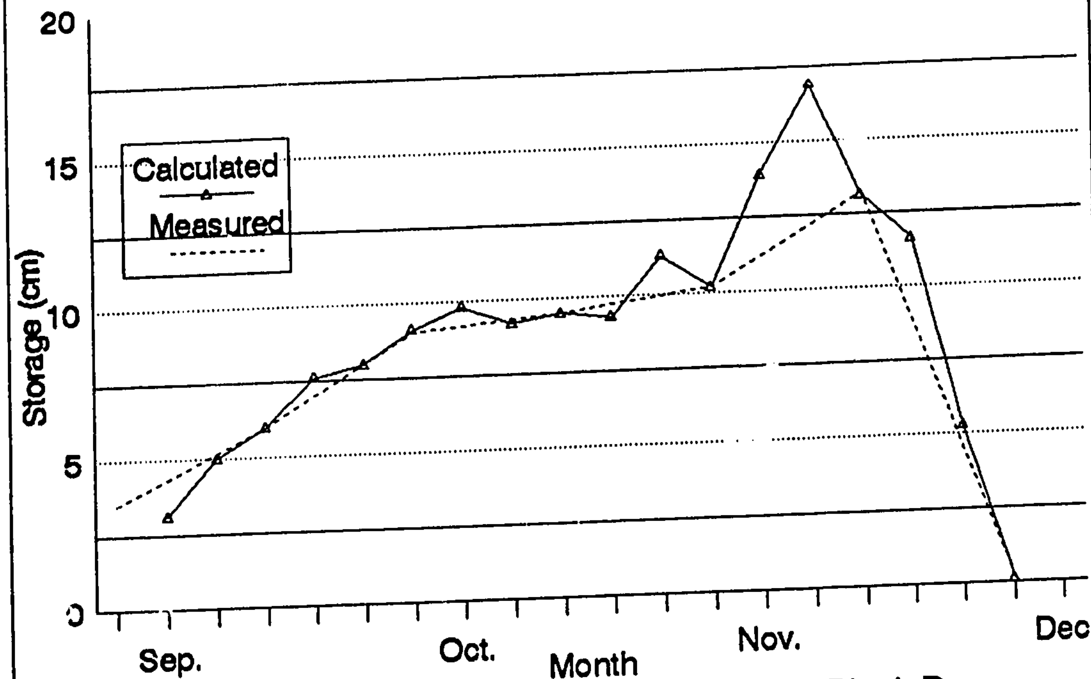


Figure 5.4: Water stored on the soil surface in Block D

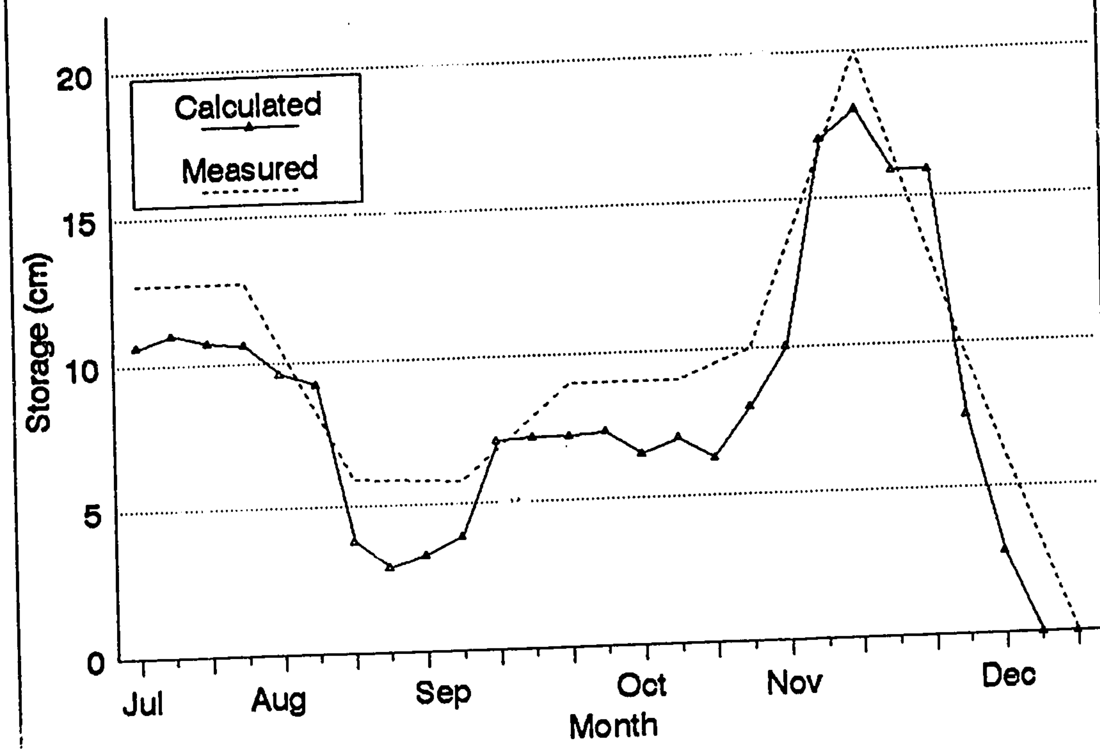


Figure 5.5: Water stored on the soil surface in Block P

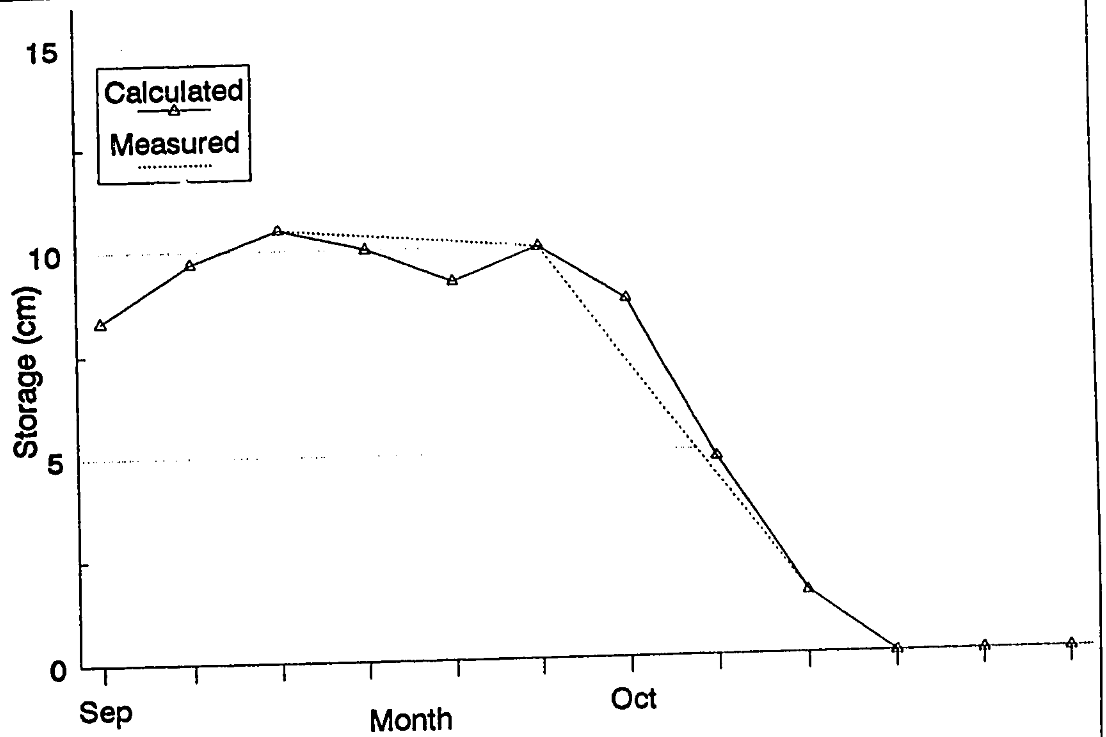


Figure 5.6: Water stored on the soil surface in Block L (1991).

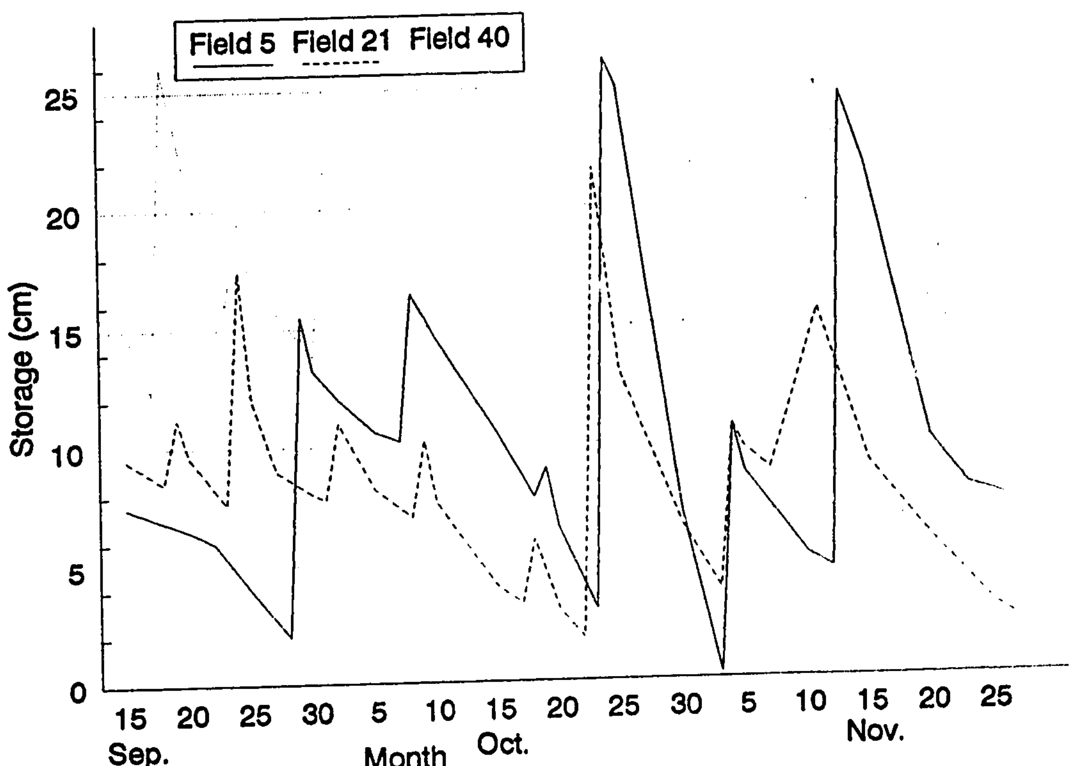


Figure 5.7: Water stored on the soil surface in some fields of Block K (1991).

storage in Block D increases after transplanting from 3 cm to about 10 cm. During the rainy season, the average storage drastically increase and remains at values between 12 and 17 cm until the water is drained off. In Block P, the average storage does not surpass 7 cm, with some fields observed completely dried up, before the first rain on 25th October. A similar scenario is seen in Block K where apparently the water distribution is better because fewer fields dried up. Block L storage resembles that of Block D the most in that hardly any fields dried up during the irrigation season. The storage increases after transplanting from about 5 cm to 10 cm. The fields are drained before the rains start.

Storage in individual fields is much more variable than the block averages and the deviation from the average storage may be large. An example of the storage in some fields in Block K is presented in Fig. 5.7.

3) Effective rainfall

The total amount of rainfall in Block D was 278 mm, between August to December 1991, of which 225 fell in the first half of November. The effective rainfall was therefore 138 mm (Table 5.5). This resulted in a 50% effective rainfall for the period from transplanting till harvest.

The total amount of rainfall in Block P was 323 mm for the same period, of which 272 mm fell in the first half of November. The increase of 225 to 272 mm in Block P would normally result in a decrease of effective rainfall. This was not the case in Block P because some of the fields were dried up before the rains. In the dried up parts the effective rainfall would be much higher. This is also clearly reflected in the storage figures of Block P (Fig. 5.5) which experienced average storage of approximately 3 cm with some fields drying up during the season. The effective rainfall in Block P has been estimated at about 160 mm or 50% based on the scheme average.

During October and December 1991 the effective rainfall for the whole scheme over the rainy season for periods of two weeks, ranged from 40 to 50%. No exact figures can be given because there was not enough water measuring structures to cover the entire scheme area.

Table 5.5. Effective and actual rainfall figures for Block D (Aug.- Dec. 1991)

Period	Actual rainfall (mm)	Effective rainfall (mm)
Aug. 1-15	2	2
16-31	2	2
Sep. 1-15	2	2
16-30	0	0
Oct. 1-15	5	5
16-31	32	27
Nov. 1-15	225	90
16-30	4	4
Dec. 1-15	6	6
Total	278	138

4) Block application efficiencies

The irrigation application efficiencies (E_a) obtained in Block D are presented in Table 5.6. The calculations have been made as indicated in equation 2.4. There was sufficient water for irrigation in the period before transplanting, after which, the river discharge was lower (Fig. 5.8) while the water demand increased. Better water management is needed to meet the requirements. This is reflected in the higher efficiency obtained. The same trend occurred in Blocks K and P (Table 5.7). The efficiencies obtained in Block K were lower than those obtained in Blocks D and P. All the drain water from Block K was conveyed into to the main canal and reused in other blocks. The lower efficiency obtained was not reflected at the scheme level.

