

PERFORMANCE EVALUATION OF
IRRIGATION WATER DISTRIBUTION SYSTEMS
OF THE KANO RIVER PROJECT

BY

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DECLARATION

I hereby declare that this thesis has been composed by myself and it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All quotations are properly distinguished and the sources of information are specially acknowledged by means of references.

A. G. GAMALIEL

Date

CERTIFICATION

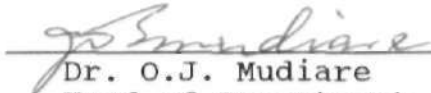
This Thesis entitled "PERFORMANCE EVALUATION OF WATER DISTRIBUTION SYSTEMS OF THE KANO RIVER PROJECT" by A.G. GAMALIEL, meets the regulations governing the award of the degree of master of Science, M.Sc. (Agricultural Engineering) of Ahmadu Bello University, Zaria; and is approved for its contribution to knowledge and literary presentation.


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DEDICATION

Dedicated to
The Glory of God
Almighty
The Development of
Irrigation in my
Country - Nigeria

and

Evergreen Memory of
My Beloved Mother
Mrs. B.N. GAMALIEL (RIP)
Who Has Been
So Kind To Us
ALL

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ABSTRACT.

The study was conducted during the 1992/93 irrigation season at the Kadawa sector of the Kano River Project (KRP), with the primary aim of evaluating the performance of a part of the distribution system (distributary canal and field channels), irrigation water distribution and allocation methods and the relative water supply (RWS) index, as they affect control, operation and equity. Block 3F7 was selected as the experimental site. Stage measurements were monitored at the selected stations on both the distributary canal, field channels and farm units. Discharge was obtained from calibrated structures (cilt-throat flumes). The water conveyance efficiencies, and losses were determined for each of the selected stations.

The results obtained from the study showed that 84 l/s on the average was recorded as discharge for the distributary canal (DC), with conveyance efficiency and losses of 87% and 14 l/s, respectively. The average field channel discharge of 15 l/s was recorded as against a design discharge of 28 l/s, while the conveyance efficiency and losses were 65% and 4 l/s, respectively. The result obtained for the various farm units showed significant variations, both at the head-end and tail-end of the farm, hence low equity of distribution as a result of low water supply.

The field evaluation of the RWS, showed that all the plots recorded low values, which indicates under irrigation in all the plots. However, the high performance of field crops and high yield recorded was due to contribution from high water table recorded in most parts of the project area. The 1.5 t/ha yield for wheat on the average, further confirmed the high performance of the crops.

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CHAPTER ONE

1.0 INTRODUCTION

Irrigation is practiced in many parts of the world with the aim of providing water for crop growth when natural precipitation is in short supply and/or distribution is erratic. In dry areas, such as some Northern parts of Nigeria, where there is little rainfall, irrigation may provide a significant part of total water needs of the crops. In some parts of the middle belt of Nigeria, where rainfall is not as completely reliable as in the Southern parts, growing crops need to be supplemented by irrigation whenever rainfall is scanty.

Many types of irrigation methods have been developed to suit different agricultural systems and the communities within the given project areas (Melvyn, 1989). Some schemes are very small covering only a few hectares of land. These types are the farmer - managed irrigation schemes. Others are large, covering so many hectares, which are usually managed by governmental or private organizations such as sugar companies, individuals or group of individuals.

The type of irrigation system adapted and employed depends on a number of factors which include: the

irrigation water quality and quantity, topographical factors, availability of capital, type of crop to be grown, climatic and soil conditions, expertise, general local conditions, and other factors. In most irrigation projects in Nigeria, these factors pose little or no problems at the initial stages, however, as time went on, their effects became pronounced as a result of management problems, leading to poor water distribution and management within the whole project area. (Thomas, 1989)

For any irrigation project to be successful, effective water distribution and management is very vital. A successful irrigation project does not only entail that, the optimum amount of available water be distributed equally, uniformly and timely, but the yield per hectare of the crop grown should be equal to the initial cost of all the inputs (Melvyn, 1989). The approximate design of irrigation water distribution system for the judicious application of water requires reliable information on the irrigation requirement or consumptive use of the particular crops (Bottrall, 1981).

Apart from the effect of water management on water distribution within the project area, other factors include; engineering constructions, operations, monitoring and maintenance of the distribution structures such as gates at the the source(dam, lake, river) which can result in inequitable water distribution within the

project area (Thomas, 1989). Where the appropriate quantity of water is released from the source, there is no guarantee that such an amount will reach the field channels and the plots at their design crop water requirement levels (Melvyn, 1989).

The Kadawa Irrigation Research Station is located in the Kadawa sector of the Kano River Project. The project took off in 1971, with the construction of the Tiga Dam on the Kano River (Nwa, 1992). The designed total potentials of the project area according to NEDECO (1974) report, stands at about 9.3×10^4 ha; while the operative phase was projected to be about 5.2×10^4 ha. according to the design. The project is sited in a region which is affected by three climatic seasons as reported by Oyeboode (1989). These seasons include:

1. The cool dry season - October to February
2. The hot dry season - March to May
3. The warm rainy season - June to September.

From the classification of the climate of the project area, the irrigation period starts from mid - November and ends mid-to-end of April the following year. This can extend at times to mid-May.

The feasibility studies report for the construction of the Tiga Dam (Reservoir), according to Haskonings (1978), indicates that the Dam is built on a river whose annual runoff is about $1.30 \times 10^9 \text{ m}^3$, while the total loss

was estimated at about $0.25 \times 10^9 \text{m}^3$ per annum. This gives a balance of $1.05 \times 10^9 \text{m}^3$ for use. Haskonings (1978), also estimated an annual irrigation release exceeding $0.708 \times 10^9 \text{m}^3$ for the irrigated area, that is the initial phase of the project, which is less than 2.20×10^4 ha. This shows that less than $0.342 \times 10^9 \text{m}^3$ of water is available for the remaining area of the project, which is about $5.3 \times 10^4 \text{ha}$.

Muhammad (1991) found out that, no additional land can be developed within the project area as planned, unless the water available is increased or the system of irrigation changed entirely. Water distribution system of the Kano River project cannot be accepted as being efficient, since there are no projects for further developments of the other phases. Muhammad (1991) found that, this was due to the high water wastage which results in environmental pollution. Many other researchers amongst whom are: Nwa (1982), Adewumi (1985) Abdulmunin (1988) and Oyebode (1989), reported environmental effects due to low irrigation efficiency and high water table in some parts of the project area, resulting in water-logged conditions which has resulted in salinity and alkalinity problems and reduction in crops yield.

Inspite of the fact that considerable work has been done by various researchers on various aspects of the

Kano River Project, especially on conveyance and irrigation efficiencies, not much has been done on the water distribution system, its evaluation as it affects the farmers and various crops grown within the project area; and the performance of the various distribution systems, controls and structures. Mention has not even been made of water allocation and distribution methods as they affect the cropping pattern and equity.

1.1 Objectives of the study

The objectives of the work reported herein include.

1. To evaluate the performance of the distribution system from a distributary canal, field channel and farm units for a particular block of the project area; and compare these values with the calculated values of crop water - use and also the design values.
2. To investigate the water allocation and distribution methods of the Kano River Project as it affects control operation level, farmer convenience, equity and charges.
3. To investigate the design management interaction and its effects on the irrigation system performance of the project area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Irrigation Water distribution systems

A successful irrigation project depends on adequate design and construction of the water distribution system and planning for the operation of the completed project (Muhammad 1991). Where water is scarce in relation to crops requirement, the most important function of irrigation management is to ensure that the available water is efficiently and fairly distributed. It is only when the water distribution system is operated properly, that other important management objectives can be realized. Such management objectives as reported by Bottrai (1981) include: on-farm management work, improvement of water course and introduction of water charges, which will result in higher returns from inputs. However, the poor quality of water distribution systems in most irrigation projects in Nigeria and the extent of management policies required to reduce the water distribution problems, have been either underestimated or completely ignored.

Abundant evidence have been obtained in recent studies of irrigation system performances in different projects in Nigeria, which show that deficiencies in water distribution practices exist. Nwa (1982),

identified two main aspects on the management of water distribution and their systems, each with a distinctive different set of problems and potential remedies associated with it. The first aspect is essentially technical and is concerned with the quality of the water distribution method used and their capacity to meet the objective of securing the best possible match between expected supply and demand. The second aspect is social and political, which is concerned with capacity and willingness of irrigation officials to ration water equitably and resist pressures from influential farmers or top management personnels to misallocate water (Nwa, 1982 and Thomas, 1989).

Good water distribution, therefore, requires not only high technical skills, but also a good management system. Another essential requirement for good water distribution both in its technical and socio-political aspects is that a well-designed two-way information system between irrigation officials (management) on one hand, and consumers (farmers) on the other hand must be put in place (Nwa, 1982).

2.2 Planning and Design for water Distribution systems

Reference had already been made of the importance of good planning and design of irrigation water distribution systems as a pre-requisite for a good water distribution.

The basic requirement for good and equitable water distribution are summarized in Bottrai (1981). The absence of adequate water measuring devices is a serious omission. Defects such as underdesign of canal capacities and in particular, insufficient control structures make it impossible to allocate water in accordance with the intended plan and design (Kra'atz, 1975, and Merriam et. al. 1980).

2.2.1 Technical consideration and planning

Water distribution, like any other irrigation management activities consists of three sub-activities. Marriam et-al (1980), reported that the kind of procedures, skills and resources needed to perform these activities vary from project to project, depending on the design characteristics and methods of water distribution being used. Irrigation officials (management) require continuous information about actual patterns of water supply and demand throughout the cropping season, so that necessary adjustments can be made as the need arises. Adequate water measuring facilities and reliable systems of communications between management, field staff and the farmers are very essential. Implications for changes in operating procedures as a result of variations in water supply levels should be specified in details, which should be clearly understood by operators at all levels.

Farmers should be regularly informed about actual water charges, deviation from initial planned levels and the reasons for such deviations.

2.2.2 **Monitoring of Water Distribution Systems**

In addition to the daily report of gauge readings from field staff, weekly reports need to be compiled on water supply situation so that management can closely monitor the water distribution within the project. Periodic reports on cropping patterns and intensities are also required, particularly, with a view to checking on the equity of water distribution. Bottrai (1981) suggested random on the-spot checks by irrigation officials in case of inaccuracies and/or falsification of records by field staff.

2.2.3. **Water distribution system Maintenance**

The maintenance of irrigation systems in general is an auxiliary activity which performance is essential for a high quality of irrigation water distribution. Maintenance and repair work on water distribution systems are categorized into three, according to Bottrai (1981):

1. Routine or preventive maintenance: which is intended to keep the distribution systems in such a condition that, it can be operated in accordance with the original design. Maintenance costs are provided for, under a regular annual budget.

2. Emergency maintenance: In the event of any natural disaster, the cost for which has to be covered by specific budget allocations, and
3. Up-grading or improving works: Usually carried out by a different organization from the one responsible for the day- to-day project maintenance.

Water distribution system maintenance can further be classified based on specialized activities which include: civil works, and mechanical and electrical works. These involve maintenance of canal and channel banks, diversion structures, earth work, gates and pump maintenance.

2:2.4 Methode of improving water Distribution systems

A number of measures for improving water distribution systems could include most if not all the elements reported by Thomas (1989). This depends to a large extent on what is required or feasible in the project area. Some of these measures include:-

1. The introduction of simple procedures such as improved information system and other measures, designed to produce significant short-term benefits from practicable and equitable water supplies.
2. The production of operation and maintenance manuals and proper job descriptions.
3. Experimentation on alternative methods of increasing

representative farmer-participation in decision making both at the local small group level and at project level.

4. Research on crop water requirements on farmers' fields on the basis of which new water distribution methods and alternative cropping patterns would be designed and tested.
5. Experimentation with new forms of water charge payments.

2.2.6 Purpose of Evaluating irrigation water distribution systems

The purpose of evaluating water distribution system in general as reported by Merriam, et-al (1980) is four-fold:

1. To determine the efficiency of the distribution system as it is being used.
2. To determine how effective the system can be operated and whether it can be improved upon.
3. To obtain information that will assist in designing other systems; and
4. To obtain information that will enable comparing various methods or systems of operating procedures as a basis for economic decisions.

Evaluation as defined by Merriam, et-al (1980) involves measuring conditions at one or more points in a field selected to be typical or representative of the

project area. Value judgement or additional measurements must be made to correlate these data to an over-all field, farm or project efficiency. The accuracy of such measurements will not justify calculating efficiencies to more than $\pm 3\%$ (Merriam, et-al, 1980).

The on-farm water distribution systems and operations need to be evaluated to determine the potential efficiency that is obtained with the present management requirements. Substantial improvements in the water distribution system evaluation are also needed for timely and equitable distribution of water. However, improving the water distribution system without evaluation may have little effect on farm water distribution and management (Merriam, et-al, 1980 and Bottrall, 1981).

Adequate water must be available when needed by the crops and the proper evaluation of the water distribution system will enable the farmer to obtain information on the amount and the rate of water application necessary to achieve efficient irrigation and reject delivery when and where it is no longer needed in order to minimize waste, (Bottrall, 1981).

Irrigation Water Distribution by Re-cycling

The planning and design of an irrigation project must include the details of terminal water distribution

systems such as drains, which play important roles in securing the optimal use and control of irrigation water distribution systems. The project should be designed so that the required amount of water is delivered and effectively utilized within the project area (Kra'atz, et. al. 1975).

While the re-cycling of irrigation water runoff re-use has not been popular for sometime in most irrigation projects in Nigeria, the idea of such practice could be useful in water distribution especially where irrigation water is scarce. Khanjana and Buch (1983), reported that water distribution is more uniform in a project where return flow is used. However, an economic analysis revealed that the benefit-to-cost ratio of this system exceeded that of the conventional system (Khanjana and Buch, 1983). Re-cycling water distribution system is only appealing where irrigation water quality is good and soil salinity is low, together with good soil permeability and infiltration characteristics.

2.3 Irrigation Water Measurement and Instrumentation

Efficient use of water for irrigation depends to a large extent on measurement of irrigation water. With the expanding exploitation of the water potentials and the ever-increasing cost of water resources development,

a close monitoring of the quantities of water used by the various consumers must be quantified. This is particularly necessary for irrigation projects where there is the increasing utilization of available water for irrigation and the growing tendency among most irrigation project managers to base annual water charges on the volume of water used. This makes it necessary to ~~understand the~~ principles and methods of water measurements in irrigation practice (Gabrecht and Bos, 1980). Information concerning the relationship between water, soils and plants cannot be utilized in irrigation practice without proper water measurement practices. The units of water measurement can either be considered as those expressing a specific volume of water at rest, or those expressing time rate of flow (Isrealsen, et al., 1979). The amount of water flowing at any time and at any place in the water conveyance and distribution system, according to Gabrecht and Bos (1980), must be known in order to facilitate the proper administration of the irrigation system. Effective use of water requires that the flow rate and volumes be measured and expressed quantitatively. Water measurement can generally be based upon the application of the definition equation which states that:

$$Q = AV$$

2.1

Where Q = Flow rate, m^3/s

A = Cross sectional area, m^2

V = mean velocity of flow, m/s .

Micheal (1985), developed an equation for evaluating applied depth into farm plots for known area, discharge and time of flow. Thus,

$$Ad = QT \quad 2.2$$

in which d = applied depth (m), T = Time of flow (secs), and other terms are as previously defined.

Water flow measurement:

Flow measurement, therefore, involves the determination of the mean velocity and area of flow. Some techniques make each of these determinations separately and use them directly in the definition equation. While in others, the calibration of the measurement device gives the flow rate directly. Schwab, et-al (1979), Isrealsen, et-al (1966) and Micheal (1985) identified a number of methods that could be used for irrigation water measurement. Some of which include:- float method, impeller meters, slope-area method, volume method and many others. The float method is used herein, for the distributary canals because of non-availability of the current meter and the problem of installation of measuring devices such as flumes and weirs, especially

separately and use them
equation. While via cell

when the canals are lined.