The efficiency obtained in Block L after transplanting ranged from 40 to 50%. Data for other blocks are less reliable. The irrigation application during September and October ranged between 400 and 650 mm, with an average of 520 mm. Extreme values of the irrigation application have been measured in Blocks A2, M and O. In all three of the constant head orifices delivering water to these Blocks, stones had been thrown to reduce erosion and the computed discharges were not accurate. Omitting these three blocks, the average application was 5[illegible]

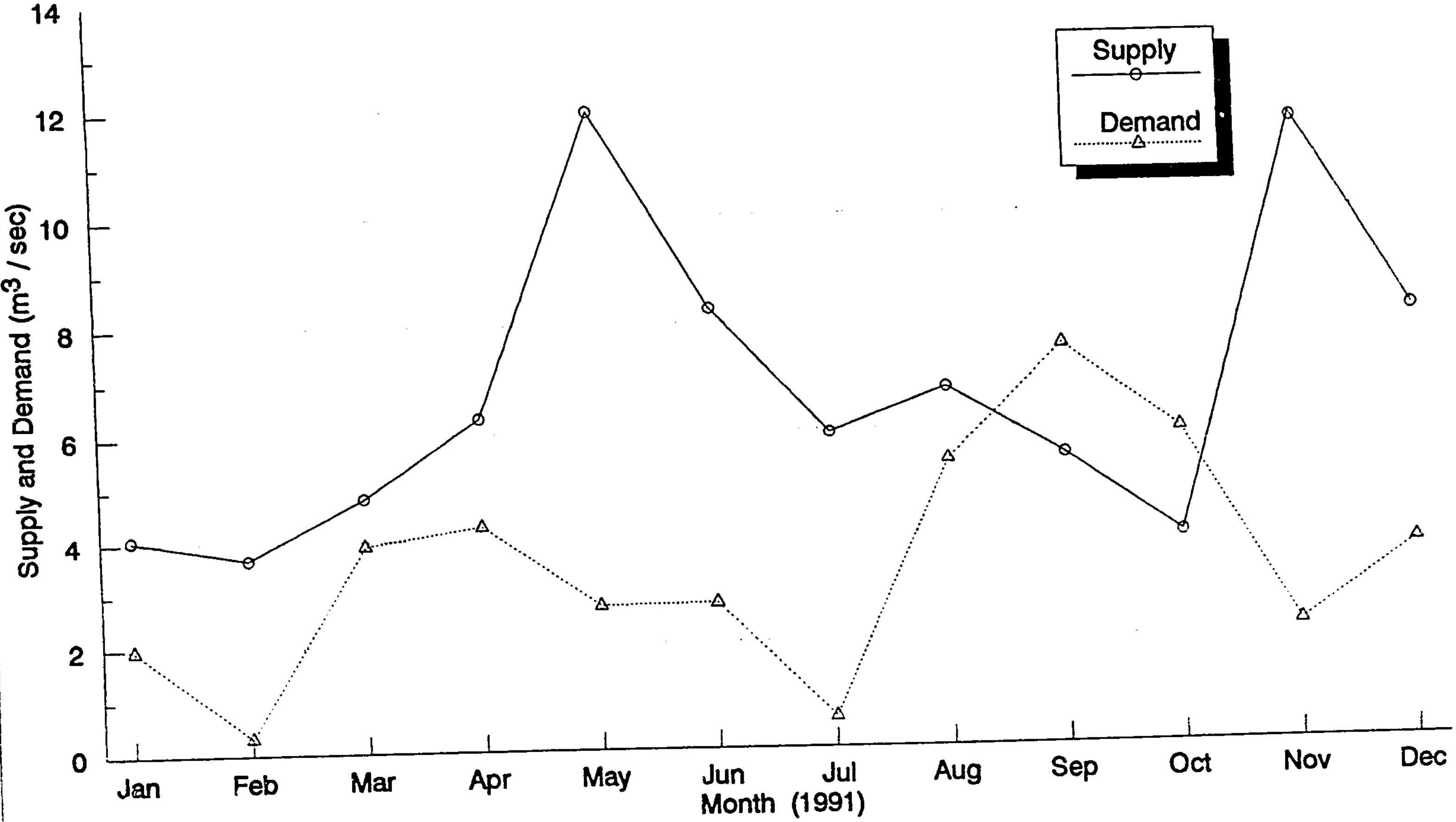
The average application efficiency for all the blocks cannot be calculated accurately because storage changes for all the blocks have not been measured. Thus,

Table 5.6. Efficiencies for Block D

Period (1991)	ET_c	R_e	dS	I	Efficiency %
Mar 28 -Apr 30	138	110	115	259	55
May 1 - 31	142	50	-	229	40
Jun 1 - 30	123	20	-	175	59
Jul 1 - 31	119	4	-	216	53
Aug 1 - 15	58	2	-	98	57
Aug 16 - 31	80	2	-15	97	65
Sep 1 - 30	165	2	55	286	76
Oct 1 - 31	202	32	10	256	70
Nov 1 - 30	174	94	-100	151	0

Table 5.7. Efficiencies for Block K and P.

Month	Block K	Block P
July/August 15th	35	40
September/October	58	68



Supply = Available drought discharge at pump station
Demand = Diversion requirement to pump station

Figure 5.8: Supply and demand of water from River Nyando

considering only the results obtained in those blocks where storage changes have been measured were examined. The storage increased by some 20 to 30 mm during September and October mainly due to the onset of the rainy season which occurred by the end of October. With the effective rainfall and ET_c approximately 40 mm and 360 mm respectively, the average seasonal application efficiency for the blocks will be 345/530 x 100 or approximately 65%. This compares well with the results obtained in Blocks D, K and P.

5) Reuse of drain water

From Blocks D, K and L the drain water may be reused for irrigation in other blocks. The amount of water involved was measured at block level in Blocks K and D. The drain water was used for irrigation in reuse Blocks A2, F, M, and O. The amount of water drained from Blocks K and D (D_s) in mm and the equivalent amount of irrigation water (I_r) in mm for the reuse Blocks is presented in Table 5.8.

The total amount of water (I) applied to the reuse Blocks has been measured as well. The difference I - I_r is the amount of irrigation water diverted from the river (I_d) assuming drainwater from other Blocks other than K and D which entered the irrigation system is negligible (See Table 5.9).

The efficiencies of irrigation water (total and diverted) in the reuse blocks are compared with those obtained in Blocks K and D (Fig. 5.9). Water reuse appears not to be very important from June to August. During September and October, the reuse is very important and the efficiencies obtained from I_d are over 80%.

Conclusions

- during the peak water requirement (saturation and flooding), ET_c is approximately equal to ET_r.
- the calculated and measured storage values validated the use of the water balance model.
- despite the scheme average seasonal application efficiency of 65 percent, poor water distribution resulted in some fields falling dry during the season.
- blocks irrigated late in the planting calender require more water for saturation and flooding than those irrigated early.

- reuse of drain water between blocks increases E_a during part of the season.

Table 5.8. Reuse of drain w.ᵗᵉʳ ʳ.om Blocks K and D.

Month	Drain water D_s (mm)		Reuse I_r (mm) Blocks A2, F, M and O
	Block D	Block K	
June	86	82	55
July	128	146	90
August	162	282	150
September	58	154	75
October	71	101	60

Table 5.9. Evapotranspiration, irrigation application and storage change in the reuse blocks (mm).

Month	ET_c	I_d	I_r	I	dS
June	70	195	55	250	50
July	100	250	90	340	50
August	140	230	150	380	20
September	170	210	75	285	30
October	200	215	60	275	10

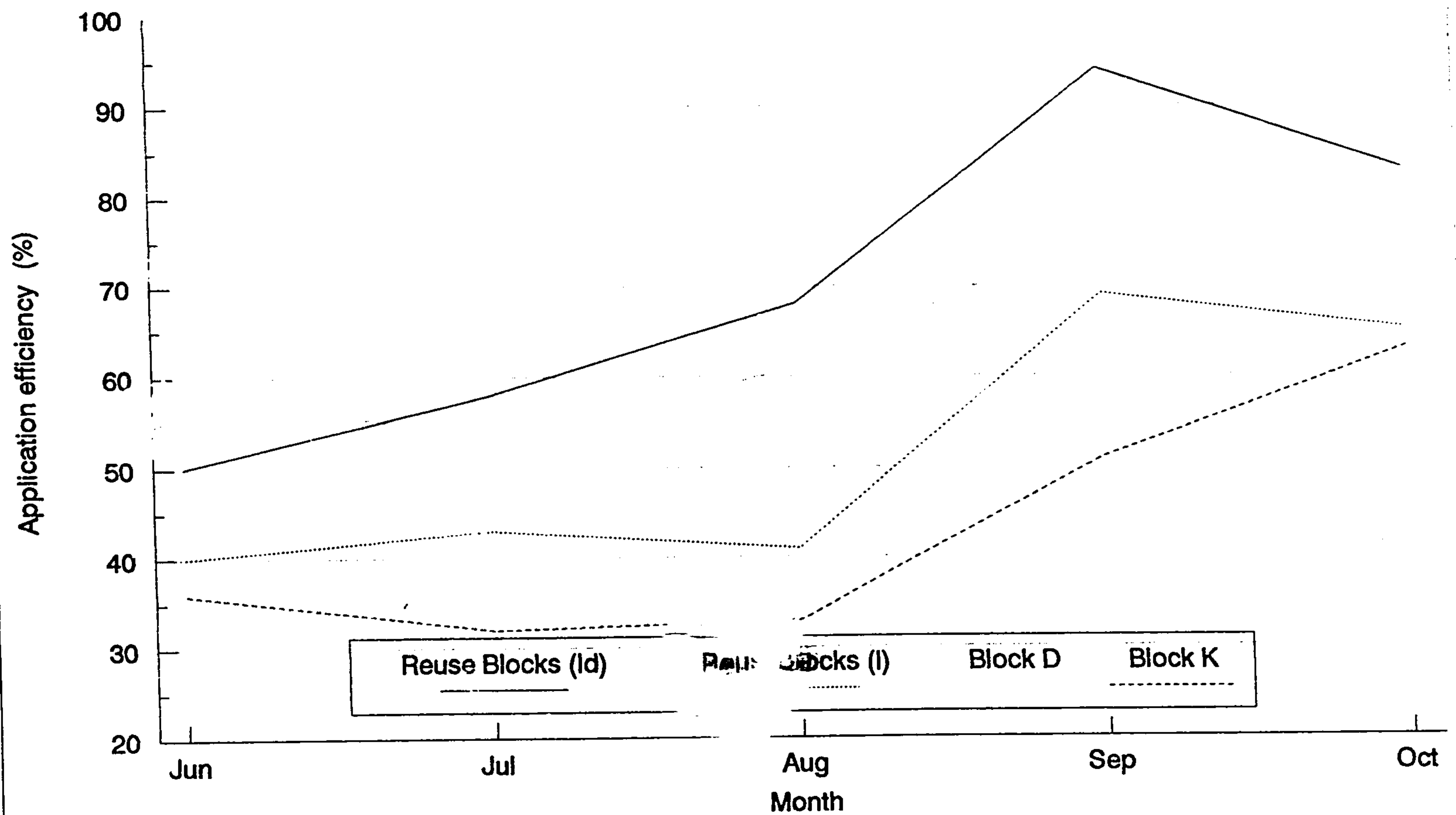


Figure 5.9: Application efficiency obtainend with river water (Id) and total irrigation water (I) in reuse blocks, compared with application efficiency obtained with total irrigation water in Blocks K and D

5.3 Project irrigation efficiency (E_p)

The project irrigation efficiency in the scheme was estimated using the results from the study at the block level and the intake discharge data measured at the pumping station. The measurements were made from January to December 1991, in order to compute the scheme irrigation efficiency on an annual basis (Table 5.10). The staggering of the planting dates at the scheme level has been taken into account.

Storage changes are estimated based on the results obtained at the block level and must be seen as a reflection of the major changes occurring during the season. The amount of water required to saturate the [illegible] the start of the season has been based on the measurements described in Appendix E.

The contribution of the Nyando River (I_d) to the total amount of irrigation water used during the 1991 season was 1850 mm. Evapotranspiration and rainfall were 1056 mm and 540 mm, respectively, for the season. The total losses are approximately 1325 mm. Of this amount, approximately 50 mm are due to deep percolation and to evapotranspiration from canal banks and field bands. Assuming the overall effective rainfall to be 50% (Section 5.2), the average annual project efficiency (E_p) is:

$$E_p = \frac{ET_c - R_e}{I_d} = \frac{1056 - 540/2}{1850} = 43\% \qquad 5.1$$

There are several reasons for the low annual efficiency. Firstly, before the season starts, water is drawn from Nyando River for domestic purposes and the water flow maintained is for a large part lost as spill water. Secondly, high water levels are maintained for weed suppression at transplanting time of which about 50 - 70 mm has to be drained from the fields. Thirdly, at the end of the season before harvest, most of the area is drained only a short time after the rainy season. At this time, the water levels are at their maximum, and there is not sufficient time to reduce the water layer by evapotranspiration only.

The project efficiency before transplanting was approximately 45 - 50%.

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The project efficiency before transplanting was approximately 45 - 50%.

Table 5.10: Water balance (mm) of the Ahero Irrigation Scheme - 1991 season.

Period	I_d	R	I+R	dS_A	dS_B	ET_c	Losses
Mar 14-31	95.0	18	113	27	-	7	79
Apr 1-15	45.7	50	96	16	-	15	65
Apr 15-30	35.5	33	68	9	-	19	40
May 1-15	76.0	25	101	10	-	27	64
May 16-31	90.6	45	136	13	-	32	91
Jun 1-15	105.6	18	124	13	-	37	74
Jun 16-30	120.9	0	121	17	-	39	65
Jul 1-15	125.9	5	131	18	-	42	71
Jul 16-31	136.8	3	140	17	-	50	65
Aug 1-15	135.9	3	139	12	-10	55	82
Aug 16-31	140.6	1	142	3	-50	79	110
Sep 1-15	129.5	0	130	3	-5	77	55
Sep 16-30	124.4	0	124	-	0	91	33
Oct 1-15	124.1	5	129	-	0	94	35
Oct 16-31	129.0	30	159	-	20	101	38
Nov 1-15	66.2	244	306	-	45	80	181
Nov 16-30	77.7	5	83	-	-75	92	66
Dec 1-15	50.5	5	85	-	-65	73	47
Dec 16-31	40.0	50	90	-	-20	46	64
Total	1850	540	2387	160	-160	1056	1325

I_d = Irrigation water from Nyando river

R = Rainfall

I + R = Irrigation and Rainfal

dS_A = Storage changes during land preparation

dS_B = Storage changes during maintenance period

ET_c = Crop Evapotranspiration

During transplanting the project efficiency was approximately 30%, which suggests, that the water stored in the field is merely drained-off and was not reused for irrigation in other blocks. After transplanting, the project efficiencies are much higher. From the first half of September till the end of October efficiencies obtained were in the order of 70 - 75%. Although the efficiencies obtained for these periods are high, it has been observed that in many blocks the water distribution was unsatisfactory (Section 5.4).

It was observed that the peak water requirement (maintenance and topping up) for the scheme occurred during September and October. The increase in storage in different blocks ranged between 10 and 30 mm (Section 5.2), with an average of 17.5 mm. In some blocks there was an increase of water level during the first half of September which was offset by the decrease in storage in the blocks transplanted later. This decrease was estimated at 20-25 mm since the blocks were transplanted early. The average increase recalculated over the whole scheme is approximately 10-15 mm. To arrive at an average water depth of 100 mm, the storage change should be about 50-60 mm over September and October while the actual storage change was only 30 mm during these months. This was a shortfall of some 20-30 mm and indicated that if the irrigation practices remain the same, then a project efficiency of 75% has to be obtained to make topping up possible.

<u>Conclusions</u>

- the project irrigation efficiency of 43% is low and can be improved (Section 5.5).
- major factors contributing to low application efficiencies are spill (D_s) and seepage (D_p) losses. Losses from P_o, P_i, and ET_n can be considered unavoidable.
- Inequitable distribution of water within the scheme results in excessive spill and high water levels in certain fields which in turn lowers (E_p).

5.4 Water Management and Resulting Water Distribution

5.4.1. Irrigation water ε ɔplied

The amount of irri;ation water applied during the first month of the irrigation season of the individual blocks is water needed for saturation, flooding and maintenance of the flood. The saturation requirement depends on much the soil has dried out. During the rainy season, the amount of water to be added is lower and the contribution of rainfall is highest. The demand will increase from the end of the rainy season onwards.

The difference in net irrigation requirement may be 100 mm (Appendix H). This difference was noticeable in the field even though the irrigation efficiency was different from block to block. In general, more water is applied in blocks that have been irrigated late in the planting calendar (Fig. 5.10).

Blocks irrigated late in the planting calendar need approximately 200 to 250 mm more water during the first month of irrigation. This difference is offset due to the fact that a water layer has to be maintained till transplanting (present practice) over a large period of time on the earlier prepared fields. On the other hand evaporation from an open water surface (ET_r) is higher than the evapotranspiration from the fields (ET_c) before flooding. For the first month, the following deduction can be made:

ET_c	=	100 to 120 mm
dSM	=	0 to 120 mm
dSTO	=	100 mm
I (net)	=	220 to 320 mm
I (gross)	=	370 to 530 mm (Assuming efficiency of 60%)

In the blocks that are early, the gross irrigation application is 260 mm, leaving the rainfall contribution to approximately 110 mm in April. It appears that the assumptions that have been made are reasonable.

At the field level (Section 5.1), the application from July 3rd to July 26th was approximately 450 mm. With an evaporation rate of 4 mm/day, continuing

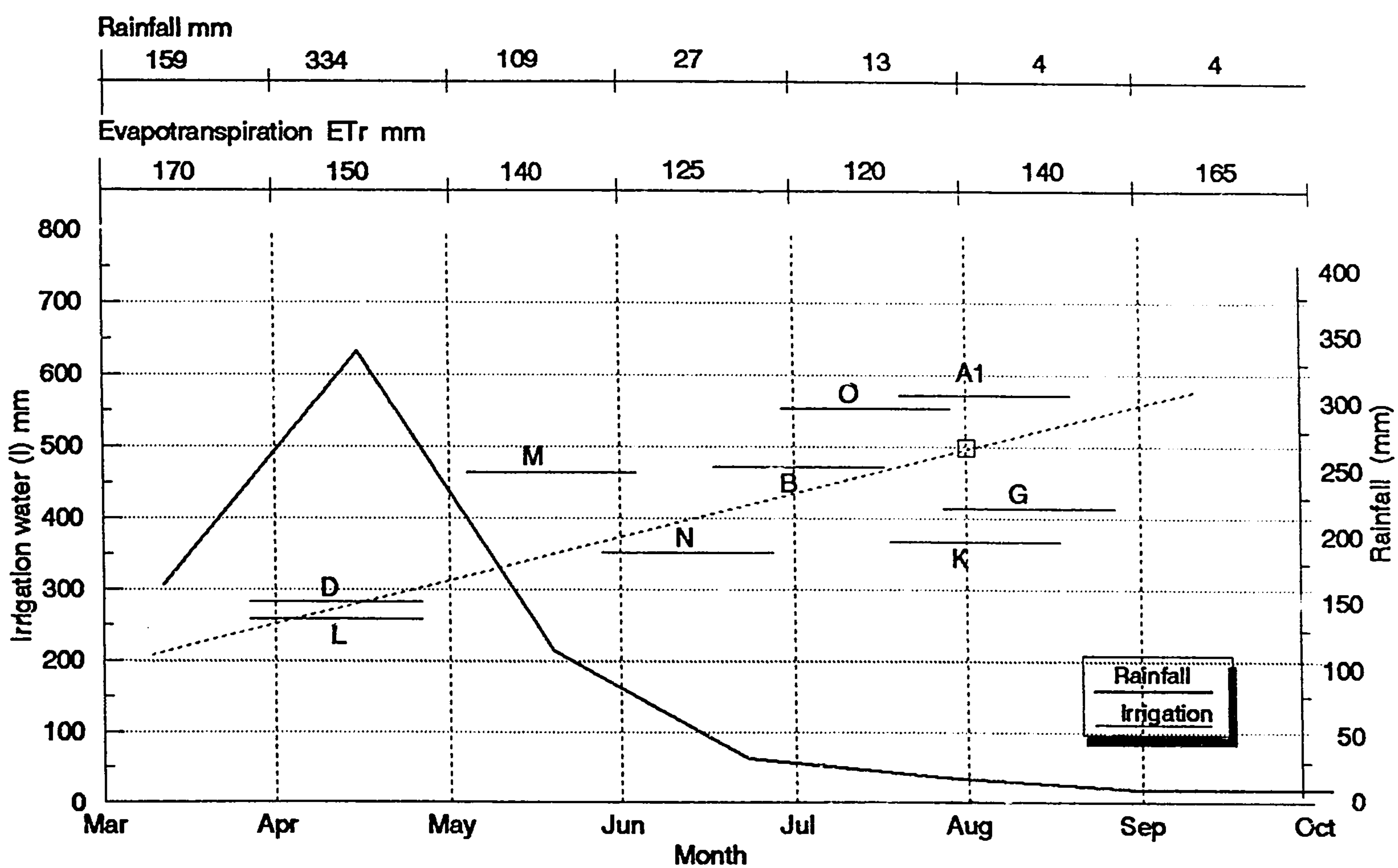

Figure 5.10: Amount of irrigation water (I) applied during the first month

losses at 5 mm/day and constant storage, the total application would be just over 500 mm, which is comparable with the results obtained at the block level for those blocks prepared late in the planting calendar.

Compared with losses at the field level, losses at block level would show less seepage through bunds but more losses through or over drain outlets and spill from irrigation canals.

5.4.2 Water distribution

The normal rice cropping routine in the AIS is to stagger the land preparation over three months. The average flood is maintained at approximately 12 cm for weed suppression. Just before transplanting, fields are drained off, leaving only a shallow water layer 4 or 5 cm.

Transplanting starts around mid-August, after which the water levels should be raised again when the rice crop increases in height. In reality this does not happen during the first two months on most of the fields because under the existing irrigation practices, there is insufficient irrigation water in certain months (Fig. 5.8). In a number of blocks, fields fall dry and severe water shortages may occur. During the short rains, the water levels increase and reach their preplanting heights again.

The draining off period commences in the second half of November not so long after the end of the short rains. Harvesting then starts mid-December and continues into February.

For land preparation, a more or less constant flow is used. The rate of progress is determined by the AIS management and depends on the number of available tractors and the acreage rotavated in a tractor day. The low water requirement at the beginning of the season and the subsequent required reduction of the water level before transplanting mean that demand is less than available river supply until the beginning of September (Fig. 5.8). Water shortages occur during the second half of and last to the end of October.

Water distribution therefore may not be so important during the first months of the rice growing season but is more so after transplanting. Because of diminishing supplies of water, a faulty distribution would cause some blocks to suffer more than others.

The water distribution to the different blocks is controlled by the head water guard. Water guards assist with the distribution of the water within the block. The water distribution is based mainly on visual appraisal of the discharges to the different blocks. Very often mistakes are made, so that flows have to be adjusted regularly. When water guards observe in the field that they either have too much or too little water, they bring this to the attention of the head water guard, who then possibly changes the discharges. Water measurement structures which exist in the field are used only by the gauge height, which more often than not must have a certain minimum flow value to obtain a reading.

Within blocks, especially in Block N, fields on part of the area tend to dry out after transplanting. The inflow is indeed lowest but this cannot be the only reason for water shortages within the blocks provided there is no difference in inflow between the individual blocks.

Apart from the significant influence of the distance from the water source, another problem seems to be in the equitable water distribution between the different feeders and the fields. For this, in principle, the water guard is responsible. In practice it is often the farmers who distribute the water within the feeders. The water guard only waits till the water reaches the lower end of the feeder, after which he opens the next feeder and closes the first. Under this conditions there is no check on what happens with the water as long as it flows into the feeder.

From the poor water distribution in Block N (Fig. 5.11), it is clear that such prolonged water scarcity in part of the block reduces the yield considerably. About 50% of the fields in Blocks N and P fell dry and showed cracks for at least one week.