2.3.1 Float Method

The velocity of a stream in a channel is made by determining the velocity of an object floating with the current. A straight uniform section of the stream of known length is selected and marked by stakes. The time required by an object to traverse the marked course is measured and the velocity calculated from the expression given by (Michael, 1985):

$$V = Z/t \quad 2.3$$

Where V = velocity of flow, m/s

t = time taken by the object to traverse the two marked points, s and

z = distance traverse by the floating object, m.

This method is simple and inexpensive but not very accurate. However, Stern (1985), observed that the velocity obtained corresponds to the velocity of the water at its surface. The surface velocity must then be multiplied by a coefficient to give the average velocity for the cross - section. This coefficient, according to Stern (1985) varies from 0.66 for water depth of less than 30 cm to 0.80 for water depth of 6m and above. A value of 0.70 is often recommended for distributary canals (DC) and field channels (FC) (Stern, 1985). This coefficient also compensates for the effects of wind among

other factors. The values of velocity obtained from Eq. 2.1 are then multiplied by 0.70 to convert them to mean velocities.

2.3.2 Flow Measurement Structures

For accurate measurement of flow in open channels it is desirable to install structures of known hydraulic characteristics. These structures cause flow to pass through critical depths. The structures also have a consistent relationship between the head and discharge as reported by Isrealson et-al (1979).

Weirs

Gabrecht and Bos (1980) described a Weir as a barrier placed in a stream to constrict the flow of water and cause it to fall over a crest. Weirs may be rectangular, trapezoidal or triangular in opening shapes. The basic and general formula as given by Schwab et. al (1966) for flow through such structures is:

$$Q = CLH^n \quad 2.4$$

where Q = Coefficient of discharge which depends on Editing the nature of the crest and the approach conditions.

L = Length of the crest, m

H = Height on the crest, m

n = constant, which depends on the shape of the crest opening

2.3.3 Flumes

Specially-shaped and stabilized channel sections may be used to measure flows. Such a section is termed a flume. Flumes are generally less inclined to catch floating debris and sediments than weirs, and for this reason, they are practically suited for the measurement of channel flows (Michael, 1985).

One of such flumes is that developed by parshall in 1926, which has the advantage of requiring a very low head loss for its operation and is accurate at low flows. It is, however, not satisfactory for wide and fluctuating runoff or flows.

Cut-Throat Flumes

The cut-throat flume is an attempt to improve on the parshall flume, mainly by simplifying the construction details. The flume has a flat bottom, vertical walls and a zero length of throat section. Since it has no throat section (zero throat length), it was given the name "Cut-throat" flume by the developers (Skogerbo et-al, 1967).

The most obvious advantage of a cut-throat flume is economic, in terms of construction. The flume can be operated under free flow conditions. Critical flow occurs in the vicinity of the minimum width, which is called flume throat or the flume neck. This makes it possible to determine the flow rate knowing only an upstream depth (h_a). The relationship between the flow

rate (Q) and the upstream depth (ha) in a cut-throat flume under free flow conditions is expressed by Michael (1985):

$$Q = C h^n a^{2.5}$$

where Q = Flow rate, m³/S

C = Free flow coefficient

n = exponent whose value depends on flume length, L.

The value of n is a constant for all cut-throat flumes of the same length regardless of the throat width (B). Kra'atz et-al (1975) reported that the use of cut-throat flume enables the measurements of irrigation water stream sizes to be made with greater ease than the other flumes, such as the Parshall flumes.

Kra'atz et al (1975) also gave a more simplified expression used for determining the discharge through the cut-throat flume under free flow conditions; and where the flumes are not calibrated as.

$$Q = CHB^{1.5}$$

Where Q = design discharge of the outlet in cm³/S

B = width of the throat in centimeters (cm)

H = Height of the designed full supply level in the supply canal above the crest level of the outlet in cm, and

C = a coefficient having different values for different widths of throat in metric units

(see Table 2.1).

TABLE 2.1: Values of B and C for cut-throat flumes

B (cm)	C
6 - 9.0	0.0160
9.1 - 12.0	0.0163
over 12.0	0.0166

Source: Kraatz et-al. (1975)

The discharge can then be calculated for any head H , by using any of the two formulae above (Eq 2.5 and 2.6), provided free flow condition exists in the flume. Where the cut-throat flumes have been calibrated, available calibration curves or formulae can be used for the purpose of evaluating the discharges. Muhammad (1991), established the following calibration expressions for the 20-cm and 10-cm cut-throat flumes; which are used herein. Thus for the 20-cm flume, the discharge is expressed as:-

$$Q = 0.332H^{1.5} \quad 2.7$$

While the 10-cm cut-throat flume discharge can be evaluated from:-

$$Q = 0.0525H^{1.5} \quad 2.8$$

Where all the terms in the equations are as previously defined. For accurate discharge measurements the recommended ratio of flow depth to length (H/L) should be less than or equal to 0.4 (Kraatz et-al, 1975), as higher values of this ratio result in greater inaccuracies in

the measurements.

Installation of Cut-throat Flumes

The cut-throat flume should be installed in a straight section of the channel. It should not be located too near a gate turn out or diversion structure, because of instability and surging effects which might result during flow measurements.

Gabrecht and Bos (1980) identified the required properties of an ideal water measuring device for irrigation and distribution systems as simplicity of operation, accuracy and low cost of construction and maintenance.

2.4 Irrigation System Efficiencies and Evaluation:

In planning and designing an irrigation system, a major problem is to decide what value of water use efficiency to apply in the calculations. Since this basic parameter is sometimes lacking; it is common to find that this efficiency is either assumed or derived from nearby existing irrigation systems. The water-use efficiency used, therefore, is not likely to suit the conditions of the project area in its future state. In order to accommodate this uncertainty, structures are often given greater capacities than would be necessary, during the design.

4.2.1 Conveyance Efficiency (E_c)

This is the efficiency of canal network from the source to the off-takes of the distribution system (Bos and Nugteren, 1982) and it is expressed as:

$$E_c = (V_d + V_2) / (V_c + V_1) \quad 2.9$$

Where V_d = Volume delivered to the distributary systems, m^3

V_c = Volume diverted or pumped from the source m^3

V_1 = inflow from other sources, m^3

V_2 = non-irrigation deliveries from conveyance system, m^3 ; in most cases, V_2 is approximately zero.

A number of factors affect the system conveyance efficiency, amongst which are: average irrigation area, size of rotational unit and the technical equipment available within the project area.

Adewumi (1985) and Melvyn (1989), stated the relationships for evaluating the conveyance and distribution performance of irrigation water distribution systems. They based the relationships on the principles of inflow and outflow discharge measurements along the distribution systems or within the distribution systems. The conveyance efficiency (E_c) according to Adewumi (1985) can be expressed as the ratio of the outflow discharge Q_o to inflow discharge Q_i ; expressed thus:-

$$E_c = Q_o / Q_i \quad 2.10$$

similarly, the conveyance losses (C.L) for the system can be evaluated as the difference between the inflow Q_i and the outflow discharge Q_o . Thus,

$$CL = Q_i - Q_o \quad 2.11$$

2.4.3 Distribution Efficiency (E_d)

Bos and Nugteren (1982) defined the distribution efficiency as the efficiency of water distribution within canals supplying water from the conveyance network to individual fields. It can be expressed as: -

$$E_d = (V_b + V_3) / V_d \quad 2.12$$

where V_d = volume of irrigation water diverted to the distribution system (m^3)

V_b = volume of water supplied to the field (m^3)

V_3 = non irrigation deliveries from the distribution system (m^3)

In most cases, non-irrigation deliveries and other sources is assumed to be zero. In order to obtain a reasonable distribution efficiency, Bos and Nugteren (1982) suggested that, the distribution system should be designed and operated by skilled farmers or a common irrigator representing a group of small farmers. The water distribution efficiency may be affected by a number of factors which include - farm size, soil type and duration of water delivery.

Similarly, for a distribution system with branch channels (Field channels), water distribution efficiency in the various field channels from the source can also be determined as the ratio of the discharge delivered into the second field channel Q2 to the discharge in the first field channel Q1. Thus,

$$Ed = Q2/Q1 \quad 2.13$$

in which all terms are as previously defined.

The system distribution losses (DL) can also be evaluated as the difference between the discharges in the two field channels as given by Adewumi (1985).

$$\text{Thus } DL = Q1 - Q2 \quad 2.14$$

2.4.4 Field Application Efficiency (Ea)

The system field application efficiency is the relationship between the quantity of water supplied at the field inlet and the one needed to maintain soil moisture level required by the crops. This is an indirect way of establishing the field capacity, since the water used for evapotranspiration by the crop is equal to the amount needed to maintain the soil at the required moisture level needed by the crop which is usually taken as the field capacity. The evaluation of the field application efficiency requires the measurement of water deliveries to each field and the measurements of soil moisture content (mc) before and after the

application of irrigation water. Although such measurements are needed in research, they are scarcely taken in the field in practice. An effective system of irrigation scheduling is possible on soils that have high water-holding capacity, or in areas where reliable data on consumptive-use and good meteorological data are available. For such cases, only periodic checks of soil moisture need to be made to ensure that irrigations are done before the soil reaches the wilting point and that the water application is not more than the allowable moisture deficit (MAD) within the crop root zone. The field application efficiency can thus be expressed as

$$E_a = V_m/V_b \quad 2.15$$

where V_b = Volume of irrigation water supplied to the field, m^3

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

A number of factors also affect system field application efficiency (E_a), such as the irrigation method, farm size, soil type and the water flow rate. (BOS and Nugteren, 1982)

2.5 Crop Water Requirement (CWR)

In irrigation, evapotranspiration data is needed for the design, management and establishingment of water

rights. Evapotranspiration, therefore, is an essential factor in the design and management of irrigation systems. (Melvyn, 1989)

Doorenbos and Pruitt (1975) presented guidelines for predicting crop water requirements, while Burman et al (1980) discussed the use of formulae and presented examples of methods for calculating evapotranspiration as it affects the design of an irrigation system. The components which must be designed in an irrigation system include:- canal sizes, pump selections and irrigation control structures.

Many of the older irrigation systems were designed based on experience and rules of the thumb in estimating the irrigation water requirements for the areas to be supplied with water. However, the design of a modern irrigation system is based on evapotranspiration estimates for the selected planned crop rotation (Heermann, 1988). Reservoir storage capacities can be adequately designed with accurate estimates of monthly or seasonal net irrigation requirements. The net irrigation requirements require estimates of evapotranspiration and effective precipitation. The design of the conveyance, delivery and on-farm distribution systems require estimates of the daily or weekly peak evapotranspiration. The length of period for evapotranspiration determination is a function of irrigation type, cropping practices and

soil - water relations as reported by Heermann, (1988). Burman et al (1980) observed that traditionally, design capacities of irrigation systems are based on the peak evapotranspiration rate.

In several irrigation projects, the volume of water that can be transferred from one system to another is based on the historical consumptive-use of the crop. It was not based on historical diversion or actual water applied on previous years of irrigation. The determination of this historical consumptive-use requires an accurate estimate of evapotranspiration or calculated values with developed evapotranspiration models available; which use historical climatological data of the project area under consideration (Burman, et-al, 1980).

2.5.1 Methods of Estimating Evapotranspiration (Et).

A number of methods have been developed by various researchers for estimating evapotranspiration (Et), using historical climatological data (Schwarb, et-al 1966; Hargreave, 1974; Isrealsen, et-al 1979, 1961; Duru 1980 and Saeed, 1986). These methods are based on empirical relationships. Hargreaves (1974), Blannet-Morin-Nigeria (BMN) Duru (1980) and the Pan Evaporation methods are used for the study reported herein. The reasons for using these three methods amongst others include: data availability, simplicity in application, adaptability to

any area and relatively fewer variables used in the computation of crop water use. Also, the Pan Evaporation method is used in the discussions because it was used by the designers (NEDECO, 1973), apart from its adaptability and suitability for the study area.

2.5.2 Hargreaves Method of Estimating (Et)

Hargreaves (1974), developed an equation for estimating evapotranspiration (Et) of crops. Hargreaves (1974) based his work on the data obtained from lysimeters. The method which is less popular, but relatively simple in application, has been used extensively in estimating crop water requirement (CWR) in most parts of the world (Saeed, 1986). In equation form, Hargreaves (1974) method can be expressed as:

$$Et_g = 00.35(T+17.78)Rs \quad 2.16$$

where Et_g = Reference crop potential consumptive-use
for well-watered grass; mm/day

T = Average daily temperature, $^{\circ}C$

Rs = Incident solar radiation, mm/day

The values of Rs for the project area as obtained from Kowal and Knabe (1972) and are reproduced in Appendix F. Also the latent heat of vapourization of water for the study area was found to be 58 cal/cm³ (Kowal and Knabe, 1972). Thus each value of Rs in the table could be

converted from cal. cm² day to mm/day.

Hargreaves (1974) and Saeed (1986), indicated that a reference crop of alfa alfa would have consuptive - use about 20 percent greater than that of grass, therefore, the potential evapotranspiration Etp can be estimated from E_{tg}, by:

$$Etp = 1.2 E_{tg} \quad 2.17$$

This allows for the use of experimental crop coefficient K_{co} values, which have already been developed for the study area, or obtained from standard tables to estimate actual potential evapotranspiration (E_{ta}) from the equation

$$E_{ta} = K_{co} Etp \quad 2.18$$

Standard values of K_{Co} for selected crops at various stages of growth are as reported by Stern (1989), and reproduced in Appendix G, herein this work.

2.5.3 Blanney-Morin-Nigeria (BMN) Method of Et

As a result of the complexity in the application and assumptions in the use of adapted evapotranspiration models, Duru (1980), developed another model which is a modification of that earlier presented by Blanney and Morin (1942). The model which was developed for application in Nigeria, can also be applied in other developing countries (Duru and Yusuf; 1981). It was designated as the Blanney-Morin - Nigeria (BMN)

evapotranspiration model. The BMN predicts potential evapotranspiration (Etp) with accuracy and consistency (Duru and Yusuf 1981). The Blanney - Morin - Nigeria evapotranspiration model as developed by Duru (1980) is:

$$Etp = r_f (0.45T + 8) (520 - R^{1.13}) 100 \quad 2.19$$

where Etp = potential evapotranspiration, mm/day

r_f = ratio of maximum possible radiation to the annual maximum ratio; values of r_f are reproduced in Appendix H.

T = average temperature, °C and

R = Relative Humidity (RH), %

The actual evapotranspiration, Eta, for any crop can then be evaluated by multiplying the Etp values with the crop coefficient Kco (Eq.2.8).

2.5.4 PAN Evaporation Method.

The most common method of measuring evaporation is by means of an evaporation Pan. The most commonly used pan is the American class A Pan, made from galvanized iron sheet, which is circular, 1.21m in diameter and 25cm deep (Micheal, 1979). Pan Evaporation (Epan) can be converted to potential evapotranspiration by multiplying it by a pan coefficient (Kp). The value of Kp differs for different types of pans (Stern, 1985). For the same type of pan, Kp varies with relative humidity, wind

speed, time of measurement and siting of pan in relation to crops and vegetation (Stern, 1985). The pan coefficient for class A pan may vary between 0.40 to 0.85, depending on climatic and geographical location. The value often used is 0.7 (Michael, 1979; Stern, 1979). The potential evapotranspiration so obtained is then multiplied by the relevant crop coefficient (K_{co}) to obtain the crop water requirement (CWR).

2.6 Irrigation Water Allocation and Distribution Methods

Irrigation water allocation and distribution are distinctive and important functions in any irrigation project. Water allocation as defined by Pradhan(1989), is the assignment of entitlement to water from an irrigation system within a project. Irrigation water allocation and distribution involve two aspects:- the first aspect distinguishes the farmers or fields having direct access to the irrigation system from those having none; and the second aspect is the quantitative allocation of water in the system among the farmers or the field which involves the designation of the amount and the timing of water to which each farmer or field is entitled. Martins and Yoder (1987), defined water distribution as the implementation of the allocation principle as agreed upon by the beneficiaries. Different

methods of allocation and distribution are in practice. Irrigation water allocation has effects on efficiency and water use equity, and can be a means for expanding the area irrigated and obtaining the measurement and comparison between the amount of water actually distributed and that allocated to different parts of an irrigation system. It also provides for the evaluation of the system performance.

The allocation and distribution of irrigation water to farm units can be scheduled in different ways. The most common is as summarized by Khanjan and Busch (1983), as continuous supply, strict rotation, demand and / or a combination of these.