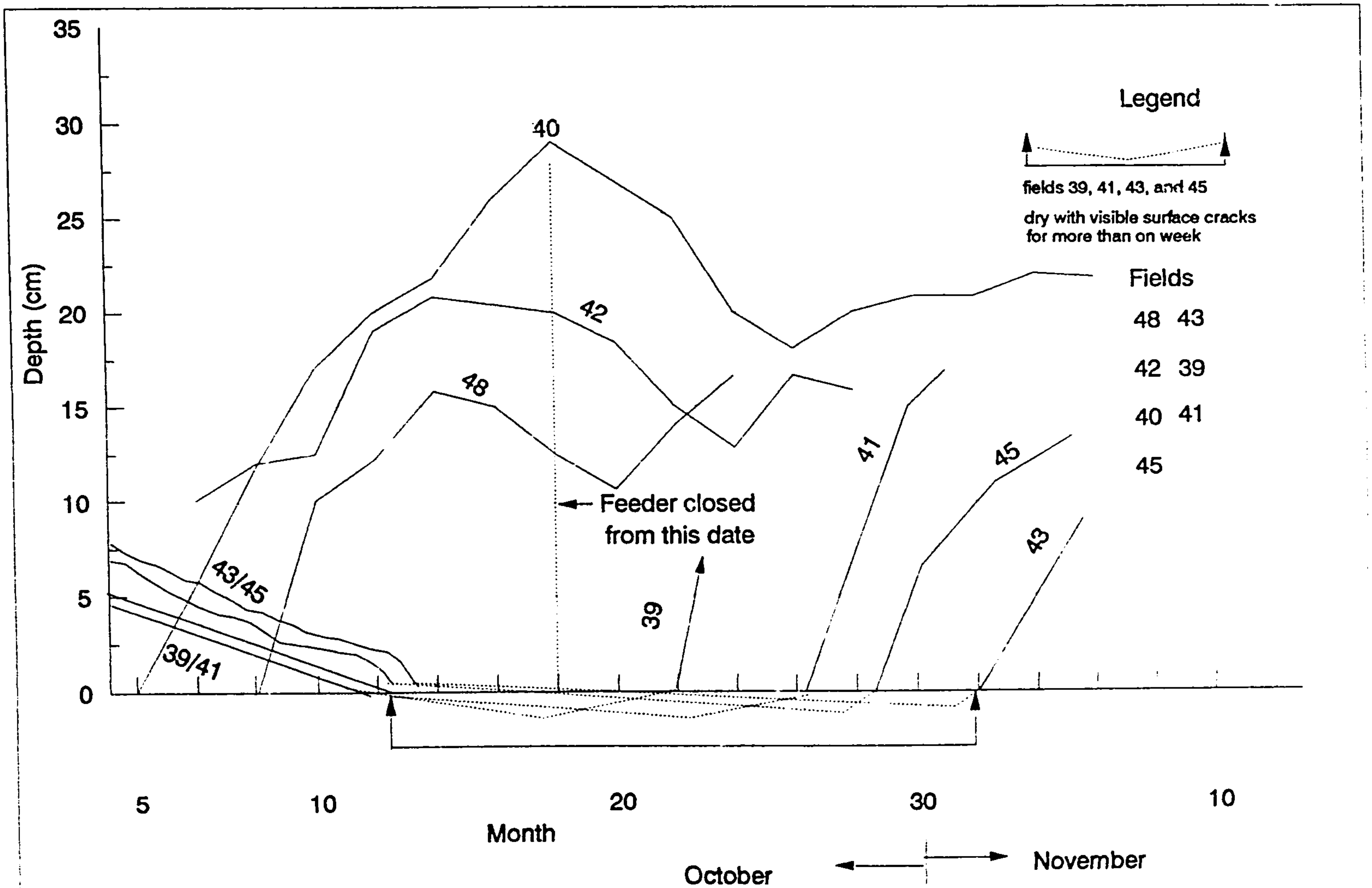

Figure 5.11: Water levels in different fields in Block N

A possibility to offset the bad water distribution is to replace most of the drain outlets by outlets to a neighbouring field. In this case if too much water is taken from a feeder, it would automatically benefit the next field in the line.

5.5 Possibilities to save water

Different methods which may be effective in reducing the scheme water requirements are examined. The following points have been considered in the evaluation:

- The water saving measures should not reduce yields in the scheme.
- Water saved in any part of the scheme through the proposed measures is not equivalent to water saved at scheme level. The first to benefit should be the farmers in the scheme to offset present inequities in water distribution.

A reduction in the peak water requirement by making better use of the rainfall has been considered. In addition to this, consideration is given to the possibility of improving the irrigation efficiency either directly, (for example by improving the performance of the field staff and farmers) or indirectly by increasing the reuse of drain water.

Reduction in the net irrigation demand can be achieved in three different ways. Firstly, changes should be made to the cropping calendar timings to optimise the use of both the short rains and long rains. Before such recommendations are put forward, it is necessary to explain why the present cropping calendar has been established. The NIB, after several years of experience wrote in their final report, that it had been found that "short" rain plantings produced much higher yields than "long" rain planting. Hence confining changes in the cropping calendar timings to the "short" rain planting. Staggering of the planting dates during the short rain period could reduce slightly the peak consumptive use while also making better use of the short rain and increase in yields.

At present, the following recommendations can be made. In some blocks, which can benefit from drain water from other blocks and which at present have annual water shortages, transplanting should be carried out at the end of July and beginning of August. The blocks to be chosen would be Blocks N, F, M, P and O. Some of the blocks which at present are transplanted late should be given additional care to make sure they get sufficient water at all times. If the yields improve, a gradual shift can be made in the transplanting dates to September and October.

Secondly, shortening of the land preparation period could greatly reduce the overall water requirements. The disadvantage is that this would involve the purchase of more tractors, which would then stand idle for longer periods. The result would be water saving during a time when it is not necessary. Furthermore transplanting would have to follow land preparation nearly immediately. The requirements for saturation, flooding and maintenance are higher than the requirement of flooding alone. This alternative is thus not viable under conditions of water shortages prevailing at present. The present situation with a long land preparation should be maintained.

Finally, decreasing the storage at the soil surface could reduce the overall water requirement and consequently lower the pumping cost. In general the storage within the fields in the scheme averages 7.5 cm despite the high levels of over 20 cm registered in some fields (see Fig. 5.7). This average is below the realistic mark of 10 cm stipulated by the NIB. It is thus impossible to save water by reducing storage; on the contrary, it appears that the average has to be increased despite the inevitable increase in cost of pumping.

The irrigation application and project efficiency can be increased in several ways. Firstly, the improvement of the performance of the farmer's water management practices. AIS farmers have a tendency to over irrigate their fields (Fig. 5.12) in anticipation of not receiving adequate supplies. The spill which occur are very high in these fields and furthermore the rotation period is prolonged so that other farmers do not receive water in time. Prolonged high levels of water in the fields than recommended results in submergence losses which reduce yield considerably.

In some cases farmers operate the flashboards in the feeder canal and should be encouraged to do so in order to obtain a greater flexibility in the irrigation management. However, without sufficient supervision and education by the AIS management, this will not have much chance of success and certainly not in the near future.

A well defined, and visible, water users group is conspicuously lacking with the farmer-management liaison left in the hands of the head cultivator. The best solution for eliminating the bureaucracy managing the AIS is to induce the farmers within each block to organise a water user group to maintain the watercourses and distribute the water within the block. This would enable the AIS bureaucracy to control water deliveries to relatively few headgates while giving the farmers within the Block access to local management. A strong water users group would also facilitate the dissemination of irrigation information and awareness among farmers.

Secondly, the improvement of the performance of the field staff so as to achieve better supervision may improve irrigation efficiency. Water guards and irrigation officers should be instructed on the proper use of the water measurement structures so that water distribution between blocks improves. Finally, technical measures such as the maintenance of structures demonstration on tenants' plots should be carried out regularly. More regular interchanges between AIS and tenants in general could increase the transmission of knowledge on rice cultivation to tenants, and would increase the awareness among the AIS staff of the conditions under which tenants operate. Another technical change might be the introduction of mechanical weeding, which can be done with a simple instrument but for which planting on line is a necessity.

Reuse of drain water offers some of the best possibilities of saving water. The quality of the drain water is good enough for irrigation purposes (<1.0 mmhos cm^{-1}). Most of the water of Ahero is not being reused at present. The water levels in the canals are in general too high and drain water cannot enter these canals. Technical measures at block level are therefore not recommended. At field level it is recommended to install additional outflow structures with outlets to adjacent fields. The work involved can be carried out by the farmers themselves with minimal costs involved.

5.6 Variability of rice production in the blocks

Yield levels within the scheme vary considerably between blocks, which appear to be related to block condition and water supply. In order to asses the variation in yield levels on the scheme, production per block was compared with average scheme production for crops 37-42[1] (1987 to 1990). Large differences in yields seem to exist between blocks (Fig.5.12). Blocks M, P, and O, which had considerably below average production for every single crop concerned. Blocks G, A1, and B, the blocks with the best average scheme production, were above the average scheme production in every single crop.

Distance from the water intake to the Block

Approximately 40% of the variance in yield levels as recorded in the NIB files from block to block and from harvest to harvest can be explained by differences in distance from the block to the inlet of the distributary canal. Distance along the main canal is the distance between the scheme inlet and the inlet of the distributary serving the block concerned. Distance along distributary is the distance from the centre of the block to the inlet of the main canal of the distributary serving the block.

The distance from the water intake to the block was a significant factor in determining the block average production. Even more important was the distance along the distributary canals as borne out by an analysis of co-variance of seasonality and distance from scheme inlet (Table 5.11).

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[1]37 - 42 crops produced at AIS since project inception

Table 5.11: Average production (delivered to the NIB) in bags/acre per trimester of below average, medium and above average producing blocks.

Sowing period	Jan - Apr	May - Aug	Sep - Dec
Blocks producing below average			
O, P, M, F			
Number of observations	10	4	6
Mean	13.7	17.6	15.1
Standard Deviation	2.1	2.8	2.4
Medium producing blocks			
D, L, A2, N			
Number of observations	7	5	6
Mean	17.7	18.4	17.8
Standard Deviation	2.9	2.4	2.7
Blocks producing above average			
[illegible], A1, B, K, D, L, & A2			
Number of observations	9	7	4
Mean	18.9	21.7	18.6
Standard Deviation	2.3	1.9	2.1

Table 5.12 Analysis of co-variance of yield per block (delivered to the NIB) with seasonality and distance along distributary canals for crops 37-42

N=58	SS	DF	MS	F	P
Seasonality (sowing periods)	63.0	2	31.5	6.2	0.004
Distance along Distributary	231.7	1	231.7	45.9	0.00
Error	272.9	54	5.1		
R^2 = 0.55					
Seasonality Tested					
	SS	DF	MS	F	P
Trim. 2=(trim. 1 + trim. 3)/2	59.4	1	59.4	11.7	0.001
Trim. 1= trim. 3	0.9	1	0.9	0.2	0.675
Error	272.9	54	5.1		

Trim. = Trimester
SS = Sum of Squares
DF = Degrees of Freedom
MS = Mean Square
P = Probability
F = Statistical F-test

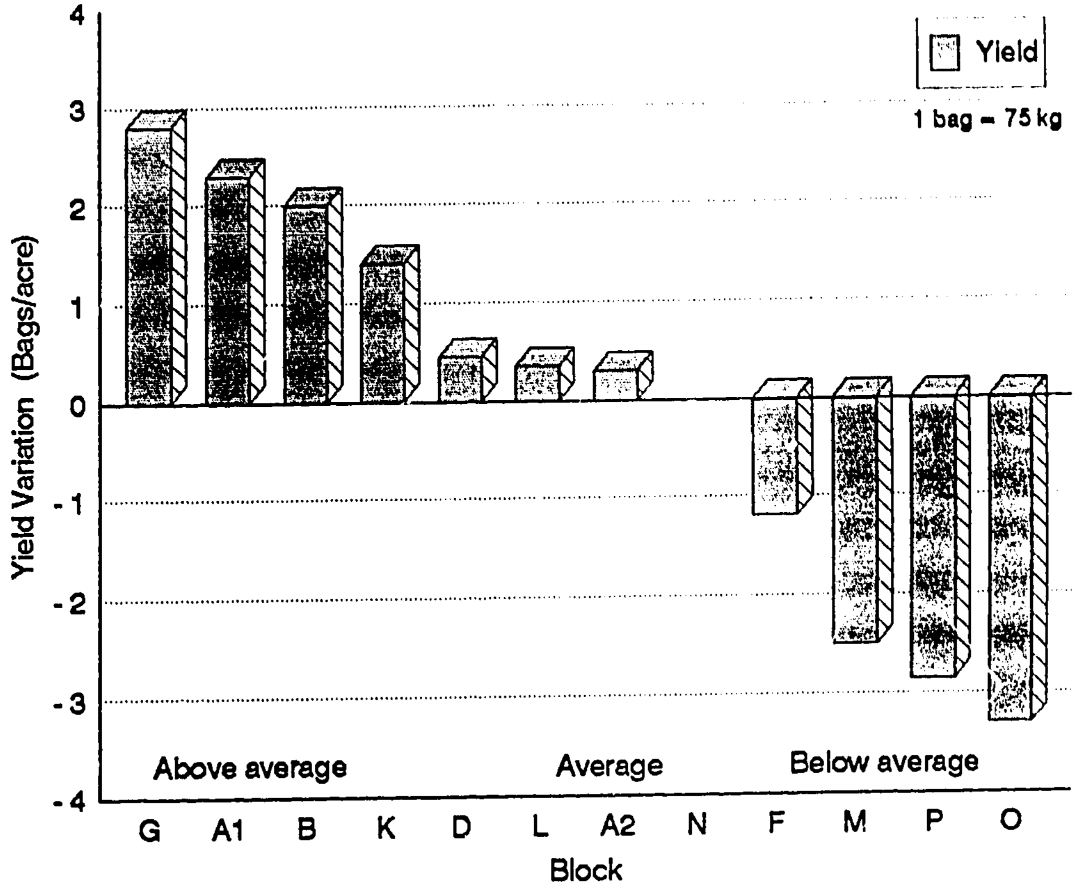

Figure 5.12 Average difference between block yield and scheme yield for crops 37 to 42

Seasonality

Some seasons (times of the year) seem to be more suited for rice production than others. In order to assess the importance of seasonality as a factor, yields were classified according to sowing dates, grouped per trimester (January to April, May to August, and September to December) because the available data did not allow for an analysis on a monthly basis.