2.6.1 Continuous Supply Method.

In the case of a continuous supply, a specific flow rate is continuously delivered to a farm unit. The water allocation is according to the free flow in the canal. Water is not limited in either volume or in relation to the size of the land to be irrigated. There is no evidence of domination of water since all the farmers or irrigators have access to water, when and where they want it. This occurs in a situation where water is abundant. This method of allocation and distribution is only beneficial to crops such as rice, wheat, and other grains, and also when the area to be irrigated is more

than 50 ha. (Zein, 1971)

2.6.2 Strict Rotation Method

Strict rotation method of scheduling is used to supply a farm or group of farmers with a flow rate several times greater than that required for the continuous supply case during a pre-defined time and period. Under this condition, the cost of the distribution system will increase and also the farmer must irrigate at certain pre-set times; and failure to irrigate on time generally, leads to waste of water or under irrigation (Khanjan and Busch, 1983, Martins and Yoder, 1987).

2.6.3 Demand Method

For modern agriculture with changing crop rotation and diverse farming systems, the demand method of water allocation is more adequate than either the continuous or rotation methods. According to Pradhan (1989), availability of water on demand is ideal for the irrigator as he is not constrained by limited water flow rates or timing of delivery. However, the cost of constructing and managing a distribution system to supply irrigation water on demand may increase significantly.

Pradhan (1989), reported that, this method requires farmers to register their names indicating when they

would need water within the command area, at the branch canal and then water is allocated according to the order in which the names are registered. Scheduling is therefore important in order to avoid possible conflicts and disorder in water allocation and distribution.

2.7 Design - Management Interaction and its Effects on Irrigation System Performance.

The irrigation projects in different countries have different sets of facilities, operating rules, organisational structures and management practices. These structures differ mainly in their performance in terms of technical and economic efficiencies, productivity and equity results, and manageability of the system (Valera and Desa, 1991). In order to improve on the performance of irrigation systems, it is necessary to also assess and evaluate the correct and existing performance with the aim to identifying the opportunities for improvement at various levels (Pradhan, 1989).

The assesment of the effects of design and management interaction on the overall performance of any irrigation project depends on certian performance indicators. Valera and Desa (1991), suggested three performance indicators: the crop intensity (CI), the relative water supply (RWS), and the water productivity(WP).

The use of RWS as an indicator of performance further makes the assessment and evaluation of irrigation water allocation and distribution performance of the project possible. Moreover, the adequacy of supply to demand within the project area could also be determined by the RWS. Valera and Desa (1991), also defined RWS as the ratio of the actual total water supply to the estimated demand for the command area.

Crop intensity index (CI) represents the capability of the project to provide irrigation water to either the entire or parts of the command area. The irrigation water is evaluated at each cropping season within the year (Valera and Desa, 1991). The crop intensity index as defined by Valera and Desa (1991) is the sum of the off-season and rain season areas, divided by the command or service area, expressed as a percentage.

The water productivity index (WPI) provides a measure of the irrigation systems effectiveness in terms of yield and the corresponding monetary value per volume of water applied (Valera and Desa, 1991; Pradhan, 1989). The water productivity index is usually assessed for each compartment or block seasonally; then based on this assessment the most productive section of the project is easily identified, while comparison of the water productivity indices amongst compartments within the project area will be feasible; from which improvement on

the productivity of water will be possible. The yield and water supplied according to Pradhan (1989), to the command areas are the major factors of water productivity. The relative water supply (RWS) index has been used herein. The use of the RSW as a measure of the performance of the irrigation project is because the indicator points out the water allocation and — distribution performance of the different plots or farm units. Also, irrigation efficiencies can also be estimated using this indicator, since the irrigation efficiency is the inverse of the relative water supply (Valera and Desa, 1991).

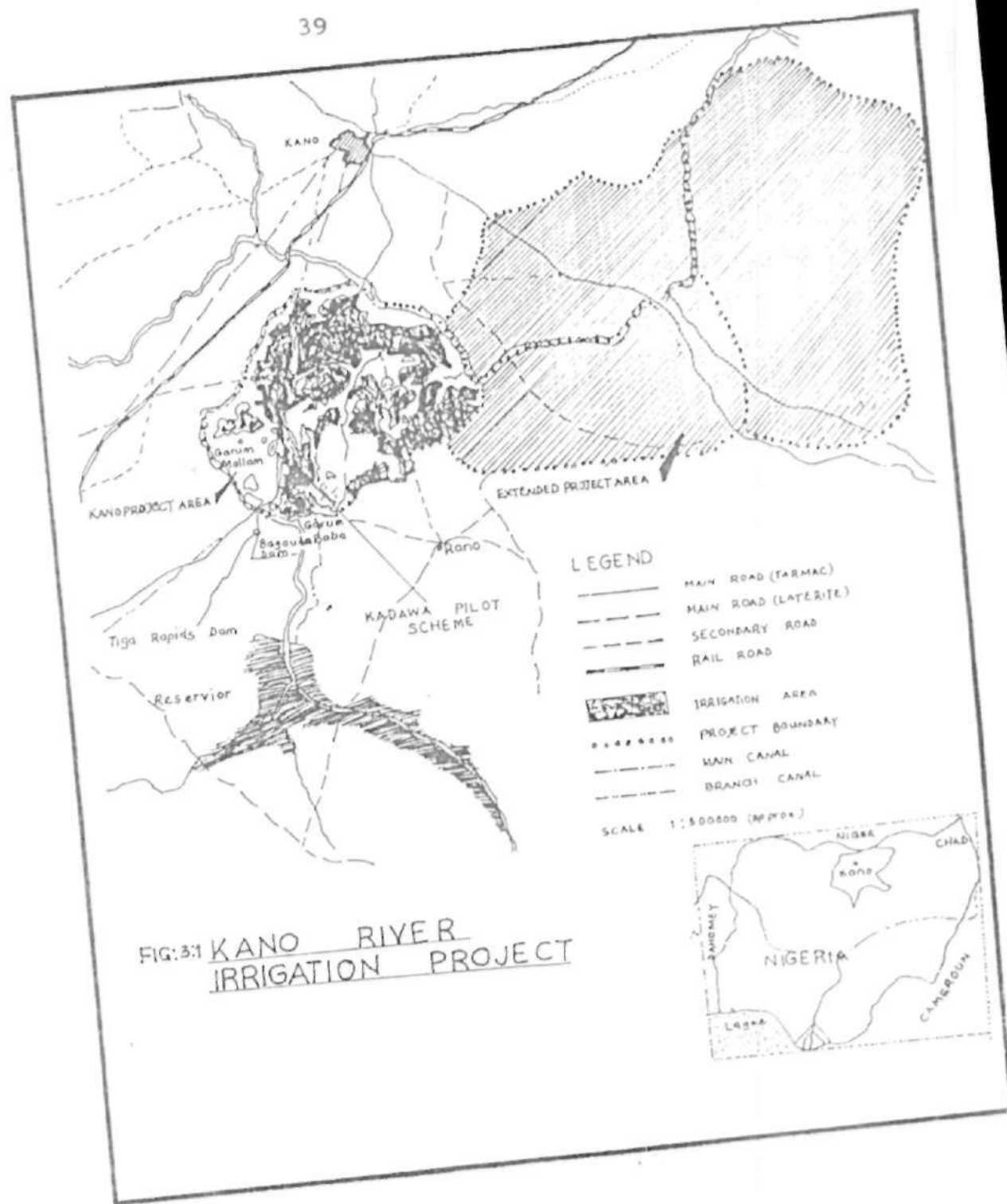
CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Location of Experimental Site

The Kano River Project (KRP), located in the Northern part of Nigeria lies between longitudes $8^{\circ} 30' E$ and $9^{\circ} 40' E$; latitude $11^{\circ} 30' N$ and $12^{\circ} 03' N$, respectively. The project, which is within the Hadejia - Jema 'are River Basin is one of the largest irrigation projects in Nigeria. It covers an approximate total area of 7.5×10^4 ha (Abdulmunin, 1988). The project is supplied with water for irrigation from the Tiga Dam, which is built on the Kano River. Irrigation water, which flows under gravity, is conveyed a distance of 22.5km from the source (Dam). Water distribution within the project is by a network of canals and turnouts as depicted in Fig. 3.1. The main canal and few laterals are lined with concrete materials, the others are unlined. The canals of varying capacities, are of trapezoidal cross-sections. The irrigation season at the project area usually starts from mid-November to early April. However, irrigation activities can extend to May. Such late irrigated crops are usually supplemented by the early rains. The main crops according to initial mandate and design were rice, tomatoes, maize and vegetables. However, with the emphasis on wheat production in Nigeria, wheat and onions

have replaced the other crops. The cropping intensity for these crops depends on the market demand and other factors. All the surface irrigation methods: basin, border, furrow and wild flooding are practiced in the Kano River Project.



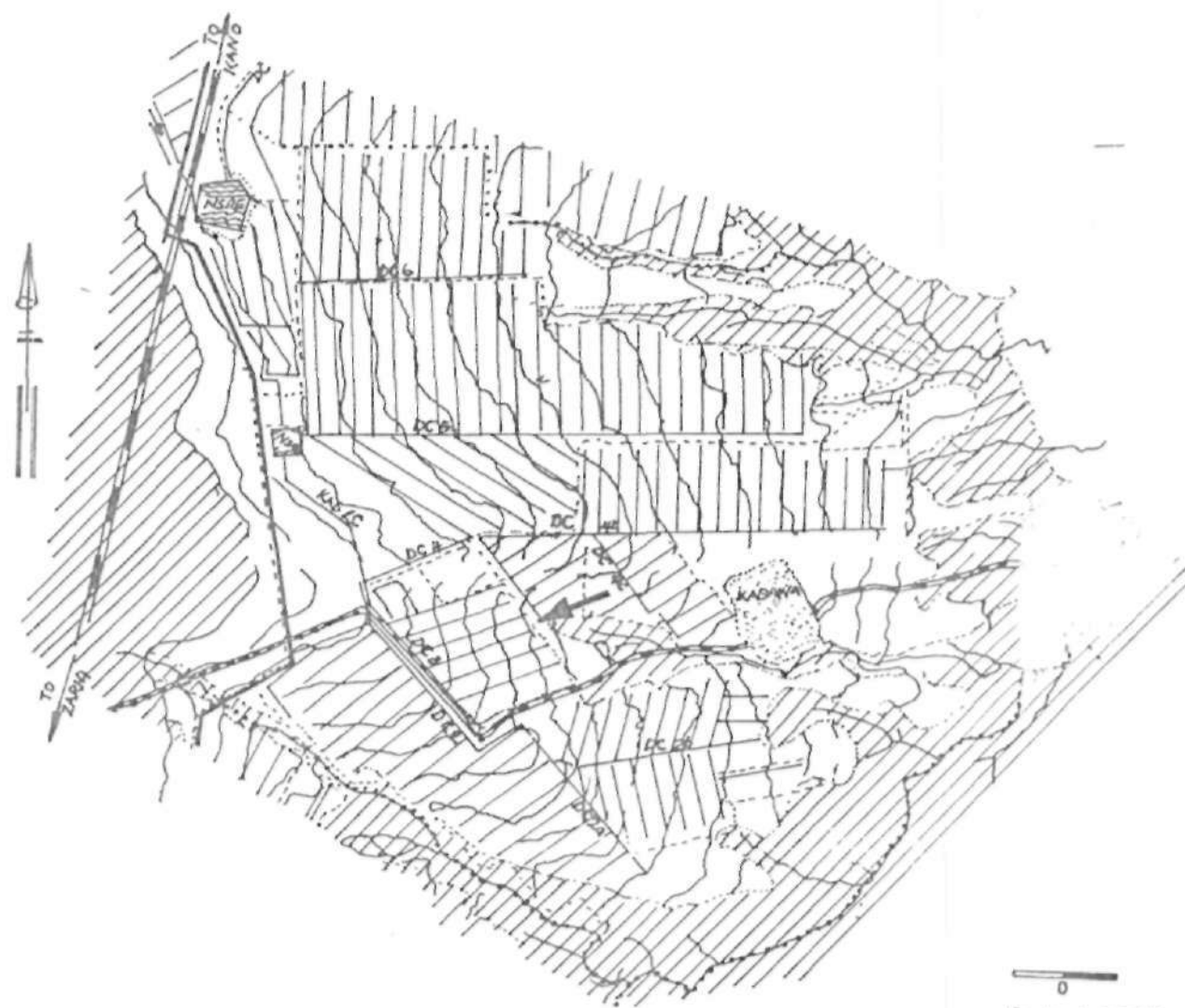
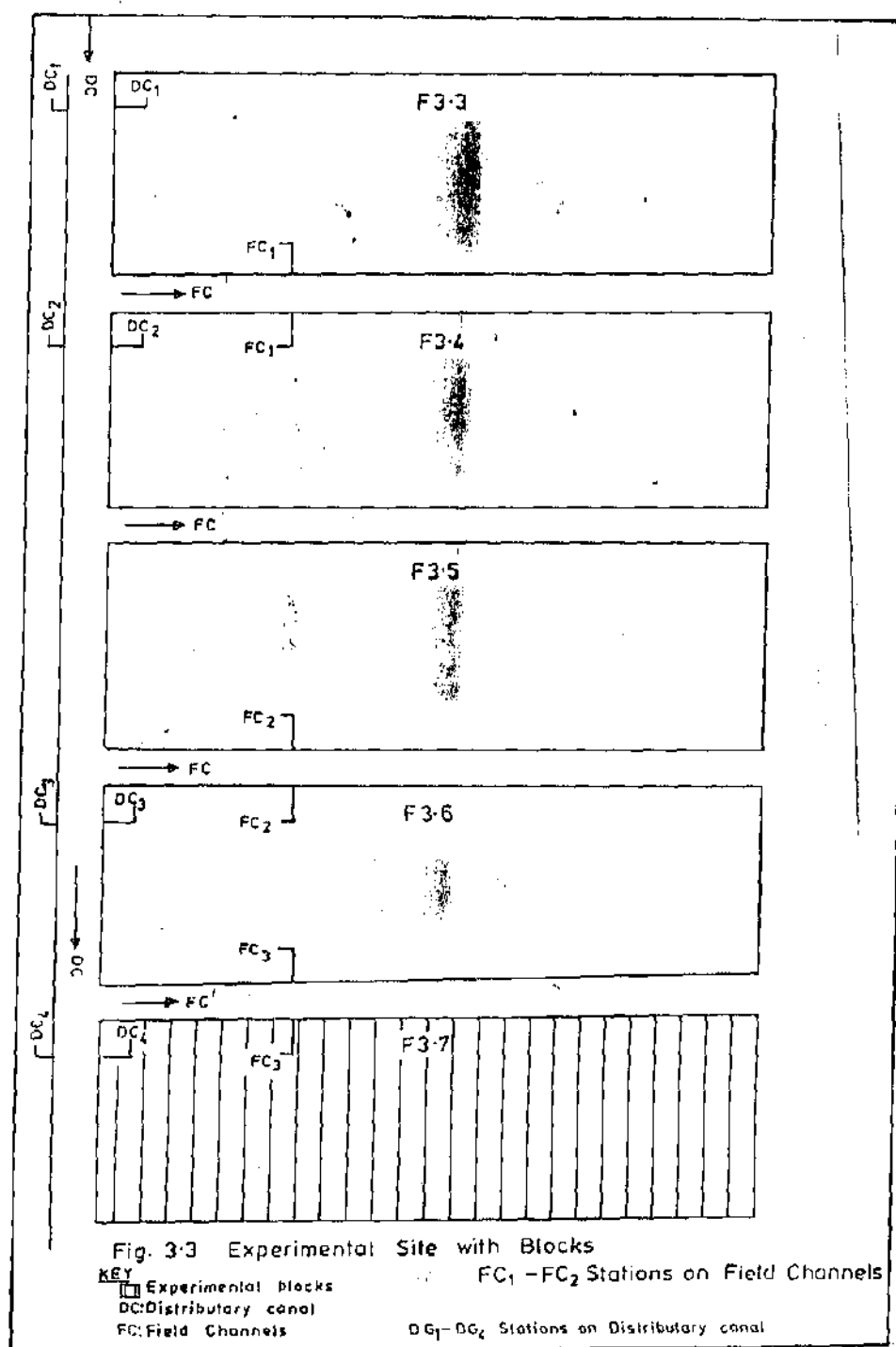


Fig.3:2 Layout map for Kadawa irrigation station showing experimental location

	RIVER
	CONTOUR LINES
	HIGHWAY
	SECONDARY ROAD
	WEST/EAST BRANCH CANAL
	LATERAL CANAL
	DISTRIBUTARY CANAL
	FIELD CHANNEL
	NIGHT STORAGE RESERVOIR
	SECTOR BOUNDARY

3.2 Experimental Set-up of the Field

The study was conducted during the 1992/93 irrigation season at the Irrigation Research Station, Kadawa, which is one of the Research Stations of the Institute for Agricultural Research, Samaru. Block 3F7 was selected as the experimental area. The field layout is given in Fig. 3.3 Instruments for recording vital measurements for the study were located at places designated as stations. Water allocation within the block were monitored and evaluated for necessary parameters throughout the irrigation season. Measurement locations were selected within the study area, taking note of areas with uniform flow and reliable geometric sections, so that approximate records could be easily established. Four different points were located on the Distributory canal (DC) Known as stations DC1, DC2, DC3 and DC4, repectively. similarly three Stations were located on field channels known as FC1, FC2 and FC3. Three other stations were located on a single field channel known as 3FC1, 3FC2 and 3FC3 (Fig;3.4). On each plot, a standard measuring device (Flume) was installed for monitoring the flow diverted. Discharge measurements were monitored for each day the farmer takes water from the field channel into the plots throughout the growing season.



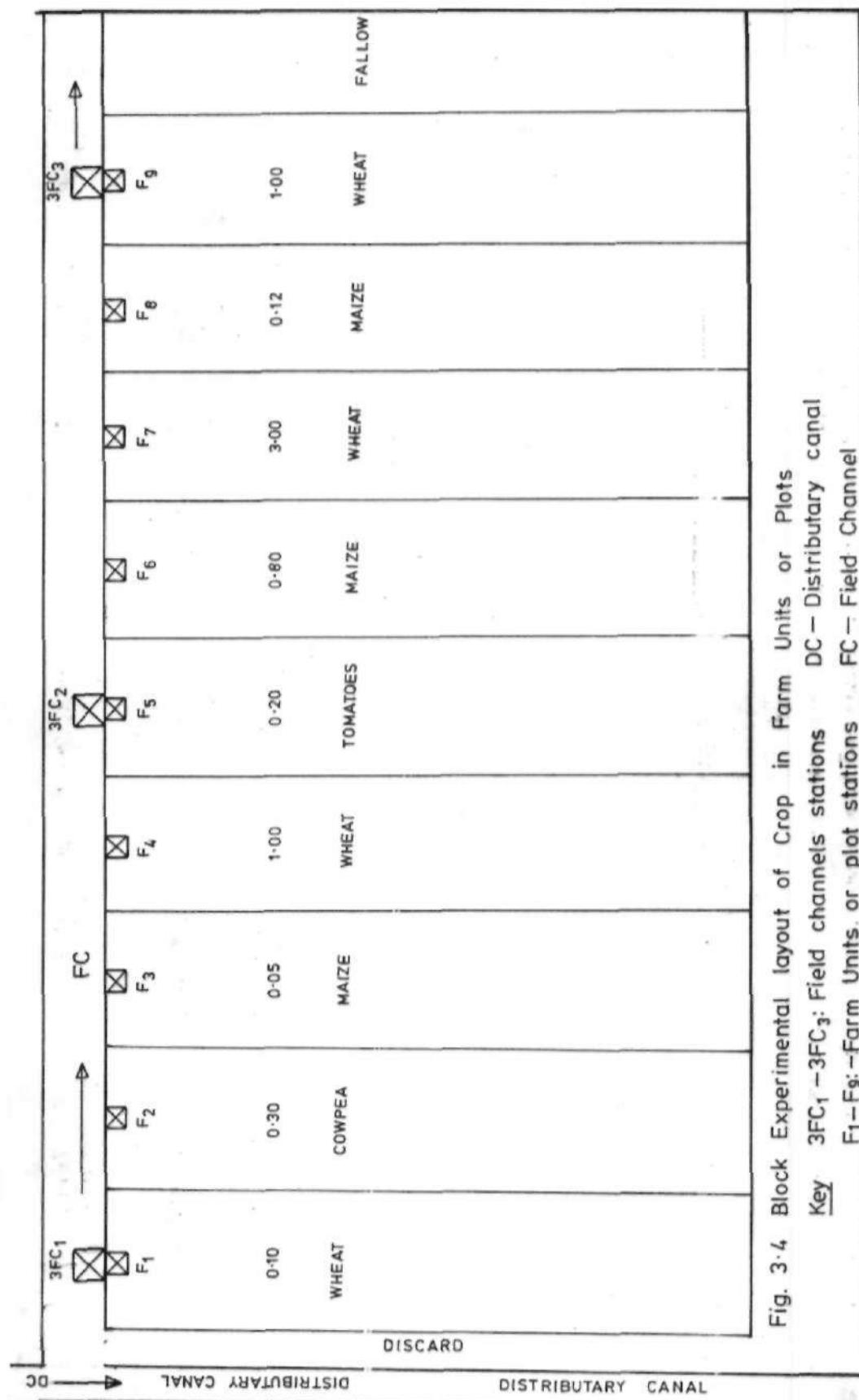


Fig. 3.4 Block Experimental layout of Crop in Farm Units or Plots

Key 3FC₁ - 3FC₃: Field channels stations DC - Distributary canal
F₁ - F₉: Farm Units or plot stations FC - Field Channel

3.3 Distributary Canal (DC) Measurements.

Four stations (DC1, DC2, DC3 and DC4) were chosen on the distributary canal supplying water to the study area (Block 3F7) in order to closely monitor flow in the canal. Station DC1 was chosen at the upstream end of the canal, stations DC2 and DC3 at the middle and station DC4 at the tail - end of the distributary canal (Fig 3.4).

The float method was used for estimating and evaluating the discharges at the stations. By using the velocity-area method of flow measurement, discharges at each station were determined. Wooden stakes of uniform size were used for this purpose. At each station, a straight and fairly clean section of the canal was chosen. Two points, 10m apart were pegged, while the float material was carefully dropped 2 to 3m away from the first point (upstream) at the centre of the channel reach. The time taken by the float to reach the downstream (second point) was noted and recorded. The distance traverse divided by the time gives the velocity. This method was repeated several times and was done three times per day for each of the four stations, during the measurement period. The velocity calculated, according to Stern (1985), is called the surface velocity. The flow velocity or average velocity through the canal depends on the flow depth and the effects of wind. The average velocity was obtained by multiplying the surface

velocity with a factor 0.75. The discharge through the canal for each station was evaluated using Eq.2.1 for each measurement period, at each of the stations, flow area was estimated, from which the discharge was then evaluated. Irrigation system conveyance efficiency (E_c) and the conveyance losses (c.l) at the selected stations on the distributary canals were, also evaluated using Eqs 2.10 and 2.11 respectively.

3.4 Field channel (FC) Discharge Measurements.

Three stations were chosen on three separate field channels (FC) supplying various blocks in the study area. Station FC1 was chosen at the upstream end of the distributary canal DC), station FC2 was at the middle and station FC3 was located at the tail-end of the distributary canal (see Fig. 3.4). Standard and calibrated 200-mm cut-throat flumes were installed at the three chosen stations FC1, FC2, and FC3, respectively. The in-flow and out-flow discharges were monitored throughout the irrigation season. Discharges at each station were evaluated using Eq. 2.7. For each station, the depth of flow into the cut-throat flume was measured at the upstream section of the flume (h_a). Using the head (h_a), equivalent discharge (Q) was established for the stations. This discharge was compared with the design discharge for the field channels of the project

area.

Rating curves for each station on the selected field channels were developed. Irrigation system distribution efficiency (E_d) for the various field channels (FC), and the distribution losses (D.L) were evaluated using Eqs 2.13 and 2.14.

Also on the field channel supplying water to the various farm units (Block 3F₇), standard cut-throat flumes were installed at selected stations 3FC₁, 3FC₂, and 3FC₃ from which discharges were monitored during the season. The irrigation system conveyance efficiency and losses along the field channel were evaluated between stations.

3.5 Farm Unit Diversions.

On each cropped farm, water use was evaluated by installing standard 100-mm cut-throat flumes to determine the discharges to the farm. The flumes were installed some distance away from drop structures, diversion structures and turn-out or gates in order to avoid splashing effects. The flume's floor should coincide with the natural channel bed slope to avoid water build-up or surging at the outflow (downstream) end of the flume (Muhammad, 1991). The depth of water at the upstream of the flume (h_a), was measured several times and averaged for each station. This was repeated for

every irrigation day. The discharge was evaluated using Eq.2.8. During each measurement for farm water use, date of irrigation, time of irrigation, time taken to irrigate and the crop yield were recorded. Earlier in the season, area of plot, type of crop grown in the plot and date of planting were all recorded. Thus farm water use was evaluated for each plot throughout the irrigation season using Eq.2.2. The seasonal irrigation water-use was evaluated from the amount of water going into the individual plots during the season.

3.6 Crop Water-Use (CWU) Measurements

The approximate design of irrigation systems and the judicious application of irrigation water in the field requires reliable information on the water requirement or consumptive-use of the particular crop. The irrigation water requirement of a crop may be defined as the maximum amount of water applied at approximate intervals, which will result in an optimum yield in both quantity and quality (Shalhavet et-al, 1976). Historical climatological data for Kadawa Irrigation Research Station for the irrigation season under review was used for evaluating the seasonal crop water requirement (CWR) for the various crops within the experimental block. Hangreave's method (Eqs 2.16, 2.17 and 2.18) was used for this purpose. The Blanney-Morin-Nigeria method (Eq 2.19)

and Pan Evaporation methods, were also used in predicting crop water requirement for the project area. The computed values of consumptive use of each crop were compared with water applied for each farm unit.

3.7 Evaluation of Water Allocation and Distribution

The methods of irrigation water allocation and distribution was monitored within the Kano River Project. Personal interactions with the farmers, field workers and irrigation officials (management) within the various sectors of the project area was adopted. Information on the various methods of water allocation and distribution problems, farmer/management preferences were also monitored.

3.8 Performance Index Evaluation.

The different performance indices: the relative water supply (RWS), the cropping intensity and the water productivity index and their effects on the rehabilitation, design and management interaction in the performance of water allocation and distribution system were determined for the project area. The relative water supply (RWS) index was evaluated for the plots within Block 3F7. Also, suggestions were made on ways to improve the relative water supply index.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

A number of parameters were considered in the field evaluation of the performance of the irrigation water distribution systems at the Kadawa sector of the Kano River Project. Meteorological data was collected from a nearby meteorological station in the area and used to compute crop water requirement for the various crops grown on different farm plots in the experimental fields. For the purpose of comparison, three empirical formulae were used namely Hargreaves (1974) Blanney-Morin - Nigeria (1980), and the Pan Evaporation method. Discharges at selected stations on the distributary canal and field channels were monitored during the same period from which the conveyance and water distribution efficiencies and losses were determined. Rating curves for the selected stations on the field channels were also developed. The relative water supply (RWS) measure, was evaluated for the area, while water applied depth was related to the crop yield was also monitored.

4.2 Distribution Canal Efficiencies

The design of the distributary canal (DC) as a water distribution system in the Kano River Project by NEDECO (1973) was based on the efficient performance and adequate canal capacity to convey the desired flow.

Consequently, average discharge were monitored through the selected stations designated as DC1, DC2, DC3 and DC4 on the distributary canal. The results obtained are given in Table 4.1. The results show a decrease in the discharge from the head-end to the tail-end of the distributary canal. This could be due to factors such as canal seepage, outgrown weeds, siltation and illegal diversions.

However, high discharges were recorded in the early parts of the day and later part than afternoons. This was notably due to few irrigation activities in the early and later part of the day, compared to the afternoons. The average discharge varies from 67 l/s to 102 l/s as shown in Table 4.1.

Table 4.1: Summary of Daily Discharges Recorded at Different Stations on the Distribution Canal (D.C.) (l/s)

Date	DC1	DC2	DC3	DC4
18-5-93	101	100	73	67
19-5-93	103	99	81	68
20-5-93	98	93	78	68
21-5-93	104	103	80	65
22-5-93	102	100	78	67
23-5-93	104	102	77	66
24-5-93	105	104	83	69
Total	717	611	550	470
Average	102	87	79	67
Standard Error	2.2	15.0	2.8	1.2

Table 4.2: Distributary Canal Losses and Efficiencies

Date	DC1- DC2, L/S	DC2- DC3, L/S	DC3- DC4, L/S	DC2- DC1, %	DC3- DC2, %	DC4- DC3, %
18-5-93	1	27	6	99.0	73.0	91.8
19-5-93	4	18	13	96.1	81.8	84.0
20-5-93	5	15	10	94.9	83.9	87.0
21-5-93	1	23	25	99.0	77.7	81.3
22-5-93	2	22	11	98.0	78.0	88.5
23-5-93	2	25	11	98.1	75.5	85.7
24-5-93	1	21	14	99.1	79.8	83.1
Total	16	151	90			
Ave- rage	3	24	13	97.7	78.5	85.9
Stand ard Error	1.8	4.7	5.8			

The conveyance efficiency of the distributary canal was found to be fluctuating. However, the average conveyance efficiency ranged from 78.5% to 97.7% for the measurements on different days and time. The range of conveyance efficiency shown in Table 4.2 above, is found to be too wide and below the design conveyance efficiency of 98% reported by NEDECO (1973). This could be attributed mainly, to a number of factors such as seepage losses through damaged canal banks and high evapotranspiration losses due to out-grown weeds as

reported by Adewumi (1985). The inability to maintain a constant head of water throughout the period of measurements at the release gates could also be a factor. The method employed in the discharge measurements especially where there are damages in the canal sections and geometry due to siltation, weed growth and section of the canal irregularities could also lead to the low conveyance efficiencies.

The conveyance losses of the canal was evaluated for the various stations as the difference in discharge between the first station and the preceeding stations. The results obtained are shown in Table 4.2. The results reveal varied conveyance losses and this trend increases downstream. The average conveyance loss ranges from 3.0 l/s to 24 l/s. The highest average conveyance loss was recorded for the distributary canal which can be attributed mainly to the general lack of maintenance of the canal structures, notably damaged banks, borrow pits and outgrown grasses within the canals.

The conveyance efficiency of the distributary canal (E_c) was also evaluated as the ratio of the outflow to the inflow discharges expressed as a percentage. A summary of conveyance efficiency for the selected stations on the distributary canal is shown in Table 4.2. above. The results indicate a general decrease downstream along the canal. However, an average overall

conveyance efficiency of about 87.4% was obtained for the distributary canal as against the 90.3% reported by Adewumi (1985) and 98% by NEDECO (1973). This shows a remarkable reduction in the conveyance efficiency of the distributary canal. The water distribution systems performance of the Kano River Project cannot be accepted as satisfactory since shortage of irrigation water in some parts of the project area will eventually result in the reduction of land that can be put under irrigation.