Table 5.11 presents a summary of the average yields in blocks of different quality for sowing dates per trimester. Highest yields are in the second trimester. Seasonal differences are greater in the below and above average producing blocks. Separate tests for the distance along the main canal and the interaction between distance and seasonality proved not significant.

Seasonality is also a significant factor in determining the block average production (Table 5.11), although of much less importance than distance along the distributary canals. It is possible that the high yields obtained when sowing takes place in the second trimester are related to the high levels of Nyando River after the long rains. There was not enough information to test the projects Relative Water Supply (RWS). However, despite the low application efficiencies obtained during the second trimester (Section 5.2), high levels of River Nyando increases the schemes (RWS) and consequently minimize water tensions. It is also not unlikely, that these yields may be related to the availability of labour for transplanting and harvesting during the school holidays in August and December. When sowing takes place in August the tenants will be able to utilize this labour to their advantage.

Other factors influencing block production

Beside distance, other characteristics of block conditions like levelness of plots and soil condition are important factors whose influence however could not be quantified for the present study. Between 1979 and 1982 rehabilitation experiments were conducted in three blocks. Part of the blocks concerned were levelled, the irrigation and drainage network was overhauled, and in field drains were made. Lenselink (1982) reported that the three crops following the rehabilitation had higher yields (an increase of approximately 20%) compared to other plots that were not rehabilitated in the same block. In the fourth crop after rehabilitation yield levels again were at the non-rehabilitated level.

Comparing the yield level of sampled cases with the average yield level of the scheme from crop 12-42, the production of all sampled cases in the study was almost equal to the average scheme production. When only the last 6 crops, crops 37-42 inclusive, are taken into account, a similar conclusion can be drawn. Variance in production however, is quite substantial (Table 5.13).

Table 5.13: Variation in production in bags per acre of sampled tenants compared to average scheme production

	Crop 12-42	Crop 37-42
Scheme	14.8	17.9
Sample (N=25)	14.8	18.2
Range in sample	10.8-20.5	10.7-28.9
Standard deviation	2.6	4.0

5.7 Possibilities to improve the economic setting

Within a scheme, two parties with different economic interests have to come to terms with each other: on the one hand there are the scheme authorities, the NIB and staff, who aim to maximize the rice production and promote the well-being of the tenants, while, on the other hand, there are the tenants, who aim to maximize their incomes. The NIB, to a large extent, assumes that maximization of tenant incomes can be achieved by maximizing paddy production, and that this also leads to a greater well being of tenants. The interest of the tenant may differ from those of their wives and sons, or other relatives who cultivate part of the rice-plot, or who provide part of the labour.

The assumption that the tenants cultivate rice as their sole activity is not tenable. The tenant, and other members of his household, often conduct other agricultural and off-farm activities. This is all the better, since it would be difficult for a household to subsist on rice production only. Even from the viewpoint of maximizing rice production, it is crucial that tenants have such income at their disposal, as work-capital to finance hired labour in peak periods.

Although tenants bear most of the risk of rice production, nearly all the factors of production are outside their control. Water management, land preparation, and delivery of all inputs are in the hands of the NIB. Inputs and services delivered by the NIB represent three-quarters of the total production costs, and cannot be reduced by an individual tenant or even a whole block of tenants, because they are divided equally among all tenants of the scheme. This does not give tenants any incentive to reduce their share in the services delivered. Nor are they able to adjust the level of costs to their specific circumstances. This applies especially to land preparation, which is done mechanically by the NIB. This part of production is capital intensive, while all other activities are done by hand, using simple implements, and are consequently labour intensive. A less capital intensive way of rotavation is land preparation by means of animal traction, i.e. oxen, which can be locally hired. If tenants are to invest in rice production and maximize yields, they should be better able to influence costs and production decisions.

Rice production is largely dependent on average block production, i.e. the condition/quality of the block. An important aspect of the condition of the block appears to be the distance of the block to the water intake of the scheme, mainly the distance along the distributary canal. In effect, this means that not all tenants are getting equal services for the rates they pay the NIB. A more differentiated system of rates would equalize the profit opportunities among the tenants, and would make investments of tenants in less producing blocks more attractive than at present.

The knowledge that plots with the largest distance of secondary canals have the lowest yield should be incorporated in the rotavation calender. Priority should be given to the blocks with the longest distance of secondary canals to guarantee an equitable distribution of water in order to increase yields in these deprived blocks.

Seasonality is most important in low production blocks. Sowing low yielding blocks in the second trimester, the optimal period, would increase yield levels of the tenants concerned, and might even increase total scheme production. The seasonal differences of medium producing blocks are very low so they are best sown in the first trimester. High yielding blocks have their highest production in the second trimester as is the case with the low producing blocks. The increase in production when low producing blocks are sown in the second trimester is nonetheless higher than when high producing blocks are seasonally favoured. This has special significance when single cropping would be introduced. In that case, the lower producing blocks should receive preference over the high producing blocks and prepared in the optimal period.

Labor is the only factor in rice production the tenants can control. By varying the amount of labour hired, or optimizing the moment at which labour is hired, they can try to increase paddy yields. If the necessary cash has to be borrowed, costs increase by up to 30% due to the interest rates on loans. This means that the volume of hired labour that is remunerative in terms of income will become less. For tenants without a regular cash income from off-farm employment, it is rational to hire less labour than is necessary for optimal production. Also for tenants in a average low producing blocks it is less productive to invest in labor. Besides labor, tenants can try to increase yields by paying more attention to the quality of labour, i.e. by improving the techniques used in the rice cultivation. As long as such improvements mainly result in better quality of the paddy harvested, the current system of fixed paddy prices provides little incentive for the adoption of new and better techniques. However, the complexities of a different pricing system might outweigh the advantage of pricing according to quality.

Costs of production are high at the AIS. The break-even point as determined by AIS is 45 bags of paddy, hired labour included. It is therefore better, in terms of income, to have one relatively good crop than two lower yielding crops. Single cropping has given good results in other irrigation studies by NIB, leading to a higher total production of rice at lower costs to the tenants. A system of single cropping could be combined with the cultivation of rain-fed crops during the long rains, with, possibly, supplementary irrigation to improve yields and to reduce risks during long spells of dry weather. From the viewpoint of the tenant economy, this would provide a way to use a surplus of labour during the long rains, for which little other employment can be found. Under these circumstances, the invested labour would remain rewarding, even if the costs of additional irrigation would be substantial.

The farmers (*Luo*) are traditionally, not only fish eaters but consider fish a delicacy. Lake Victoria, their main source of fish, is some thirty kilometers from the scheme and any fish consumed by the farmers is a strain on their limited cash resource. Fish production should be introduced once the field layout and water control structures are improved and adapted to suit both rice and fish production. This would provide extra income from the sale of fish and an increase in the available food.

Rice production can be increased when tenants have regular access to cheap credit. When cash is less expensive than at present, the hiring of a larger labour volume would become rewarding. Access to cash for hiring labour is one of the goals of some small societies, which recently started their activities. Tenants give part of their pay-out to the society and receive money to hire labour when needed. This activities should be stimulated by the NIB and need extension. Access to credit via organisations at the block level has the advantage that organizations of family members (block members are often related) have the means to ensure repayment of loans within a reasonable time span at their disposal. Backing up by the NIB however, will remain a necessity.

Costs should be more differentiated and be more in accordance with the actual use of water and services by each tenant (or group of tenants) to give the tenants an interest in reducing these costs. In terms of organisation, the calculation of individual water rates would tax the NIB too much, but if costs are considered per block, self organizing groups of tenants would be encouraged to reduce costs together.

The best way for the NIB to deal with the tenants would probably be to deal with them in the way a new irrigation scheme would deal with them: i.e. to interact more with groups of tenants (co-operatives) and less with individual tenants. This could be part of a process of shifting responsibilities, i.e. the role of the NIB would partly change to that of a service organisation, while co-operatives would take their place as deciding bodies concerning as many issues as possible, without impeding the aim of rice production. The present forms of tenant representation could be organised into an effective intermediate level such as water users group, especially when based on the division in villages or blocks. This would enable farmers to participate more directly in the running of the scheme.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Water utilization and management practices are studied for the AIS, Kenya in 1991. The strength of this system lies in the irrigation network of canals and structures which are operational and capable of moving the water equitable through the system if carefully manipulated. Several system weaknesses are attributed to the bureaucracy running the scheme.

Field application efficiency of approximately 80% was obtained from 3rd to 7th, July 1991, in two experimental fields. This period was one for pre-irrigation before transplanting. The irrigation application efficiency at the block level before transplanting was on the average 40-45% but increased during the peak month (September) to over 65%. Scheme seasonal application efficiency of 43% obtained in 1991 is low and there is ample scope for improvement. Major factors contributing to low application efficiency are spill and seepage at the farm level.

Effective communication between the users and suppliers of water that make the physical delivery and application of water take place in a meaningful way is non-existent. The system management must have an understanding of the physical interface between the farmer system and the main system to develop this two-way communication.

Inequity in water distribution results in excessive spill and high water levels in some fields while others fall dry. Consequently, the irrigation project efficiency and yield are lowered considerably. Reduction in yield could either be because of water stress or submergence.

Drain water was used in a few blocks for irrigation purposes in the scheme. A comparison between the application efficiency obtained with the abstracted water (drain) and the total amount of irrigation water showed clearly the importance of reuse especially during the months of September and October.

Rice yields are lowest in fields located in blocks furthest from the water intake of the scheme. Without a diligent management strategy to achieve equitable distribution and high water-use efficiency, the limited water supply is captured by the proverbial head enders.

6.2 Recommendations

From the AIS study, important lessons are learnt which should also be of value to others involved in similar irrigation projects. The following observations and recommendations are listed to help in the development of the AIS irrigation improvement plan.

1) Staggering of the planting dates during the short rain period could reduce the peak consumptive use while also making better use of the short rain and increase in yields.

2) Introduction of a single cropping of rice and use of animal traction in land preparation would lead to a higher total production of rice at a lower cost to the farmer.

3) The present forms of tenant representation could be organized into an effective intermediate level allowing the farmers to get experience in running sections of the scheme. This could improve the maintenance of the structures at the block level and consequently improve the irrigation efficiency. Lasting changes can be achieved if the farmers and personnel throughout the organization understand current paddy water management principles.

4) At the field level, installation of additional outflow structures with outlets to adjacent fields is recommended to enhance the reuse of drain water within fields.

5) Rice production can be increased when tenants have regular access to subsidized credit facilities via farmer organization at the block level.

6) Seasonality is most important in low producing blocks and should be incorporated in the sowing calender to increase total scheme production.

7) Introduction of fish production in the paddy fields should be set up when the field layout and water control structures are improved and adapted to suit both rice and fish production. The effect would be an increase in the

available food and resource base of the tenant farmer.

6.3 Suggestions for Future Study

Future study at the AIS should focus on:

1) Determination of the actual demand and supply hydrographs of the AIS. The overall objective should be to find an optimum fit of the two variables at the existing management levels. The results would invariably show the dynamics between the variability in water application and rice production. The basic data of the measurement in the AIS study such as evaporation, crop coefficient, percolation, etc. can be referenced and used.

2) Determination of a cropping programme that could optimize the use of the short rains and seasonality effects.

3) A comparison of the economic performance of the irrigation system under a single crop with animal traction used in land preparation and a single crop with tractor managed land preparation.

4) Identification of socioeconomic factors constraining the formation of an effective "Water Users Group", WUG, with an aim of revitalizing the existing "invisible" WUG.

5) Determination of design and socioeconomic parameters necessary for the simultaneous production of rice and fish.

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Appendix A. Net areas under rice within the Ahero Irrigation Scheme

Table A.1: Total net area of each Block under rice (1991 season).

Block	Holdings (acres)	Extra Fields (acres)	Total (acres)	Total (ha)
G	176	3	179	72.5
A1	240	6	246	99.5
B	260	7	267	108.0
K	204	17	221	89.5
D	360	23	383	155.0
L	236	35	271	109.5
A2	136	66	202	62.0
N	196	38	234	94.5
F	262	13	275	111.5
M	228	43	271	109.5
P	105	21	126	51.0
O	248	36	284	115.0
Total	2,651	308	2,959	1,177.50

Source: (Cropping Programme for 1991 Season, NIB)

Appendix B. Profile Description of a typical soil pit found in AIS

Pit K 12

	Pellic Vertisol (FAO)
Soil classification	: Udic Pellustert.
Ecological Zone	: Scattered Tree Grassland: "Low Tree, High grass zone".
Observation	: Kisumu district; E 712.6, N 9983.2; on topographical map of the Kano Plains; 1165 m; 17-3-1978.
Geological formation	: Alluvial holocene and pleistocene deposits of Lake Victoria and some small rivers (Nyando and especially the Miriu), mixed with no or few volcanic material (ashes)
Local petrography	: Clay (alluvial) mixed with no or some volcanic material (ashes).
Physiography	: Plain (Backswamp).
Relief macro	: Flat - slopes < 2% - uniform.
Relief micro	: Levelled for rice irrigation.
Relief meso	: backswamp.
Vegetation/landuse	: Wooded bushland, now rice cultivation.
Erosion	: Nil.
Surface stoniness	: Class 0, (Nil).
Salinity/alkalinity	: can not be seen in the field.
Surface sealing	: nil
Drainage class	: poorly drained to imperfectly.

K12: I A_p 0 - 15 cm : Very dark grey; common, medium, faint, brown to dark brown rusting; clay; massive, sticky, slightly plastic; common, very fine to medium pores; common, fine to medium roots; abrupt and smooth boundary.

I A_{12} 15 - 30 cm : Very dark grey; common, medium, faint dark brown rusting; clay; moderate, fine subangular blocky; slightly sticky, plastic; common, very fine to fine pores; common, fine to medium roots; very many minerals; gradual and wavy boundary.

I B_2 30 - 60 cm : Dark brown; common, medium, faint, very dark grey mottling in channels (closed cracks); clay; moderate, medium angular blocky; breaking into moderate very fine angular blocky; slightly sticky, plastic; few pressure cutans; common, very fine pore; common, fine to medium and few, very fine roots; many minerals; clear and wavy boundary.

II A_1 60 - 70 cm : Black to very dark grey; clay; moderate, fine angular blocky; slightly sticky, plastic; few to common, very fine pores; few, very fine roots; clean and wavy boundary.

II A_2 70 - 85 cm : Very dark grey; to very dark brown; clay; moderate, fine angular blocky; slightly sticky, plastic; pressure cutans and some occasionally slickensides; clear and wavy boundary.

II B_2 85 - 120 cm : Very dark grey, ; in channels (closed cracks); clay; moderate, fine angular blocky; slightly sticky, plastic; pressure cutans and slickensides close enough to intersect; reaction HCL: slight effervescence; not much black point minerals.

Appendix C. Meteorological Data for AIS

Table C.1 Monthly average meteorological record for the 1975 - 1990 period.

AIS	T	R.H	n	Ra	W	E_{pan}
JAN	21.3	55	9.1	610	5.8	197
FEB	22.6	52	9.0	596	6.4	213
MAR	3.3	57	8.0	565	6.3	225
APR	23.0	66	7.3	532	5.1	178
MAY	22.2	67	6.8	510	3.9	147
JUN	21.0	66	5.3	437	3.4	126
JUL	20.2	67	3.7	390	4.2	121
AUG	20.5	64	3.9	393	5.3	148
SEP	22.0	57	6.5	505	6.4	187
OCT	23.0	56	6.5	558	6.4	212
NOV	22.2	66	7.0	538	5.2	158
DEC	21.0	63	8.7	584	5.6	177

T . . . Mean Temperature (° C)
R.H . Mean Relative Humidity (%)
n . . . Actual Sunshine Hours (hours/day)
W . . Mean Daily Windspeed (km/h)
Ra . Radiation (cal/cm^2/day) = 0.01699 Ra mm/day
R . . Rainfall (mm)

Source: Annual Report (AIS) 1990

Table C.2: Monthly rainfall (mm) at Ahero weather station (1975 - 91).

	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1975	46.3	33.0	66.3	476.3	216.3	38.2	0.0	0.0	14.8	72.7	184.1	139.2	1,287.2
1976	15.3	18.8	184.7	325.7	4.3	7.1	7.4	131.8	20.4	171.9	85.7	98.2	1,071.3
1977	30.2	0.8	43.5	199.3	23.6	5.6	8.7	16.6	10.7	45.4	297.8	48.9	731.1
1978	41.9	3.3	143.9	5.1	45.0	41.2	6.3	6.3	14.6	85.3	202.8	7.4	603.1
1979	2.3	0.0	38.1	288.3	391.4	38.7	20.1	20.7	15.5	236.4	206.1	0.0	1,257.6
1980	0.0	127.9	122.9	303.5	94.8	17.1	19.9	9.0	0.3	168.4	335.0	136.1	1,334.9
1981	49.0	123.1	168.7	47.0	114.9	10.0	5.1	8.1	0.5	19.6	170.7	22.8	739.5
1982	59.8	0.0	162.8	54.8	133.3	3.4	7.2	14.2	2.1	27.0	125.2	30.0	619.8
1983	0.0	4.1	29.9	225.6	183.2	13.2	180.4	0.0	1.2	30.6	80.2	51.8	800.2
1984	40.1	28.1	43.1	16.9	257.3	47.3	4.5	3.4	33.3	199.8	165.6	37.0	876.4
1985	58.2	65.6	33.9	110.3	49.6	7.0	9.2	1.3	30.6	70.4	222.7	16.6	675.4
1986	0.0	16.2	49.4	232.4	67.3	125.3	108.0	41.8	11.6	14.8	149.3	16.6	832.7
1987	5.3	14.7	25.3	231.7	104.4	10.0	71.4	43.0	37.6	126.5	57.5	20.4	747.8
1988	0.0	5.1	6.2	180.0	110.9	95.0	5.2	2.1	19.6	88.4	136.3	30.5	679.3
1989	24.5	38.8	61.8	469.6	147.4	12.8	3.2	6.0	18.7	51.3	326.1	58.7	1,218.9
1990	14.4	89.1	129.3	377.0	73.5	2.5	8.8	4.0	48.1	264.7	96.7	55.7	1,163.8
1991	98.5	24.3	158.7	333.7	109.1	27.3	12.6	4.0	4.3	41.0	220.8	58.1	1,092.4
Ave.	40.5	49.4	122.4	323.1	177.2	41.8	39.8	26.0	23.7	142.9	255.2	69.0	1,311.0

Table C.3 Average daily evapotranspitation by month (mm/day) for the 1979-1991 period calculated with the Penman equation

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	5.8	6.4	6.1	5.1	4.2	3.9	3.8	4.3	5.2	5.2	5.4	6.5
1980	5.5	5.2	5.1	4.5	4.2	3.4	3.4	3.6	5.2	5.2	4.6	5.3
1981	5.2	5.1	5.3	5.4	4.7	4.3	3.9	4.8	5.5	6.2	5.2	5.5
1982	5.2	6.3	6.0	5.3	4.6	4.0	4.0	4.1	5.2	6.0	5.1	5.4
1983	5.7	6.7	6.5	5.4	4.4	-	3.7	4.0	5.7	5.8	5.4	5.2
1984	5.4	5.4	6.2	6.1	4.7	4.1	4.2	4.7	-	5.6	5.0	5.0
1985	5.3	5.9	6.3	5.7	5.0	4.4	4.0	4.7	5.4	6.0	5.1	5.3
1986	5.7	6.0	5.6	5.0	4.6	3.9	3.9	3.7	4.7	5.6	4.9	5.2
1987	5.8	6.2	6.4	5.6	4.8	4.0	3.9	3.8	5.0	5.2	5.5	5.3
1988	5.8	6.1	6.5	4.7	4.8	4.4	4.2	4.9	5.8	5.8	5.2	5.3
1989	5.6	6.2	6.0	4.9	4.8	-	3.7	4.2	5.3	-	4.6	4.7
1990	5.3	5.6	5.2	5.0	4.6	4.7	3.9	4.0	5.4	5.1	5.0	4.9
1991	4.9	5.5	5.7	5.0	4.6	4.1	3.8	4.5	5.5	[illegible].7	4.8	5.0

- Data not available

Table C.4: Monthly mean temperatures (^{o}C) for the 1979 - 1990 period at AIS weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	20.5	22.1	22.7	22.0	21.2	21.7	20.0	19.9	21.3	21.9	19.9	21.2
1980	21.1	21.7	21.6	21.0	21.1	20.1	19.2	19.1	21.6	22.7	20.4	20.9
1981	20.6	21.7	21.9	22.8	22.7	21.5	20.9	22.2	22.7	24.2	21.2	20.9
1982	22.5	23.3	24.0	22.8	22.2	20.8	20.1	19.9	21.6	23.8	21.5	22.0
1983	22.0	22.6	23.3	23.3	21.7	19.8	19.8	19.9	22.2	23.2	21.4	21.8
1984	21.1	22.2	23.5	25.1	23.0	21.3	21.2	21.6	23.1	23.5	21.5	22.4
1985	21.7	23.5	24.1	24.7	23.2	21.5	20.1	21.3	22.9	23.7	20.6	22.5
1986	21.4	22.0	23.0	23.0	22.2	21.2	20.3	19.8	21.2	23.4	21.1	21.7
1987	21.7	22.9	24.8	23.6	22.5	20.5	20.5	20.0	22.0	22.6	21.2	22.2
1988	21.7	23.7	24.4	23.2	23.0	21.4	20.4	21.1	22.8	23.1	21.8	22.4
1989	22.2	23.5	24.2	23.2	22.8	21.3	20.7	21.5	22.4	23.0	21.4	22.1
1990	21.0	22.4	22.8	22.5	22.2	21.8	20.4	20.8	22.7	22.9	21.6	21.9

Table C.5: Monthly class A pan evaporation (mm) for the 1977 - 1990 period at the AIS weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	170	197	254	179	140	121	111	126	189	180	134	187	1,988
1978	196	204	154	200	134	128	107	140	183	235	183	203	2,067
1979	227	247	236	171	156	115	116	139	182	194	142	174	2,099
1980	162	170	160	137	128	113	101	102	190	174	127	154	1,718
1981	178	149	168	179	154	144	135	72	228	244	176	199	2,026
1984	205	193	254	244	162	129	150	174	223	202	157	160	2,253
1985	185	212	262	206	176	162	146	172	203	236	172	192	2,324
1986	241	214	221	151	152	111	117	117	146	212	146	188	2,016
1987	230	248	279	191	153	132	126	272	187	195	172	200	2,385
1988	252	240	289	194	179	145	141	170	210	231	171	164	2,386
1989	224	232	226	180	167	135	122	184	197		135	152	-
1990	-	-	-	-	129	123	118	137	190	171	151	151	-

- Data not available

Appendix D. Daily evapotranspiration calculations

Appendix D1. List of symbols

R_n	net solar radiation	(mm/day)
γ	psycrometric constant	(mb/ °C)
Π	pi (22/7)	(-)
E_a	aerodynamic term (function of e_{sa}, e_a, and u_2)	(mm/day)
e_{sa}	saturation vapour pressure at air	(mb)
e_a	actual vapour of the air	(mb)
u_2	mean day time wind velocity at 2 m height	(m/s)
P_a	atmospheric pressure	(mb)
h	elevation above sea level	(m)
RH	relative humidity	(%)
R_a	extraterrestrial solar radiation	(mm/day)
R_s	observed solar radiation	(mm/day)
T_a	average air temperature	(°C)
h_{do}	daytime hours at zero declination	(h)
r_{ve}	radius vector of the earth	(-)
h_s	sunrise to sunset hour angle	(°C)
Φ	location latitude (positive for north latitudes and negative for south latitudes)	(°C)
δ	declination of the sun	(°C)
θ	day of year expressed in degrees	(°)
J	days from January 1 (Julian day)	(-)

Appendix D2. Estimation of evapotranspiration using Penman method

The Penman (1948) equation has been used for the computation of evapotranspiration. This equation has the form

$$ET_p=\frac{\Delta R_n+\gamma E_a}{\Delta+\gamma}$$

where

$$\Delta=\frac{4098e_{sa}}{(T_a+237.3)^2}$$

$$e_{sa}=\exp(\frac{19.08T_a+429.4}{T_a+237.3})$$

$$e_a=e_{sa}(RH/100)$$

$$\gamma=\frac{1615P_a}{2.49(10)^6-2.13(10)^3T_a}$$

$$P_a=1013-0.1152h+5.44(10)^{-6}h^2$$

$$E_a=(0.27+0.2333u_2)(e_{sa}-e_a)$$

$$R_n=0.75R_s-2.00(10)^{-9}(T_a+273.16)^4(0.34-0.044\sqrt{e_a})(-0.35+1.8R_s/R_a)$$

$$R_a = 1.26714(h_{do}/r_{ve}^2)(h_s \frac{\Pi}{180} \sin\Phi \sin\delta + \cos\Phi \cos\delta \sin h_s)$$

$$h_{do} = 12.126 - 1.8519(10)^{-3} ABS(\Phi) + 7.61048(10)^{-5}(\Phi)^2 \tag{A10}$$

$$r_{ve} = 0.98387 - 1.11403(10)^{-4}(J) + 5.2774(10)^{-6}(J)^2 - 2.68285(10)^{-8}$$

$$(J)^3 + 3.61634(10)^{-11}(J)^4$$

$$h_s = \cos^{-1}(-\tan\Phi \tan\delta)$$

$$\delta = \frac{180}{\Pi}(0.006918 - 0.399912\cos\theta + 0.07050257\sin\theta - 0.006758\cos2\theta$$

$$+ 0.000907\sin2\theta - 0.002697\cos3\theta - 0.001480\sin3\theta)$$

$$\theta = 0.986(J-1)$$

Appendix D3. Sample Calculation

Given:

The following, 15 January 1991, data from AIS, (latitude = 0° 30' South; elevation = 1150 m).