4.3 Field Channel (FC) Discharge Efficiency

The different field channels on the experimental farm were selected and the measurement stations were designated as FC1, FC2, and FC3, respectively. The discharges were measured for the stations and given in Tables 4.3, 4.4 and 4.5. The results for the three stations revealed a decrease in discharge from station FC1 to FC3. The average discharges recorded at these stations were 18.2 l/s, 16.2 l/s and 10.8 l/s respectively. The results show a general decrease in the discharge as compared to NEDECO (1973), design discharge range of 28 l/s to 36.6 l/s. The result also shows a general decrease in the discharge from the head-end to the tail-end of the farms or distributary canal given in Tables 4.3, 4.4 and 4.5. The rating curves developed for the three field channels are as shown in Figs. 4.1, 4.2

and 4.3. The overall average discharges for the field channels was evaluated as 16.3 l/S, while the average discharge of the distributary canal supplying the field channels was 18.7 l/S. The distribution efficiencies (Ed) for the field channels from the distributary canal were evaluated as 86.5%, and 54.9%, while the distribution losses (D.L.) were 5.5 l/S, and 7.7 l/S

Table 4.3: Field Channel Discharge Records for Station: FC1

Date	Upstream Height (ha) (cm)	Discharge Q (l/S)
26-11-92	16.5	22.2
7-12-92	14.0	17.4
18-12-92	12.5	14.7
29-12-92	13.0	15.6
12-1-93	11.0	12.1
21-1-93	12.0	13.8
9-2-93	14.5	18.3
19-2-93	11.5	13.0
27-2-93	17.0	23.3
1-3-93	16.5	22.3
11-3-93	17.0	23.3
16-3-93	16.5	22.3
21-3-93	14.0	17.4
26-3-93	15.5	20.0
1-4-93	17.0	23.3
Total		280.8
Average		18.7
Standard error		0.6

Table 4.4: Field Channel Discharge Records Station FC2

Date	Upstream Height ha (cm)	Discharge Q (L/S)
26-11-92	16.0	21.3
7-12-92	13.0	15.6
18-12-92	10.0	10.5
29-12-92	12.0	13.8
12-1-93	9.0	9.0
21-1-93	11.5	13.0
9-2-93	12.5	15.0
19-2-93	10.0	10.5
27-2-93	16.0	21.3
1-3-93	15.5	20.0
11-3-93	16.0	21.3
16-3-93	15.0	19.3
21-3-93	12.5	14.7
27-3-93	14.5	18.3
1-4-93	15.5	20.0
Total		234.6
Average		16.2
Standard Error		2.7

Table 4.5: Field Channel Discharge Records Station: FC3

Date	Upstream Height ha (cm)	Discharge Q (L/S)
26-11-92	14.0	17.4
7-12-92	8.5	5.2
18-12-92	7.5	6.8
29-12-93	8.0	7.5
12-1-93	8.0	7.5
21-1-93	11.0	10.5
9-2-93	11.0	12.1
19-2-93	7.5	6.8
27-2-93	8.5	8.2
1-3-93	13.0	15.6
11-3-93	9.0	9.0
16-3-93	13.5	16.5
21-3-93	9.5	9.7
26-3-93	11.0	12.1
1-4-93	12.5	14.7
Total		162.7
Average		10.8
Standard Error		3.5

Table 4.6: Summary of Discharge at Stations FC1 FC2 And FC3 on Different Channels (L/S)

Stations			
Date	FC1	FC2	FC3
26-11-92	22.25	21.25	17.4
7-12-92	17.39	15.56	8.2
18-12-92	14.67	10.50	6.8
29-12-92	15.56	13.80	7.5
12-1-93	12.11	8.96	7.5
9-2-93	18.30	14.67	12.1
19-2-93	12.95	10.50	6.8
27-2-93	23.27	21.25	8.2
1-3-93	22.25	20.63	15.6
11-3-93	22.27	21.25	9.0
16-3-93	22.25	19.26	16.5
21-3-93	17.39	14.67	9.9
26-3-93	20.03	18.33	12.1
1-4-93	23.27	20.03	14.7
Total	280.79	243.01	162.7
Average	18.72	16.20	10.8

Table 4.7: Distribution Efficiency (Ed) and Distribution Losses (DL) for Field Channels FC1 FC2 and FC3

Distribution Efficiency			Distribution Losses DL			
Date	FC1 vs FC2, %	FC1 vs FC3, %		FC1- FC2, l/S	FC2- FC3, l/S	FC1- FC3, l/S
26-11-92	95.51	78.20		1.1	3.9	4.9
7-12-93	89.48	47.27		1.8	7.3	9.2
18-12-93	71.58	46.35		4.2	3.7	7.9
29-12-92	88.68	48.27		1.8	6.3	8.1
12-1-93	74.00	62.01		3.2	1.5	4.6
21-1-93	93.84	76.10		0.9	2.5	3.3
9-2-93	80.36	66.12		3.6	2.6	6.2
19-2-93	81.05	52.25		2.5	3.7	6.2
27-2-93	91.28	35.37		2.0	13.0	15.0
1-3-93	91.24	70.11		2.2	4.4	6.7
16-3-93	86.56	74.16		3.0	2.8	5.8
21-3-93	84.36	55.89		2.7	5.0	7.7
26-3-93	91.51	60.41		2.3	6.2	7.9
1-4-93	86.08	63.17		3.22	5.3	8.6
Total	-	-		34.6	80.3	116.1
Ave- rage	86.45	53.87		2.3	5.4	7.7

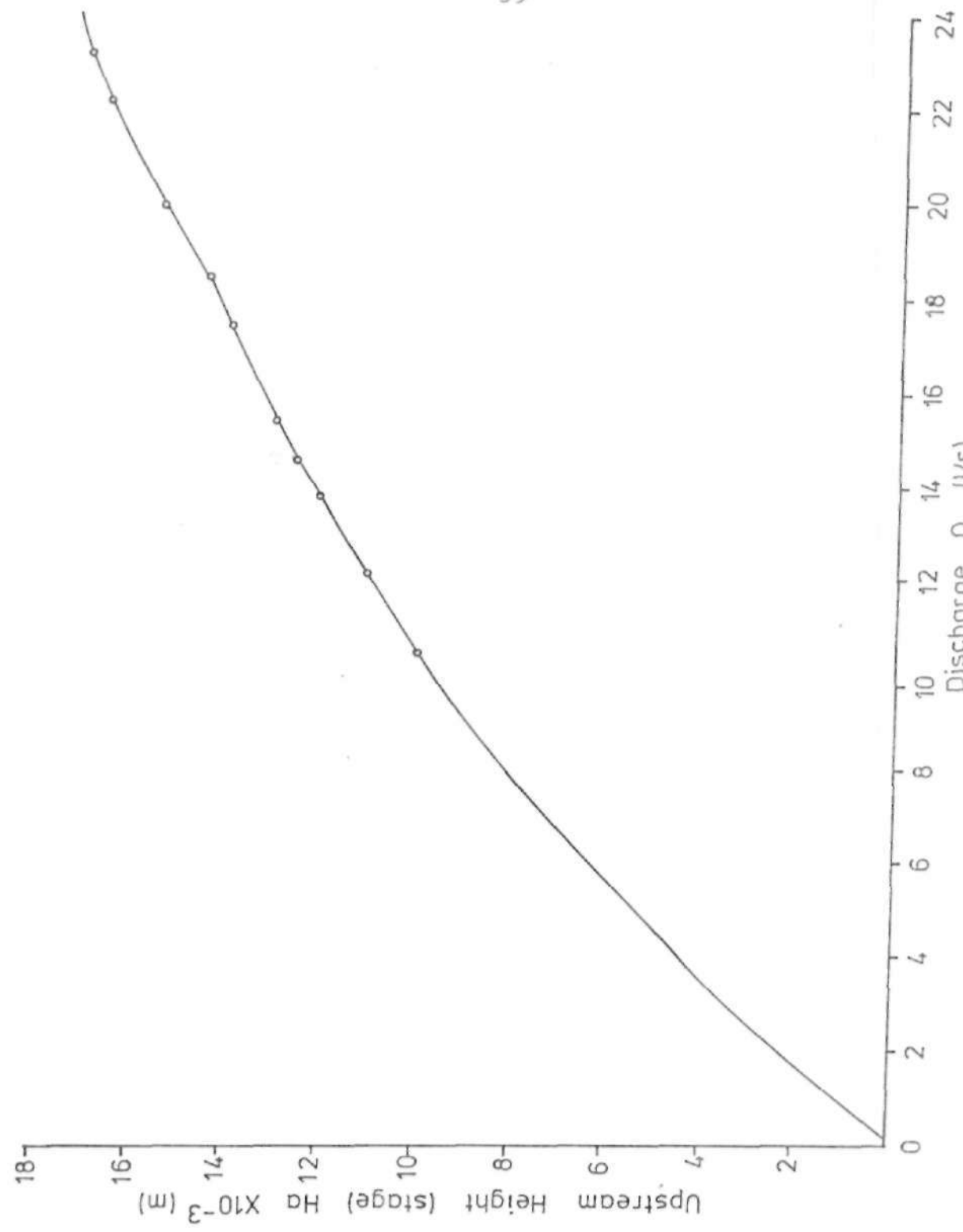


Fig. 4.1 Calibration Curve for Station FC1

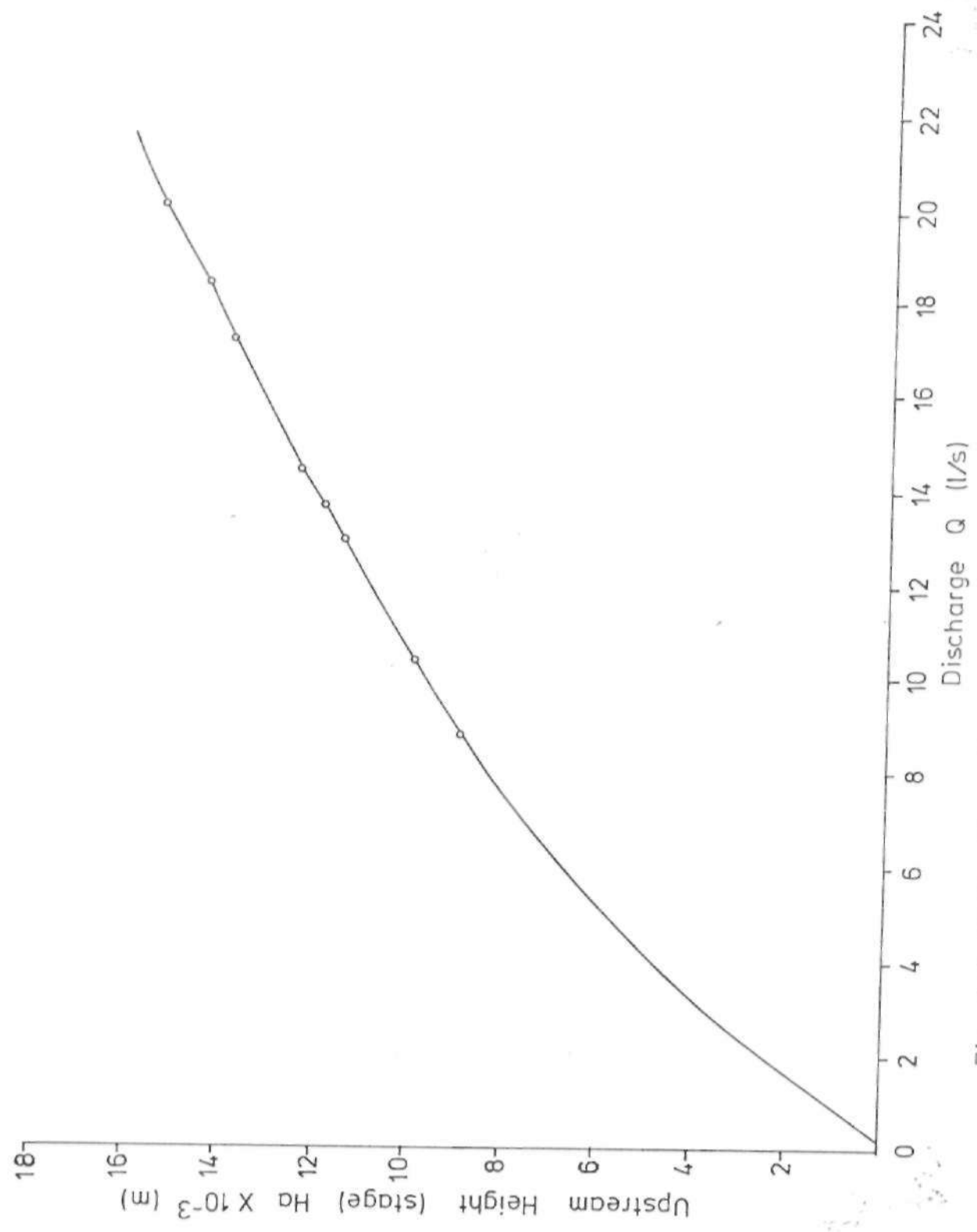


Fig. 4.2 Calibration Curve for Station FC2

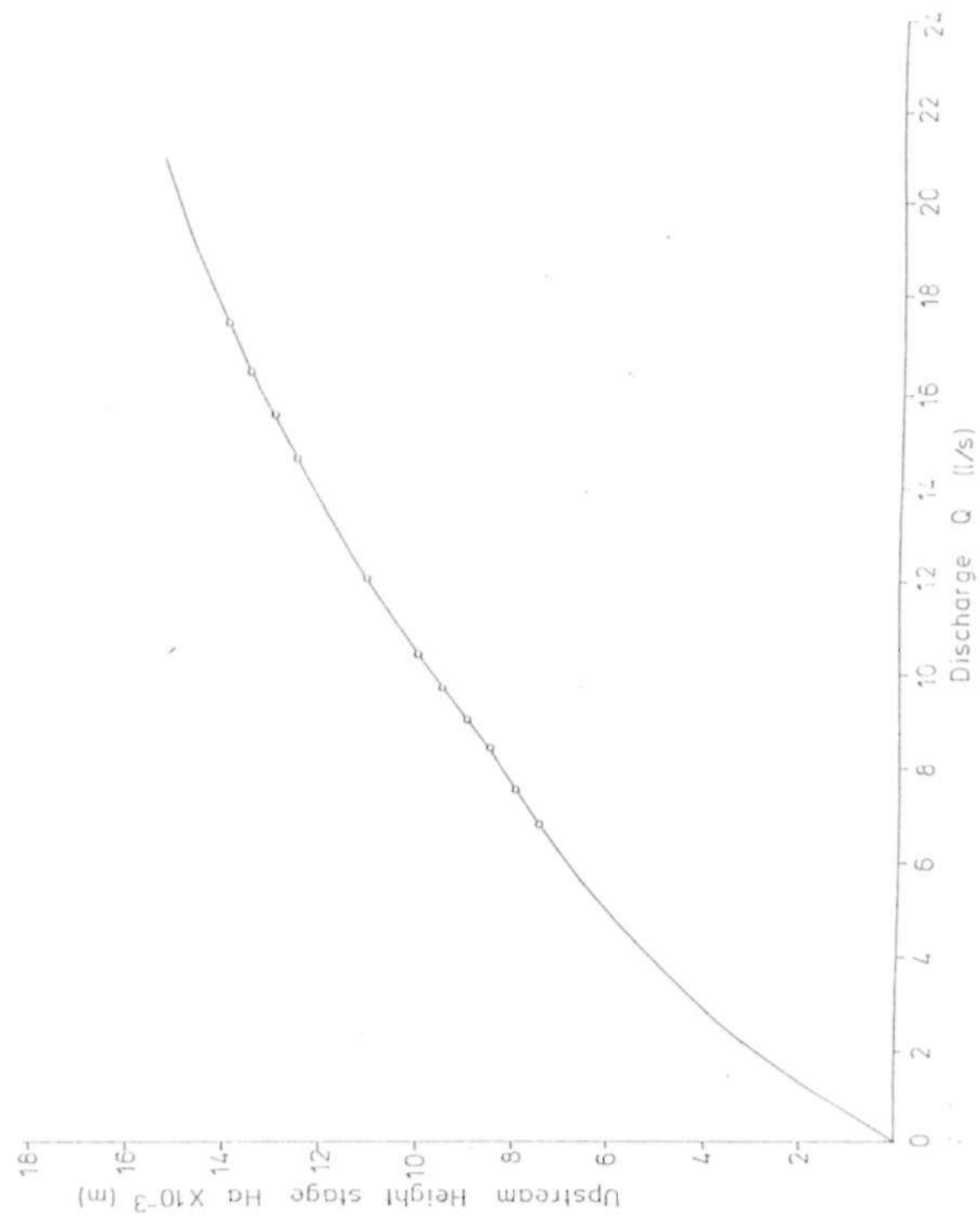


Fig. 4.3 Calibration Curve for Station FC3

(Tables 4.6 and 4.7). The results indicate that the field channel at the head-end of the distributary canal has a higher conveyance efficiency than that at the tail-end of the farm. The conveyance losses increased from the head-end of the distributary canal to the tail-end of the farm. This shows that water distribution favours field channels at the head-end of the farm only and hence, these receive and convey more irrigation water than those at the tail-end of the farms. Also the results of the distribution losses (DL), were found to increase from the head-end to the tail-end of the farm or distributary canal. Thus, farms at the tail-end receive less irrigation water due to these losses. The result also show that the performance of the irrigation water distribution system of Kano River Project is not satisfactory. The low distribution efficiency which occurs as a result of the high water distribution losses within the project area could be due to factors such as; illegal diversions from the distributary canals, faulty diversion structures and leaking control gates. Water distribution and allocation within the project area is therefore not equitable. Equity of water distribution within the project area was evaluated to be as low as 13.6% on the average. The results of discharge measurements on three stations on a single field channel obtained are presented in Tables 4.8, 4.9 and 4.10, and

the rating curves are given in Figs. 4.4, 4.5 and 4.6.

Table 4.8: Field Channel Discharge Records Station; 3FC1

Date	Upstream Height ha (cm)	Discharge Q L/S
26-11-92	14.0	17.4
7-12-92	8.5	8.2
18-12-92	7.5	6.8
29-12-92	8.0	7.5
12-1-93	8.0	7.5
21-1-93	10.0	10.5
9-2-93	11.0	12.1
19-2-93	7.5	6.8
27-2-93	8.5	8.2
1-3-93	13.0	15.6
11-3-93	9.0	9.0
16-3-93	13.5	16.5
21-3-93	14.0	17.4
26-3-93	11.0	12.1
1-4-93	12.5	14.7
Total		170.3
Average		11.4
Standard Error		3.7

Table 4.9: Field Channel Discharge Records Station: 3FC2

Date	Upstream Height ha (cm)	Discharge Q (L/S)
22-11-92	12.5	14.7
7-12-92	8.2	7.9
18-12-92	6.0	4.9
29-12-92	7.0	6.2
12-1-93	6.0	4.9
21-1-93	9.0	9.0
9-2-93	9.0	9.0
19-2-93	3.2	1.90
27-2-93	7.0	6.1
1-3-93	11.0	12.1
11-3-93	8.0	7.5
16-3-93	9.0	8.9
21-3-93	12.0	13.8
26-3-93	8.5	8.2
1-4-93	10.4	11.1
Total		126.1
Average		8.4
Standard Error		3.2

Table 4.10: Field Channel Discharge Records Station:
3FC3

Date	Upstream Height ha (cm)	Discharge Q (l/s)
26-11-92	8.2	7.9
7-12-92	4.0	2.7
18-12-92	3.0	1.7
29-12-93	3.5	2.2
12-1-93	4.0	2.7
21-1-93	6.0	4.9
9-2-93	5.0	3.7
19-2-93	1.0	0.3
27-2-93	3.0	1.7
1-3-93	4.0	2.7
11-3-93	3.5	2.2
16-3-93	5.2	3.9
21-3-93	6.0	4.9
26-3-93	7.0	6.2
1-4-93	8.5	8.2
Total	17.4	55.7
Average		3.7
Standard Error		1.9

Table 4.11: Summary of Discharge at Stations 3FC1, 3FC2 and 3FC3 on a Field Channel in (l/s)

Station		Discharges	
Date	3FC1	3FC2	3FC3
26-11-92	17.5	14.7	7.9
7-12-92	8.2	7.9	2.9
18-12-92	6.8	4.9	1.7
29-12-93	7.5	6.2	2.2
12-1-93	7.5	4.9	2.7
21-1-93	10.5	9.0	4.9
9-2-93	12.1	9.0	3.7
19-2-93	6.8	1.9	0.3
27-2-93	8.2	61.5	1.7
1-3-93	15.6	12.1	2.7
11-3-93	9.0	7.5	2.2
16-3-93	16.5	9.0	3.9
21-3-93	17.4	13.8	4.9
26-3-93	12.1	8.2	6.2
1-4-93	14.7	11.1	8.2
Total	170.3	126.1	55.7
Average	11.4	8.4	3.7
Standard Error	3.7	8.4	1.9

The values of the discharges measured at a station showed remarkable variations. This implies that the discharges through a station varied with time. A comparison between the three stations (3FC1, 3FC2 and 3FC3), also indicates decrease in discharge from the head-end and the tail-end of the farm, respectively. These results are consistent with those obtained by

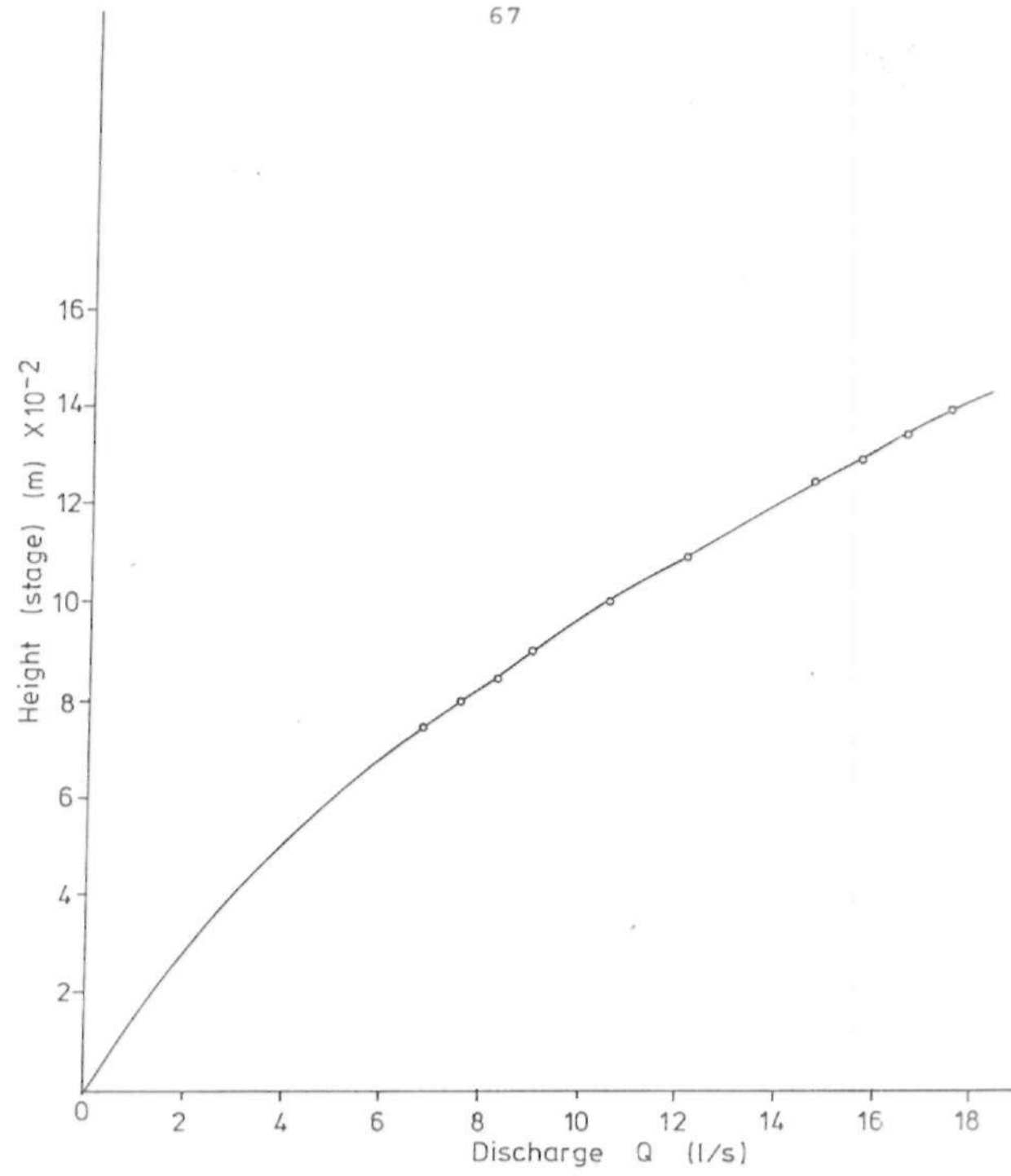


Fig. 4.4 Calibration Curve for Station 3FC1

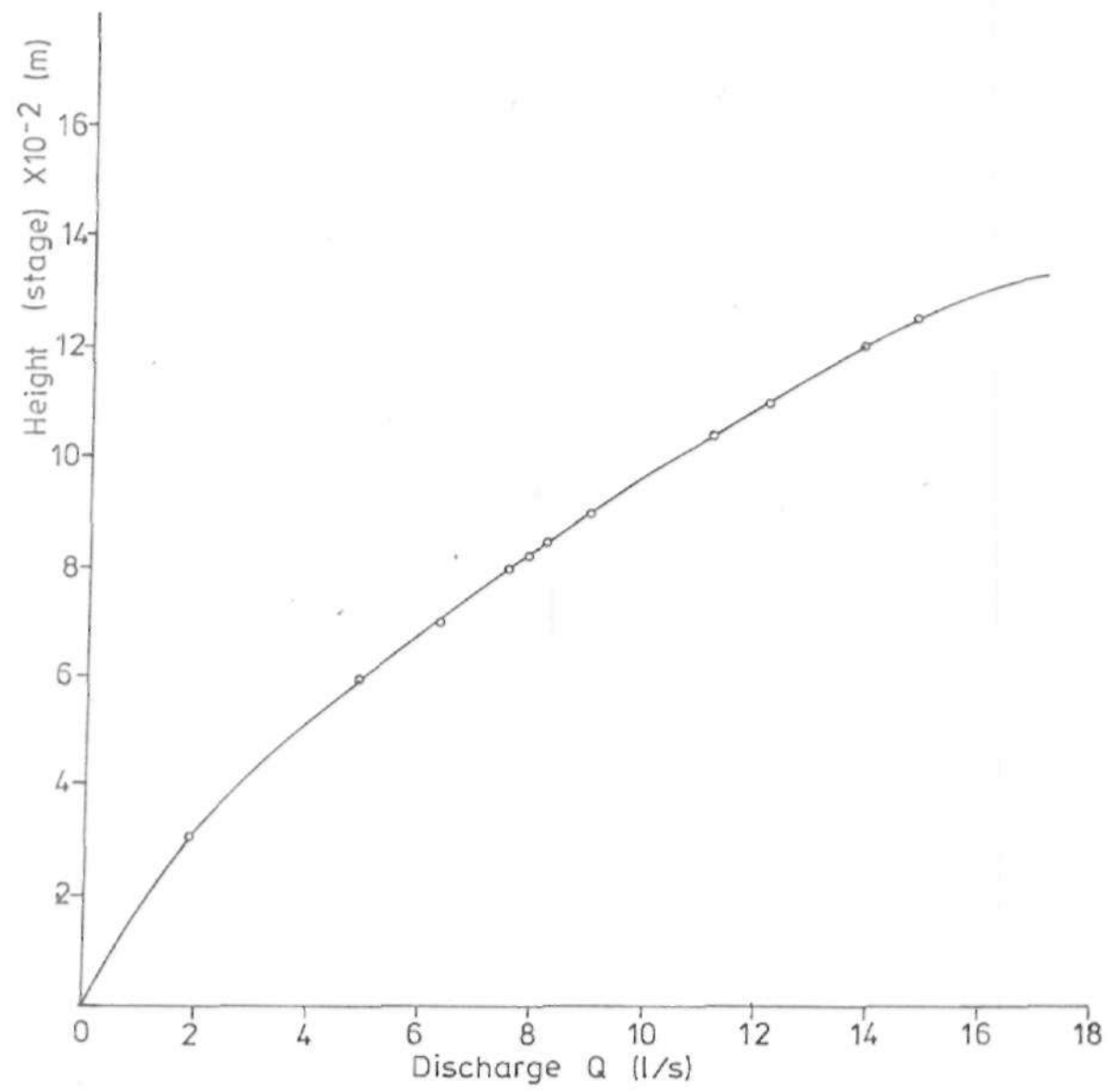


Fig. 4-5 Calibration Curve for Station 3FC2

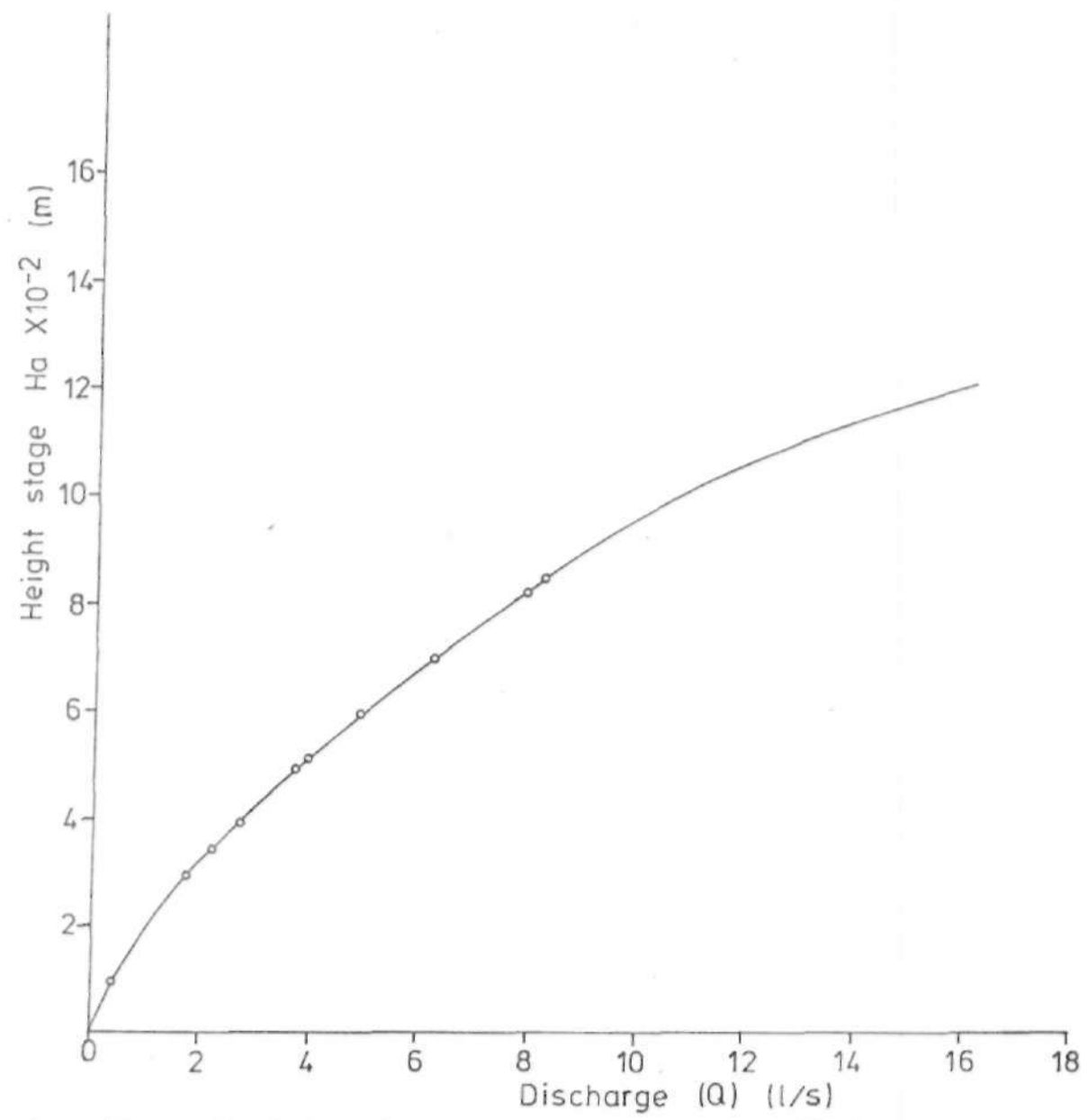


Fig. 4-6 Calibration Curve for Station 3FC3

Adewumi (1985), Maurya and Sachan (1985), and Muhammad (1991) which suggest that the fields close to the water source in the Kano River Project, generally, stand a better chance of getting more irrigation water than those far away.