$J = 15$ $T_a = 21.3\,^{0}C$ Mean RH = 55% $R_s = 610$ (cal/cm_2) $u_2 = 1.89$ m/sec

$$P_a = 1013 - 0.1152(1150) + 5.44(10)^{-6}(1150)^2 = 887.7mb$$

$$e_{sa} = \exp\left(\frac{19.08(21.3) + 429.4}{21.3 + 237.3}\right) = 25.3mb$$

$$e_a = (25.3\frac{55}{100}) = 13.92mb$$

$$\Delta = \frac{(4098)(25.3)}{(21.3 + 237.3)^2} = 1.55$$

$$\gamma = \frac{1615(887.7)}{2.49(10)^6 - 2.13(10)^3(21.3)} = 0.59$$

$$\Theta = 0.986(15 - 1) = 13.8^{O}$$

$$\delta = \frac{180}{\Pi}(0.006918 - 0.399912\cos(13.8) + 0.070257\sin(13.8)$$

$$-0.06758\cos(27.6) + 0.000907\sin(27.6)$$

$$-0.002697\cos(41.4) + 0.001480\sin(41.4) = (-)24.4)$$

$$h_s = \cos^{-1}(-\tan(-0.5)\tan(-24.4)) = 90.2$$

$$r_{ve} = 0.98387 - 1.11403(10)^{-4}(15) + 5.27747(10)^{-6}(15)^2$$

$$-2.68285(10)-8-(15)^3 + 3.61634(10)^{-11}(15)^4 = 0.98$$

$$h_{do} = 12.126 - 1.85191(10)^{-3}ABS(-0.5) + 7.61048(10)^{-5}(0.5)^2 = 12.13$$

$$R_a = 1.26714\frac{12.13}{(0.98)^2}(90.2\frac{\Pi}{180}\sin(-0.5)\sin(-24.4)$$

$$+\cos(-0.5)\cos(-24.4)\sin(90.2)) = 14.7$$

Daily solar radiation, Rs, is normally reported in cal/cm^2 or langleys. These are converted to equivalent depths of evaporation assuming a heat of vaporization of 2464.9 kJ/kg. The conversion factor is equivalent to 0.01699 mm/(cal/cm^2).

$$R_s = (610)(0.01699) = 10.4 mm/day$$

$$R_n = 0.75(10.4) - 2.00(10)^{-9}(21.3 + 273.16)^4(0.34 - 0.044\sqrt{13.92})$$

$$[-0.35 + 1.8\frac{10.4}{14.7}] = 5.4 mm/day$$

$$E_a = (0.27 + 0.2333(1.89))(25.3 - 13.92) = 8.1 mm/day$$

$$ET_p = \frac{(1.55)(5.4) + (0.59)(8.1)}{1.55 + 0.59} = 6.1 mm/day$$

Table D.1: Daily evapotranspiration (mm) for the 1991 season calculated with the Penman equation

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	5.8	5.2	4.2	3.6	3.0	4.5	6.2	5.9	5.1
2	5.4	4.6	3.0	3.4	3.4	5.2	5.9	5.0	5.4
3	5.6	4.9	4.5	3.0	4.2	6.1	5.5	4.7	5.2
4	5.6	5.0	3.9	3.3	4.8	6.2	5.2	5.0	5.6
5	4.7	5.2	3.6	4.2	4.8	4.4	5.5	4.5	5.4
6	5.2	5.2	4.5	3.2	4.6	5.2	5.4	3.8	5.1
7	5.1	4.7	4.7	3.5	3.3	4.9	5.8	3.8	4.6
8	5.3	4.8	4.1	3.5	4.8	5.1	5.8	3.9	5.4
9	5.0	5.2	5.5	4.6	4.8	4.7	6.5	4.4	5.1
10	5.1	5.3	4.5	4.8	3.2	4.3	5.9	3.3	5.0
11	4.9	4.6	4.5	3.8	3.2	4.4	5.9	3.3	5.2
12	3.5	4.8	4.9	3.7	4.7	4.7	5.8	4.5	5.5
13	4.1	4.7	5.0	3.1	3.4	5.5	6.1	4.1	5.7
14	5.3	4.0	4.6	3.0	3.2	5.7	6.4	5.8	5.5
15	5.7	4.7	4.3	2.9	3.4	6.0	5.8	5.2	4.6
16	5.6	5.2	4.5	3.4	4.4	6.3	5.8	5.3	5.4
17	5.3	4.9	4.4	4.3	3.7	6.3	5.3	4.8	3.9
18	5.5	4.8	4.8	4.1	5.0	6.0	6.2	4.9	4.5
19	5.2	4.5	3.8	4.8	4.7	5.5	6.2	4.5	4.6
20	4.2	4.7	3.7	4.6	5.4	5.8	6.0	4.0	4.1
21	5.1	4.2	3.7	4.8	5.1	6.2	5.5	5.4	4.3
22	4.9	4.9	3.9	3.8	5.6	6.1	5.5	5.5	3.9
23	5.5	3.2	4.0	4.6	5.2	5.9	5.7	5.2	4.5
24	5.7	3.8	3.3	4.0	5.1	5.5	5.7	5.4	4.4
25	4.7	4.4	4.3	3.7	5.3	5.9	4.2	5.5	4.9
26	4.2	3.7	4.5	2.9	4.9	5.1	5.1	5.4	5.3
27	4.3	3.2	3.6	3.4	5.0	5.2	5.2	5.6	4.7
28	5.2	4.1	3.2	4.2	5.6	5.6	6.0	5.6	5.0
29	5.0	4.0	3.0	3.6	5.7	5.8	5.7	5.3	5.7
30	4.5	3.5	3.8	4.4	5.4	5.6	5.6	5.7	5.4
31	-	5.0	-	4.8	4.4	-	5.7	-	5.4

Appendix E. The water requirement of the black cotton (clay) soils of AIS.

Introduction

A detailed water balance study has been carried out on two fields located in Block D. The study covered the period of saturation of the soil (flushing), flooding the soil and maintaining the flood prior to and during the first two weeks after rotavation. One of the factors of the water balance is the change in the moisture content in the soil, which equals the net amount of water needed to saturate the soil.

The main period of field preparation including flushing and flooding for rotavation starts in March and continues until early August. The rainy season is from March to May. The moisture content in the soil before the start of irrigation depends on rainfall and evapotranspiration in the weeks preceding.

Investigation on the amount of water which can be stored in the soils of the two fields in Block D took place from the end of May until Mid-July 1991. Irrigation started on the third of July, while the fields were rotavated on the 8th of July. Investigations have also been conducted in a field of Block N. In Block N irrigation started on the 20th of July and rotavation the 31st of that month. Thus irrigation in Block D started about one month after the rainy season, while irrigation in Block N started some three weeks later. Consequently before the start of irrigation, the soils in Block N are expected to be drier than in Block D. Field observations supported this assumption.

Procedure

Soil sampling was done wihthin fields of Blocks D and N. This took place few days before flooding and one to three weeks after rotavation was completed. Soil samples were taken in 8 replicates at depths of 0-30, 30-60 and 60-90 cm. Usually weathering bedrock was found at a depth of 90 cm.

After rotavation, soil sampling was conducted on submerged fields. To that purpose an infiltration cylinder was pressed into the mud. The overlying layer of water was scooped out and soil samples were taken. It appeared that the depth of rotavation in general did not exceed 15 cm. The samples were brought to the laboratory. The wet weight was taken and the samples put to drying on the same day.

The moisture content data, determined in weight %, were multiplied by the bulk density (1.26 gm/cm^3) to arrive at the m.c in volume %. The bulk density data were obtained from undisturbed core samples taken from a profile pit in the Block D field. These bulk density data were used to transform the weight % data obtained in the Block N field into volume %. By multiplying the moisture content in volume % with the depth of each sampled soil layer gives the total amount of moisture retained in the soil. The difference in the moisture content of the soil before and after flooding is the amount which can be stored in the soil profile which is the net amount needed for saturation.

Results

The m.c in volume % in the various soil layers before and after flooding for the two fields is given in Table A1.

Table E.1: Moisture Content (volume %) of Block D and N Fields.

Block	Soil Layer	Before Flooding			After Flooding
	depth (cm)	May 28	Jun 7	Jun 30	Jul 13
D	0 - 30 30 - 60 60 - 90	65 61 60	63 - -	52 60 -	74 63 60
		Jul 26			Aug 22
N	0 - 30 30 - 60 60 - 90	36 43 47			53 51 48

The soil in Block D was very wet at the time of the first sampling. There was an additional 20 mm of rain in the first week of June, after which the soil dried out gradually. This drying out of the soil, however, was limited to the soil layer of 0 - 30 cm. Soil drying progressed with time. In Block N the soil layer of 30 - 60 cm started to dry out. In Table E.2 the moisture content of the soil in mm before and after flooding has been presented.

Table E.2: Moisture Content (mm) of Block D and N Fields (Soil Layer 0-60 cm).

	Date	Block D	Date	Block N
Before Flooding	Jun 30	336	Jul 26	237
After Flooding	Jul 13	411	Aug 22	312

According to Table E.2 data, 75 mm of water has been added to the soil in both blocks. Most probably the bulk density of the soils of Block N are higher than those of Block D. For the calculations they were considered to be equal. Furthermore the moisture content after flooding of the 0 - 30 cm top layer in Block N seems to be low in comparison with the moisture content, of the deeper layers.

Had rotavation in Block D taken place in the beginning of June, 35 - 40 mm of water would have been sufficient to saturate the soil. After the last rains in the beginning of June, the soils in Block D lost moisture at a rate approximately 1.5 mm/day, which brings the moisture deficit to 75 mm by the end of June. Assuming the same rate of loss in Block N during July and considering the rainfall of 10 mm during this month, some 35 mm of water would have been added to the moisture deficit of 75 mm. The amount of water needed to saturate the soil in Block N would thus be 110 mm. The results obtain in the water balance study of Block N show this last figure to be more realistic than 75 mm.

The blocks which are flooded and rotavated during the long rains will require up to 50 mm of water for flushing. For the blocks flooded after the long rains, the requirement will from 50 to 100 mm. The blocks which are irrigated before the long rains start, December till March, will require much more than 100 mm. This is based on the following observation:

A part of the soil moisture content will be used by the ripening rice crop in general in December. According to the data in the water balance study, the evapotranspiration after fields have dried out is iapproximately 60 mm. Assuming that the relation between ET_c and ET_r is the same during January to March as during June and July ($ET_c/ET_r=0.4$), the evapotranspiration from the bare soil and weeds is approximately 1.0 mm/day. In the beginning of March, given an average year, the soil moisture deficit will be between 120 and 150 mm, while in a dry year deficits between 150 and 200 mm may be expected for the period.

Reference

The contents of Appendix D on soils and soil moisture have been based on the following memorandum:

J.G Alphen, 1991. Water storage in the Black clay soils of Ahero during flooding and rotavation. NIB, Field Station Reports, 1991.

Appendix F. Estimation of runoff from uncultivated land (D_n)

This method was developed from many years of storm flow records for agricultural watersheds in many parts of the United states. Equation (F.1) applies to the U.S. Soil Conservation Service, US SCS, (1972) curves that gives the relationship between rainfall and runoff.

$$Q = \frac{(I-0.2S)^2}{I+0.8S} \qquad \text{F.1}$$

where Q = direct surface runoff in depth in mm

I = storm rainfall in mm

S = maximum potential difference between rainfall and runoff in mm, starting at the time the storm begins.

The value of S can be obtained directly by plotting I against Q. For convenience in evaluating antecedent moisture, soil conditions, land use, and conservation practices, the US SCS (1972) defines

$$S = \frac{25400}{N} - 254 \qquad \text{F.2}$$

where N = a curve number obtained from accompanying US SCS tables.

Table F.1: Values of the runoff (AIS) from uncultivated land (D_n) estimated by the empirical US SCS method.

Period	D_n (mm)	Period	D_n (mm)
Apr. 1-15	18	Oct. 16-31	1
Apr. 16-30	7	Oct. 21-25	1
May 1-15	4	Nov. 1-5	4
May 16-31	5	Nov. 6-10	9
Jun. 1-15	1	Nov.11-15	5

Appendix G. Estimation of the average amount of rainfall and effective rainfall on a certain area.

i) Isohyetal Method (amount of rainfall).

This consists of the depth of rainfall at the location of various rain gauges and plotting isohyets (lines of equal rainfall) by the method used in drawing topographic maps. The area between isohyetals is then planimetered and the average rainfall determined by the following equation:

$$P = \frac{A_1 P_1 + A_2 P_2 + \ldots\ldots A_n P_n}{A} \qquad \text{G.1}$$

where P represents the average depth of rainfall in a watershed of area A and P_1, P_2, ...,P_n represent the rainfall depth in the polygon having areas A_1, A_2, ..., A_n within the watershed.

An example of the average amount of rainfall in Blocks G, A_1, B, K, D and O for the period of 21st October to 4th November 1991 is given in Table G.1. Three rainfall stations are located near the blocks in question. The rainfall differs sometimes considerably from station to station. The rainfall for the different stations was as follows for the period in question:

Station 1. - 257 mm, Station 2. - 293 mm, and Station 3. - 239 mm.

Isolines of rainfall were drawn and the computed average rainfall for the different blocks tabulated (Table G.1).

Table G.1: Estimated average rainfall for different blocks

Block	Rainfall (Oct. 21 to Nov. 4, 1991)
O	240
A_1 and K	253
D	280
G and B	266

ii)Effective Rainfall

An empirical method developed by US SCS based on analysis of 50 years of data for soil water storage, precipitation, and evapotranspiration can be used to estimate effective rainfall. This method produces a monthly estimate of effective precipitation and is not theoretically valid for shorter periods of time. Regression analysis has been used (US SCS, 1970) to force a function to fit through the data. This function is given as

$$P_{ef} = f(D)[1.25(P_t)^{0.824} - 2.93] \ X \ 10^{(0.000955 ET_c)} \qquad \text{G.2}$$

where: P_{ef} = effective precipitation, mm/month

$f(D)$ = function to account for depth of soil moisture depletion other than 75 mm

P_t = total precipitation, mm/month

The function f(D) is given by

$$f(D) = 0.53 + 0.0116D - 8.94 \ X \ 10^{5}(D)^2 + 2.32 \ X \ 10^{-7}(D)^3 \qquad \text{G.3}$$

where: D = normal depth of soil moisture depletion prior to irrigation (mm). The value of effective precipitation is limited to the lesser of P_t, ET_c, or P_{ef}, computed using G.2.

Appendix H. Water balance calculations for the 1991 season.

Table H.1: Water balance of Block L for two week periods.

Month	Days	I mm	R mm	D[1] mm	ETn + P mm	dSTO mm	STO[2] mm	ETc mm	ETr mm	Kc ETc/ETr
Apr	7-30	180	235	185	1	110	110	119	119	1.00
May	1-15	165	70	180	2	-20	90	73	73	1.00
	16-31	220	75	204	1	20	110	70	70	1.01
Jun	1-15	110	25	101	3	-35	75	66	66	1.00
	16-30	132	0	89	5	-20	55	58	58	1.00
Jul	1-15	187	0	104	5	25	80	53	53	1.00
	16-30	189	0	107	5	10	90	67	67	1.02
Aug	1-15	142	0	90	5	-15	75	62	58	1.07
	16-31	215	0	104	5	15	90	91	80	1.14
Sep	1-15	209	0	95	5	15	105	94	77	1.22
	16-31	199		99	5	-5	100	100	87	1.15
Oct	1-15	86	5	82	5	-85	15	89	88	1.01
	16-31	0	40	24	3	-40	0	53	89	0.60

Table H.2: Water balance of Block P for two-week periods.

Month	Days	I mm	R mm	D[1] mm	ETn + P mm	dSTO mm	STO [2] mm	ETc mm	ETr mm	Kc ETc/ETr
Jul	16-31	180	0	122	5	- 13	127	66	66	1.00
Aug	1-15	188	0	125	5		127	58	58	0.73
	16-31	117	0	100	5	- 68	59	80	80	1.00
Sep	1-15	148	0	65	5	- 1	58	79	79	1.03
	16-30	159	0	35	5	32	90	87	87	1.00
Oct	1-15	102	14	25	4	0	90	87	87	0.99
	16-31	111	28	37	3	10	100	89	89	1.00
Nov	1-15	80	272	177	1	100	200	74	67	1.10
	16-30	112	6	126	3	- 105	95	94	78	1.21
Dec	1-15	9	3	36	5	- 95	0	66	80	0.83

Table H.3: Water balance of Block K for two-week periods.

Month	Days	I mm	R mm	D mm	ETn + P mm	dSTO mm	STO mm	ETc mm	ETr mm	Kc ETc/ETr
Jul	20-31	210	1	88	4	82	73	37	48	0.77
Aug	1-15	246	2	161	5	25	98	57	58	0.98
	16-31	176	2	121	5	- 30	68	82	80	1.03
Sep	1-15	176	2	94	5	0	68	79	77	1.03
	16-30	162	-	60	5	5	73	92	87	1.06
Oct	1-15	129	5	42	5	- 10	63	97	88	1.10
	16-31	151	31	59	3	20	83	100	89	1.12
Nov	1-15	29	225	134	1	35	118	84	67	1.25
	16-30	94	3	63	1	- 60	58	93	78	1.19
Dec	1-15	40	6	30	3	- 80		93	80	1.16

Table H.4: Water balance of Block K for five-day periods (1991 season).

	Days	I mm	R mm	D[1] mm	ETn + P mm	ETc mm	dSTO mm	STO[2] mm
Jul	20-25	109	1	41	2	15	23[3]	72
	26-31	101	0	47	2	22	1	73
Aug	1-5	88	1	48	2	20	19	92
	6-10	88	0	49	2	20	17	108
	11-15	70	1	64	1	18	-12	97
	16-20	53	1	53	2	23	-24	73
	21-25	48	0	27	2	26	-7	66
	26-31	75	1	41	1	31	3	69
Sep	1-5	66	0	31	2	27	6	75
	6-10	54	1	32	2	24	-3	72
	11-15	56	1	32	1	27	-3	69
	16-20	67	0	23	2	31	11	80
	21-25	60	0	23	2	32	3	83
	26-30	35	0	14	1	29	-9	74
Oct	1-5	46	5	12	2	31	6	80
	6-10	44	0	19	2	33	-10	70
	11-15	39	0	11	1	33	-6	64
	16-20	42	0	5	2	32	3	67
	21-25	52	31	21	1	31	30	97
	26-31	57	0	33	0	39	-15	82
Nov	1-5	11	67	19	0	31	28	110
	6-10	15	100	57	1	24	33	143
	11-15	3	58	58	0	29	-26	117
	16-20	15	3	20	0	29	-31	86
	21-25	46	0	23	1	32	-10	76
	26-31	33	0	20	0	32	-19	57

1) D = corrected outflow

3) dSM = 29 mm

2) STO on 19 July = 4.3 cm

Table H.5: Water balance of Block P for five-day periods (1991 season).

Month	Days	I mm	R mm	D 1) mm	ETn + P mm	ETc mm	dSTO mm	STO 2) mm
Jul	26-31	87.0	0	41	2.0	23	21	106
Aug	1-5	64.0	0	39	1.0	20	4	110
	6-10	65.0	0	46	2.0	20	-3	107
	11-15	59.0	0	40	2.0	18	-1	106
	16-20	27.0	0	13	1.0	23	-10	96
	21-25	56.0	0	32	2.0	26	-4	92
	26-31	34.0	0	55	2.0	31	-54	38
Sep	1-5	41.0	0	21	2.0	27	-9	29
	6-10	55.0	0	26	1.0	24	4	33
	11-15	52.0	0	18	2.0	26	6	39
	16-20	75.0	0	11	2.0	30	32	71
	21-25	46.0	0	13	2.0	30	1	72
	26-30	38.0	0	10	1.0	27	0	72
Oct	1-5	30.5	6	6	1.5	28	1	73
	6-10	25.0	7	9	1.0	30	-8	65
	11-15	47.0	0	10	2.0	30	5	70
	16-20	32.0	0	9	1.0	29	-7	63
	21-25	25.0	28	8	1.0	27	17	80
	26-31	54.0	0	20	1.0	33	0	80
Nov	1-5	34.0	59	47		26	20	100
	6-10	28.0	136	72	1.0	21	70	170
	11-15	18.0	77	58		27	10	180
	16-20	22.0	6	22		27	-21	159
	21-25	83.0	0	49	1.0	33	0	159
	26-30	7.0	0	55	2.0	34	-84	75
Dec	1-5	6.0	0	24	2.0	27	-47	28
	6-10	0.0	1	8	1.0	20	-28	0
	11-15	0.0	0	4	1.0	15	-20	0

1) D = corrected outflow 2) STO on 25 July = 8.5 cm

Table H.6: Water balance of Block A1 for five-day periods (1991 season).

Month	Days	I mm	R mm	D1) mm	ETn + P mm	ETc mm	dSTO mm	STO 2) mm
Jul	20-25	127	1	15	2	7	104	0
	26-31	136	0	47	2	21	66	60
Aug	1-5	121	1	57	2	20	43	103
	6-10	107	0	53	2	20	32	135
	11-15	55	1	67	1	18	- 30	105
	16-20	35	1	34	2	23	- 23	82
	21-25	54	0	22	2	26	4	86
	26-31	68	1	36	1	31	1	87
Sep	1-5	59	0	30	2	27	0	87
	6-10	54	1	38	2	24	- 9	78
	11-15	39	1	25	1	26	-12	66
	16-20	50	0	10	2	30	8	74
	21-25	46	0	9	2	30	5	79
	26-30	24	0	4	1	27	(8)	71
Dec	1-5	20	3	10	1	32	- 20	85
	6-10	17	3	12	1	32	- 25	60
	11-15	3	0	8	2	29	-36	24

1) corrected outflow   2) STO on 19 July = 0.0 cm   STO on 30 Nov. = 10.5 cm

Table H.7: Water balance of Block K for five-day periods (1991 season).

Month	Days	I mm	R mm	D[1] mm	ETn + P mm	ETc mm	dSTO mm	STO[2] mm
Apr	18-30	120	90	159	1	64	(14)	86
May	1-15	187	57	144	1	73	26	112
	16-31	168	80	192	1	69	-14	98
Jun	1-5	9	23	10		19	3	101
	6-10	67	1	33	2	23	10	111
	11-15	67	0	60	2	23	-18	93
	16-20	57	0	18	1	21	17	110
	21-25	40	0	26	2	19	-7	103
	26-30	45	0	25	2	18	0	103
Jul	1-5	52	0	32	1	17	2	105
	6-10	61	5	49	2	20	-5	100
	11-15	45	0	23	2	16	4	104
	16-20	35	1	19	1	17	-1	103
	21-25	90	1	69	2	25	-5	98
	26-31	63	0	48	2	23	-10	88
Aug	1-5	50	1	39	2	20	-10	78
	6-10	67	0	45	2	20	0	78
	11-15	88	1	60	1	18	10	88
	16-20	72	1	73	2	23	-25	63
	21-25	41	0	33	2	26	-20	43
	26-31	83	1	47	1	31	5	48
Sep	1-5	73	0	31	2	28	12	60
	6-10	54	1	26	2	25	2	62
	11-15	76	1	39	1	28	9	71
	16-20	85	0	38	2	33	12	83
	21-25	76	0	39	2	33	2	85
	26-30	48	0	24	1	30	-7	78

1) corrected outflow 2) STO on 17 April = 10.0cm

Table H.8: Water balance of Block L for five-day periods (1991 season)

Month	Days	I mm	R mm	D[1)] mm	ETn + P mm	ETc mm	dSTO mm	STO [2)] mm
Sep	1 - 5	56	0	28	2	33	-7	83
	6 - 10	71	0	26	2	29	14	97
	11 - 15	82	0	41	1	32	8	105
	16 - 20	64	0	31	2	36	-5	100
	21 - 25	62	0	34	2	34	-8	92
	26 - 30	73	0	34	1	30	8	100
Oct	1 - 5	63	5	49	2	30	-13	87
	6 - 10	23	0	30	2	30	-39	48
	11 - 15	0	0	3	1	30	-34	14
	16 - 20	0	0	2	2	29	-33	0
	21 - 25	0	40	12	1	22	5	0
	26 - 31	0	0	10	0	17	-27	0

Table H.9: Water balance of Block N for indicated periods (1991 season)

Period	I mm	R mm	D[1)] mm	En+P mm	ETc mm	dSTO mm	STO [2)] mm
Oct 11 - Nov 2	239	31	68	7	145	50	+
Nov 15 - 30	19	5	59	1	89	-125	+
Nov 15 - Dec 5	20	10	65	1	109	-145	+

1) D = corrected outflow 2) STO on 31 August = 9.0 cm