The field channels of the project area was designed to carry an average discharge of about 30 l/s at a bed slope of 0.1% (NEDECO, 1973). However, field measurements gave an average discharge of 11.4 l/s at the head-end of the block. This was found to decrease downstream. The field channel conveyance losses were also determined for different days and throughout the irrigation season. The flow through the station 3FC1 was considered as the inflow, while the subsequent ones, as the outflow. The conveyance loss between any two stations was evaluated as the difference between the inflow and the outflow. On the first day of irrigation (26 - 11 - 92), the conveyance losses for the field channel were 2.7 l/s and 6.8 l/s for stations 3FC1 to 3FC2, and 3FC2 to 3FC3, respectively. The conveyance losses for the other days are given in Table 4.12. The average seasonal conveyance losses of 3.0 l/s and 5 l/s was recorded for the field channel at the designated stations stated above. The reliability of the field channel was also evaluated for the purpose of conveyance

Table 4.12: Summary of Field Channel Conveyance Losses and Conveyance Efficiency

Date	Channel losses between 3FC1 and 3FC2 (l/s)	Losses between 3FC2 and 3FC3 (l/s)	Conveyance efficiency between 3FC1 and 3FC2 (%)	Conveyance efficiency between 3FC2 and 3FC3 (%)
26-11-92	2.7	6.8	84.31	53.58
7-12-92	0.4	5.2	95.62	33.84
18-12-92	1.9	3.2	71.76	35.45
29-12-92	1.4	4.0	81.89	35.28
12-1-93	2.6	2.2	64.98	54.51
21-1-93	1.5	4.1	85.33	54.46
9-2-93	3.5	5.3	88.71	41.41
19-2-93	4.9	1.6	31.15	15.79
27-2-93	2.1	4.4	74.73	28.13
1-3-93	3.5	9.4	77.56	21.98
11-3-93	1.5	5.3	83.82	28.89
16-3-93	7.5	5.0	54.30	43.94
21-3-93	3.6	8.9	79.31	35.36
26-3-93	3.8	2.1	67.93	74.82
1-4-93	3.57	2.91	75.71	73.85
Total	44.2	70.4	74.05	44.18
Average	3.0	4.7	74.03	44.23

efficiency. This was determined as the ratio of outflow to inflow discharges, expressed as a percentage. A summary of the field channel conveyance efficiency (E_c) at the selected stations (3FC1, 3FC2, 3FC2) given in Table 4.12 shows a decrease in efficiency downstream. However, an average field channel conveyance efficiency

for the entire period of measurement was found to be 58% which is 4.32% less than that obtained by Adewumi (1985). The field channels losses were assumed to be about 11.0 l/s by NEDECO (1973), but the field measurements reported herein gave a value of about 41 l/s. This value is also greater than the value of 18.3 l/s reported by Muhammed (1991). A comparison of the design losses and those obtained from field measurements indicate that the operation of the distribution systems within the project area, are below expectations.

A number of reasons could be attributed to the variations in discharge and low values of efficiencies for the water distribution system within the study area. Since the field channels were unlined and erodible, the channels were infested with aquatic weeds, which retarded flow through the channels. The channel sections, which were trapezoidal in shape, according to design, have gradually become parabolic in shape; which could have reduced the discharges. Most of the diversion gates at the field turnouts were not functional, thus, allowing continuous flow of water through damaged points, and thus reducing the discharge downstream. Also, indiscriminate and illegal diversions of water by farmers, through channel banks "cuttings" divert part or the whole water to individual farm units. These damaged banks after closing, provide permanent seepage points from the

channels. Investigations amongst farmers and field workers, revealed that irrigators either do not want to use the recommended Siphon tubes or they are not provided with any, by management. These were the reasons given by farmers for illegal "cutting" of the channel banks in addition to the general complaints that more time is wasted when Siphon tubes are used.

Insufficient water supply at the tail-end of the field channel is sometimes due to complete blockage of water flow in the channel by the upstream farmers in order to divert the whole water into their farm units. Such blockages which often take long time, deny all the farmers at the tail-end of the field channel the right of water use. Another problem is the issue of damages done by cattle to canal banks. These damaged banks usually result in permanent seepage at canal banks and/or overflow, reducing flow and discharge in the field channels.

4.4 Farm Units Discharge Records

Farm units are individual plots owned by farmers or group of individuals. These units add up to a block. Block 3F7, was selected for the purpose of monitoring the water-use by each farm unit (Fig. 3.3). Each farm unit was taken as a measurement station and designated by the prefix F (Fig. 3.4). The experimental block which is ~~made up of nine farm unit~~ designated as F1 to F9, was monitored for discharge measurements. The measurements obtained for fam units F1, F2, F3, and F5 are given in Tablea 4.13, 4.14, 4.15 and 4.16, while the others are presented in Appendix E. The farm units (plots) were cropped to different crops. The parameters determined for each farm units were irrigation date, time used for irrigation, irrigation intervals and numbers, type of crop grown and the area of the unit in the study area

Table 4.13: Discharge, Volume and Depth of Water Applied to Farm Unit F1
Crop. Wheat Area = 0.01 ha.

mm/day						calculated CWR		
Date	Time used to irrigate (min)	Upstream Height (cm)	Discharge Q (m ³ /5) 10-4	Volume Applied QT (m ³)	Depth Applied % (mm)	HE	BMN	PAN
26-11-93	2.8	3.4	0.5712	1.90	-	-	-	-
7-12-93	2.4	4.0	4.2	0.67	2.02	4.5	5.2	1.6
18-12-93	2.5	3.8	3.9	0.59	1.95	5.5	4.4	2.6
29-12-93	1.8	4.8	3.5	0.60	1.98	5.0	4.8	4.1
12-1-93	1.5	5.0	5.9	0.53	1.77	5.6	6.3	6.1
21-1-93	1.8	3.8	3.9	0.52	1.74	4.1	4.5	4.0
9-2-93	1.8	4.5	5.0	0.54	1.80	7.7	9.8	8.2
19-2-93	1.5	4.0	4.2	0.38	1.26	4.0	5.3	4.9
1-3-93	2.5	3.5	3.4	0.51	1.76	5.5	4.8	2.2
Total				4.84	16.12	388	451	338
Average				0.54	1.79	48	56	42
Standard error				0.06	0.17	10	14	18

Date	Time used to Irriga ted (min)	Upstre am Height ha cm	Dischar ge Q (cm ³ /6) x 10 ⁻⁴	Volume Applied QT (m ³)	Depth Applied d (mm)	HE	BMN	Pan
1-3-93	9.0	3.0	2.7	1.456	19.44	-	-	-
11-3-93	8.6	3.8	3.9	1.87	24.96	63	42	58
16-3-93	75	3.3	3.1	1.40	18.60	30	29	29
21-3-93	80	4.0	4.2	2.02	26.88	30	37	32
26-3-93	80	3.5	3.4	1.63	21.76	30	28	19
1-4-93	78	4.0	4.2	1.97	26.21	36	30	35
15-4-93	79	2.8	2.5	1.19	15.80	84	83	73
22-4-93	58	3.8	3.9	1.36	18.09	49	39	39
28-4-93	50	3.5	3.4	1.02	13.60	39	31	16
3-5-93	53	4.0	4.2	1.34	17.81	30	23	18
Total			35.5	15.20	203.15		342	320
Average			3.6	1.52	20.32	391	38	36
Standard Error			0.46	0.31	4.13	43	13	16
Error						16		

Table 4.15: Discharge, Volume and Depth of Water Applied to Farm Unit - F3
 Crop - Maize.
 Area - 0.05 ha.

Date	Time used to Irrigate (min)	Up-Strm Height ha (cm)	Disch. Q (m ³ /s x10 ⁻⁴)	Volm. Appld. Qt (m ³)	Depth Appld. d (mm)	Calculated Water HE	Daily requirement BMN	Crop Pan
26-11-92	23	3.5	3.4	0.48	6.25	-	-	-
7-12-92	20	4.0	4.2	0.50	6.72	21	33	26
18-12-92	22	3.0	2.7	0.36	4.75	48	58	74
29-12-92	15	3.5	3.4	0.31	4.08	31	38	54
12-1-93	16	3.8	3.9	0.37	4.99	42	73	75
9-2-93	14	3.8	3.9	0.33	4.37	96	98	111
19-2-93	15	3.0	2.7	0.24	3.24	60	52	66
1-3-93	16	4.0	4.2	0.40	5.38	64	50	67
11-3-93	17	3.5	3.4	0.35	4.62	70	27	62
16-3-93	16	3.3	3.1	0.30	3.97	35	15	33
21-3-93	19	4.0	4.2	0.48	6.38	35	16	32
26-3-93	16	3.5	3.4	0.33	4.35	35	18	26
1-4-93	15	3.0	2.7	0.24	3.24	39	19	38
Total			49.4	5.08	67.72	622	553	711
Average			3.5	0.36	4.89	48	43	55
Standard Error			0.46	0.06	0.99	17	21	21

Table 4.16: Discharge, volume and Depth of Water Applied to Farm Unit - F5
 Crop: Tomato
 Area: 0.20 ha

Date	Time used to	Up-Strm Height	Disch. Q	Volm. Appld.	Depth Appld.	Calculated Daily Crop Water requirement		
	Irrigate (min)	ha (cm)	(m ³ /s x10 ⁻⁴)	Qt (m ³)	d (mm)	HE	BMN	Pan
20-11-92	21	2.8	2.5	0.32	4.2	-	-	-
7-12-92	18	3.5	3.4	0.37	4.9	47	52	47
18-12-92	17	4.3	4.7	0.48	6.4	66	44	53
29-12-92	16	2.5	2.1	0.20	2.7	61	48	54
12-1-93	15	3.5	3.4	0.31	4.7	70	63	76
9-2-93	16	3.3	3.1	0.40	5.3	50	45	47
19-2-93	15	3.8	3.8	0.35	4.7	52	53	78
1-3-93	15	3.8	3.9	0.35	4.7	40	51	60
Total			32.0	3.25	43.3	491	453	522
Average			3.6	0.36	4.8	61	57	65
Standard Error			0.8	0.07	0.9	16	13	19

The empirical expression developed by Hargreaves HE (1974), Blanney-Moris-Nigeria - BMN (1980), and Pan Evaporation methods were used in estimating crop water requirements for the different crops grown on the plots in Block 3F7. The computed values of crop water requirement for the crops on plots F1, F2, F3 and F5 are presented in Tables 4.13, 4.14, 4.15 and 4.16, while those for plots F4 and F6 to F9 are given in Appendix E. The computed values of crop water requirement obtained from the three methods, (Table 4.17) are very close to each other. However, the constants developed by Hargreaves (1974) in the equation could possibly be location-dependent, and thus may need local calibration for the study area. Similarly, the global radiation table (Appendix F), for the study area used in the HE is because of lack of sunshine hours records for the study area during the season

Table 4.17: Summary of Computed Values of CWR and Applied Depth

Plot	Crop	Applied water Depth (mm)	calculated CWR mm/day		
			HE	BMN	PAN
F1	WHEAT	16	383	451	388
F2	COWPEA	203	391	342	320
F3	MAIZE	67	622	553	771
F5	TOMATO	43	491	453	522

NOTE

HE = Hargreaves Equation
 BMN = Blanney - Morin - Nigeria
 PAN = Pan Evaporation Method

Analysis of the individual farm units showed that plot F1, which was cropped with wheat covered an area of 0.1 ha, the seasonal average water application depth recorded was 16mm while the calculated crop water requirement was 338mm for the same period. The plot which was irrigated at an average interval of 12 days and irrigation number of 9 covered an irrigation period of 96 days as can be seen in Table 4.13. This frequency was not consistent with a 5-7 day interval recommended for wheat at the Kano River Project by Chari and Maurya (1980). Also, the water applied to the plot could not satisfy the recommended value of 431mm for wheat obtained by Abdulmunmin (1988) for the Kano River Project. In spite of the low level of irrigation, the crops were doing well, probably due to the high water table of about 65cm recorded in some parts of the project area. The value of the water table is slightly higher than the 80-100cm recorded by Dalhat (1989), for the project area. Plot F2 made up of 0.3 ha. was cropped with cowpea. The cowpea was harvested fresh (green). The water applied was 203mm for the period of 6 days with an average irrigation interval of 64 days. While the computed crop water requirement during the same period was 320mm. The recorded irrigation interval was more than that of 3-4 days reported by Aremu and Chari (1983), for normal irrigation activities at the project area. The low

level of irrigation recorded was observed to have no physical affect on the crops, since no sign of stress was observed from the crops.

Maize was cropped on plot F3, which covered an area of 0.05 ha. The plot was irrigated for 127 days with a seasonal water application depth of 67mm as against the computed crop water requirement of about 711mm. The average irrigation interval was 10 days for the season, which does not conform with the 5-7 days intervals recommended by Aremu and Chari (1983) for maize, for the Kano River Project. The performance of the crops was not affected, probably due to the high water table recorded in the project area.

Plot F4, with an area of 1.0 ha. which was cropped with Wheat, was irrigated 9 times for the 96 days irrigation period with an average interval of 12 days. The seasonal water application was 87mm as against the 338mm computed as the crop water requirement for the same period under consideration. This low irrigation level did not affect the performance of the crops since the farmers obtained reasonable yields at harvest.

Tomatoes were grown on plot F5, with an area of 0.2 ha. It was irrigated for 96 days with an average irrigation interval of 12 days. 34mm was recorded as the seasonal water application depth, while the computed crop water requirement for the same period was 522mm. The

tomato yield was found to be reasonable at harvest time by the farmers. Ground water contribution due to high water table could have been responsible for the high yields of the crop and probably, the location of the site in relation to the source (Dam).

Plot F6, which was cropped with maize covered a total area of 0.8 ha. and used a total irrigation water of 53mm and the calculated crop water requirement was 528mm for the same period. Average irrigation interval and number of 12 days and 9, respectively were recorded during the 96 days of irrigation period. Despite the gross under-irrigation recorded, the performance and yield of the crop was quite impressive at harvest.

Wheat, covering an area of 3.0 ha. was grown on plot F7 and was irrigated for 96 days with an average interval of 12 days. An irrigation number of 9 was recorded with the total application of 18mm and computed crop water requirement of 338mm for the same period. There was no sign of stress observed on the crop in any part of the plot inspite of the low level of irrigation. This was due to high water table and seepage contributions..

Plot F8, with an area of 0.12 ha cropped with maize was irrigated at an interval of 6 days for a period of 122 days, received 96mm of irrigation water during the season, while the crop water requirement computed for the same period was 710mm. The maize which was also

harvested fresh gave reasonably high yield inspite of low level of irrigation.

The last cropped plot, F9 was seeded to wheat, covering an area of 1.0 ha. The average irrigation interval and number was 12 days and 9, respectively for the period of 96 days during the season under consideration. The total seasonal irrigation water application depth was 15mm as against the computed crop water requirement of 338mm during the same period. The value shows under-irrigation. Therefore, the high performance of the crops could have been due to the high water table recorded in the project area.

Analysis of the results above indicates that the determining factors for water allocation equity within an organised irrigation project, such as time used for water application, irrigation, date and the area cropped, crop grown and farm unit position, was grossly undermined by both the farmers and management of the project.

A crop by crop analysis of the results showed that plots F1, F4, F7 and F9 having the same irrigation frequencies and numbers have different water application depths of 16, 87, 18, and 15mm respectively. This can be justified by the variation in the cropped area, time used to irrigate, and time of irrigation. However, the difference in applied depth for plots F4 (87mm) and F9 (15mm), can be contested, since the plots have the same

areas. This shows that even on the same block of equal size, equitable water allocation cannot be attained in the project area. Unequitable water allocation could be responsible for the over irrigation and under-irrigation in some parts of the project area as reported by Muhammed (1991). Field investigations revealed cases where crops (tomato) were only irrigated twice and yet harvested with reasonable yield in most parts of the project area. This was a practical evidence that underground replenishment due to the high water table was responsible for low levels of irrigation in the project area.

Plots F3, F6 and F8 cropped with maize, did not only record variations in water application depths per area cropped, but irrigation intervals and number. The irrigation intervals of 10, 12 and 6 days, respectively, were recorded for the plots, while the irrigation number of 14, 9 and 23 respectively were also recorded during the season. The crop water requirement calculated for the different plots using the three methods remained fairly constant for the same crops.

A summary of the results indicate significant variations in water used by farmers of both the head-end and the tail-end of the block, regardless of farm size and type of crop grown. This was due to uncontrolled water supply to the affected areas. Water allocations amongst plots was unsatisfactory as indicated by the

relatively low water allocation equity. If all plots were to be irrigated at the same time and on the same day, the farmers at the head-end of the block (F1), will receive the highest average application depth per irrigation, since the highest average discharge was recorded at the head-end of the block. Apart from this plot, the rest of the plots could be seen to receive considerably, lower supplies. Field investigations also revealed that generally, crops at the tail-end of the block could only be adequately irrigated in the afternoons and late evenings. This method was adopted so that farmers at the tail-end will have enough irrigation water, since it was assumed that the head-end farmers might have irrigated in the morning. This fact is contestable, since there was no defined time for irrigation for both the head-end farmers and the tail-end farmers.

The wide variations in seasonal water application within the project area, resulting in under irrigation, was brought about by monopoly of water-used by the head-end farmers. This could be traced back to both the field channels and distributary canals. Complete absence (Zero) of run-off at the outflow in all the furrows during the season was enough evidence of under-irrigation as recorded in most of the plots. The reasons could be that, the field workers were either not patient enough to

run water in the furrows up to the time the water reaches the lower end of the furrow, or there was insufficient water from the field channels.

The average irrigation number and interval as shown in Table 4.18, ranges from 9 to 23

Table 4.18: Summary of Irrigation Intervals, Number and Period for Various Crops in the Project Area

Plot	Crop grown	Period of Irrigation	Average Irrigation Interval days	Irrigation Number
1	WHEAT	96	12	9
2	COWPEA	64	17	10
3	MAIZE	127	10	14
4	WHEAT	96	12	9
5	TOMATO	96	12	9
6	MAIZE	96	12	9
7	WHEAT	96	12	9
8	MAIZE	122	6	23
9	WHEAT	96	12	9

and 6 to 17 days, with overall averages of 9 and 12 days respectively, almost twice of what was assumed by NEDECO (1973) and adopted by the projects management. The average value, however, agrees reasonably well with the 14 days recommended by Dalhat (1989), for check basin irrigation for the wheat crop in the Kano Project. The low irrigation number and high irrigation intervals evaluated might be due to the low soil moisture depletion

as a result of high water retention capacity of the soils and the contributions from ground water table as a result of shallow water table, reluctance on the part of the irrigators to irrigate, when the crops are not observed physically to be under stress and inadequate irrigation water in the affected areas. Since all the crops were harvested with reasonable yield inspite of scanty water application in most parts of the project areas, reported cases of high water table by researchers, such as Nwa (1982). Adewumi (1987) and Dalhat (1989) in the Kano River Project are thus confirmed. If this trend continues, a time will come when the crops grown, need not be irrigated and this will lead to salt accumulation and general reductions in the crop yield.

4.5 Irrigation Schedule

Irrigation scheduling mainly depends on the crop grown, soil type, evaporative demand, location of field and availability of water. For instance, Aremu and Chari (1983) found that a field close to the water source in the project could receive as much as 500mm depth of water application in each irrigation. A survey conducted through farmers' group meetings in the Kano River Project, indicates that at least 20% of the farmers irrigate their fields between 25-30 days intervals due to either shortage of water or because the crops are not stressed under such intervals. However, the field study

showed that the average irrigation interval of between 10-12 days was in the use in the project area.

Drainage

Most of the water removal systems in the project area was observed silted and full of aquatic weeds. Consequently, most of the drainage channels were not carrying surface run-off and seepage water from irrigated fields that could be utilized or re-cycled. Poor drainage in the project area has resulted in noticeable salt accumulation within the soil profiles, especially in low areas of the project, which may eventually affect crop production in the future.

4.6 Water Applied and Crop Yield

Table 4.19 shows the effects of water applied and area, on the yield of crops.

Table 4.19: Water Applied (mm) and Crop Yield (Kg/ha)

Plot	Area cropped (ha)	Crop Grown	Water Applied (mm)	Yield Kg/ha
1	0.01	Wheat	16.0	1580
2	0.30	Cowpea	20.3	*
3	0.05	Maize	68	*
4	1.00	Wheat	87	1520
5	0.20	Tomatoe	53	*
6	0.80	Maize	53	*
7	3.00	Wheat	18	1480
8	0.12	Maize	96	*
9	1.00	Wheat	15	1540
Average				1530

* Harvested fresh and Randomly.

The crops on plots F1, F2, F3, F5, F6 and F8 where harvested fresh and randomly by the farmers, thus yield could not be monitored and quantified. However, visual assessment from the field showed that high yield were recorded for these plots. The crops on plots F1, F4, F7 and F9 were monitored up to harvest, gave an estimated yield in Kg/ha of 1580, 1520, 1480 and 1540 respectively, with an average yield of 1530 Kg/ha. However, plots F4 and F9 having the same area recorded varied water applied depth and crop yield. The result showed that crop yield was not influenced by either area cropped or water applied. The variability in crop yield could have been influenced by both agronomic and cultural treatments

adopted by individual farmers. Similarly, apart from plot F2, all other plots recorded very low water supply, thus the high performance of the crops was due to contribution from the high water-table recorded within the project area.

4.7 Performance Index Evaluation

~~The actual~~ The actual relative water supply (RWS) measure or indicator was used to determine the adequacy and equity of irrigation water supply to various plots in the study area. This was determined as the ratio of the actual water supply (irrigation water) to the estimated demand (crop water requirement). The supply includes the irrigation water diverted into each plot while the demand is the computed crop water requirement. In this study, rainfall which could have formed part of the supply was zero, since no rainfall was recorded during the irrigation season. Also seepage and percolation losses were not considered as the components of the crop water requirement, (Valera and Desa, 1989).

The daily RWS values for each of the farm plots were estimated (Tables 4.20a, 4.20b, and 4.20c).

Table 4.20a: Weekly Relative water Supply (RWS) for plots F1, F2 and F3

plot	F1			F2			F3		
Date	D	S	RWS	D	S	RWS	D	S	RWS
26-11-92	-	-	-	-	-	-	-	-	-
7-12-92	16.1	2.0	12.4				25.9	6.7	29.5
18-12-92	26.1	2.0	7.7				73.8	4.8	6.5
29-12-92	41.4	2.0	4.8				53.8	4.1	7.6
12-1-93	61.0	1.8	3.0				74.9	5.0	6.7
21-1-93	40.0	1.7	4.3				47.3	5.4	11.4
9-2-93	81.5	1.8	2.2				111.7	4.4	3.9
19-2-93	48.5	1.3	2.7				66.3	3.2	4.8
1-3-93	23.4	1.8	7.7				66.6	5.4	8.1
11-3-93				58.4	25.0	42.8	66.2	4.6	7.4
16-3-93				29.0	18.6	64.1	32.8	4.0	12.2
21-3-93				31.5	26.9	85.4	31.6	6.4	20.3
26-3-93				19.3	21.8	113.0	25.6	4.4	17.2
1-4-93				34.9	26.2	75.1	38.0	3.2	8.4
15-4-93				73.3	15.8	21.6			
22-4-93				38.9	18.1	46.5			
28-4-94				15.8	13.6	86.1			
3-5-94				18.5	17.8	96.2			
Tota	338.1	16.1	47.6	319.6	203.2	630.8	710.5	67.7	95.3

D = Water demand

S = Water supply

RWS= Relative water supply $\times 10^{-3}$

Table 2.20b: Weekly Relative water supply (RWS) for plots F4, F5 and F6

Plot	F4			F5			F6		
Date	D	S	RWS	D	S	RWS	D	S	RWS
7-12-92	16.1	15.7	99.5	47.2	4.9	10.4	47.2	7.3	15.5
18-12-92	26.1	8.2	31.4	52.5	6.4	12.2	52.5	6.5	12.4
29-12-92	41.1	10.7	25.8	53.8	2.7	5.0	53.8	7.4	13.8
12-1-93	61.0	8.7	14.3	76.0	4.1	5.4	75.9	5.2	6.9
9-2-93	81.5	10.1	12.4	106.7	6.4	6.0	111.7	5.7	5.1
19-2-93	48.5	6.7	13.8	77.6	4.8	6.2	66.3	4.4	6.6
1-3-93	23.4	6.1	26.1	60.4	4.7	7.8	73.7	4.4	6.0
Total	338.1	86.8	257.6	521.5	43.4	83.2	528.4	53.0	100.3

D = water demand

S = water supply

RWS = Relative water supply $\times 10^{-3}$

Table 4.20c: Weekly Relative water supply (RWS) for plots F7, F8 and F9

plot		F7			F8			F9		
Date	D	S	RWS	D	S	RWS	D	S	RWS	
7-12-93	16.1	2.5	15.2				16.1	2.4	14.9	
9-12-92				56.0	2.8	5.0				
16-12-92				32.1	4.3	13.4				
18-12-92	26.1	2.0	7.7				26.1	2.4	9.2	
22-12-92				29.5	9.0	30.5				
29-12-92	41.4	2.4	5.8				41.4	1.6	3.9	
4-1-93				41.9	3.9	9.3				
10-1-93				30.4	6.1	20.1				
12-1-93	61.0	2.6	4.3				61.0	6.9	11.3	
15-1-93				25.6	1.7	6.6				
21-1-93	40.0	2.7	6.8	31.9	7.6	23.8	40.0	1.9	4.8	
26-1-93				30.8	2.0	6.5				
1-2-93				36.6	3.2	8.7				
6-2-93				28.2	2.0	7.1				
9-2-93	81.5	1.6	2.0				81.5	1.4	1.7	
13-2-93				43.0	5.7	13.3				
19-2-93	48.5	1.9	3.9				48.5	1.8	3.7	
20-2-93				45.9	2.0	4.4				
27-2-93				44.8	6.6	14.7				
1-3-93	23.4	1.4	6.0	15.6	6.0	38.5	23.4	1.4	6.0	
11-3-93				62.2	3.5	5.6				
16-3-93				22.7	7.0	30.8				
21-3-93				31.6	5.4	17.1				
26-3-93				25.1	6.6	25.6				
1-4-93				37.6	5.2	13.8				
Total	338.1	18.0	53.2	701.4	96	136.9	338.1	15.1	44.7	

D = water demand

S = water supply

RWS = Relative water supply $\times 10^{-3}$

and using these values, equity in irrigation water distribution and allocation amongst the components were evaluated. The results showed inadequacy of supply to demand as indicated in Table 4.20. Almost all the farm plots indicated less supply than demand. There were low values of irrigation water supply recorded in farm plots F1, F5, F6, F7 and F9. This can also be observed by the

low values of RWS recorded for the same farm plots. The irrigation water supplied, on the average, was far less than the estimated demand. The RWS values showed that the upstream plots were provided with more irrigation water than the downstream plots (Table 4.20a, 4.20b, and 4.20c). The low values of RWS which indicates inadequacy and unreliability of irrigation water supply, were compensated for by the high water table of 65cm, on the average, recorded for the project area during the season under considerations. The value was higher than the 85cm monitored by Dalhat (1989), for the same area.

The performance of the project area in terms of the relative water supply (RWS), indicates that there are opportunities wherein improvement can be made. As regard to the equity of irrigation water distribution, better distribution can be attained if proper monitoring and control of irrigation activities are undertaken by the Management Authorities of the project area.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

A study was conducted in the Kadawa sector of the Kano River Project during the 1992/93 irrigation season, with the primary aim of evaluating the performance of a part of the distribution system (distributary canals, and ~~field~~ channels), irrigation water distribution and allocation methods as they affect control, operation and equity. The crop water requirement (CWR) of the various crops grown within the selected field (3F7), was computed using meteorological data of the study area during the season for comparison with the water application depth. Stage measurements were monitored at the selected stations on both the distributary canal, field channels and farm units respectively. Discharge was evaluated from the data obtained from the calibrated structures (cut-throat flumes) at the selected stations on the field channels and farm units. The water conveyance losses and efficiencies were determined for each of the selected stations. Block 3F7, located at the tail-end of the farm was selected for the purpose of monitoring water flows into the various farm units. Measurements were taken from the Block which was made up of nine plots, and were used to evaluate the irrigation water application depth, irrigation intervals and number, equity of irrigation

water distribution and allocation, and the relative water supply (RWS) index for the project area.

The results obtained from the study shows that variations exist in discharge both with space and time. A general decrease from the head-end to the tail-end in discharge was observed. However, an average discharge of 84 l/S was recorded for the distributary canal with an average conveyance efficiency of 87%. The distribution equity of the selected field channels on the distributary canal was evaluated to be as low as 14%, on the average. However, the average field channel discharge for the selected stations in a particular field channel (block 3.7) was 11.4 l/S. The results obtained from the various farm units indicate significant variations, both at the head-end and the tail-end of the farm and also between plots, regardless of size and crop grown. Irrigation intervals and number were also evaluated and found to be inconsistent, and thus undermining design recommendations. Water application for crop use was grossly underestimated for the plots which in plies under irrigation. Comparison with computed values of crop water requirements for various crops, showed wide differences.

Apparent lack of proper organisation and monitoring of water distribution in the Kano River Project was very glaring. Unprofessional and ill-planned rotational method of water distribution and allocation was imposed

on the farmers by the management without prior knowledge of such changes. Water allocation in the project area was not properly defined, since there was no realistic basis for the allocations.

The relative water supply (RWS) index was investigated for the project area. Field evaluation showed that all the plots had low values of RWS, which is ~~an indication of low level of irrigation.~~ However, the high performance of the field crops was as a result of high water table recorded in most parts of the study area. Similarly, the yield was not influenced by the land area cropped and water applied depth.

5.2 Conclusion

The following conclusions could be drawn from the results obtained in this study:

1. The performance of the water distribution systems (distributary canal, field channel and farm units) of the project area was found to be very low as can be seen from the low conveyance and distribution efficiencies and high distribution and conveyance losses. The low values are attributed to poor canal conditions, damaged structures and indiscriminate operation of release gates by the farmers. Illegal diversions of water through canal bank "cuttings" and complete blockage by the head-

end farmers are also contributing factors.

2. Equity in water distribution and allocation within the study area was found to be generally low amongst the field channels and the farm units within the selected block (Block 3F7). The variability of water distribution equity was being influenced primarily, by the distance from the turnouts and possibly, presence of over-grown weeds within the distribution systems.
3. Since depth of water applied to individual plots was found to be generally lower than the computed crop water requirements, due to low irrigation number and high irrigation intervals, the survival of the crops depended on other sources, probably, contributions from ground-water which further confirmed reported cases of high water table within the project area.
4. The low values of relative water supply (RWS) as a measure of the performance of irrigation water distribution systems, showed that water supplied to all the farm units fallshort of the demand. Inspite of the low level of irrigation, the performance of the crops and the yields were not affected.

5.3 Recommendations

The following recommendations are presented herein for the attention of the management Authorities and

future areas of study:

1. Permanent and functional discharge measuring devices should be installed at strategic locations within the project area at the beginning of each irrigation season, while damaged structures should be serviced and repaired.
2. Annual general maintenance of the distribution systems should be carried out before the commencement of each irrigation season, while routine maintenance should be done at least three times per season.
3. Organised farmers associations or groups should be formed amongst farmers within the project area for the purpose of easy management. In furtherance of this, farmers' organisations should be adequately educated and trained on the operation and maintenance of some few field turnouts and even recording of daily discharges to their blocks. This should be under strict supervision by management.
4. Water distribution and allocation in the project area should be based on the following:
 - (i) Labour contribution by an individual or group of farmers towards general maintenance of water distribution system
 - (ii) Size and location of land holding by farmer(s) in the command area and

(iii) Type of crop grown.

5. Meteorological data, though easier and quicker to use, should be employed for at least 3-4 years period before obtaining the data that can be used for practical purposes, rather than just one year.
6. It should be recommended that, similar work be conducted at all the sectors of the project area, especially on the three performance indices. Apart from the water application depth and yield, agronomic, cultural practices and cost benefits should also be monitored and evaluated for each farmers plot.

REFERENCES

- Abdulmunin, S. 1988. Crop coefficients and water requirements of irrigated wheat (Triticum aestivum L.) in the Nigerian Savannah zone. Journ. Irrig. Science No 9, pp 177-186.
- Adewumi, J.K. 1985. Irrigation efficiency at the Kadawa sector of the Kano River Basin. M.Sc. Thesis, Dept of Agric. Engr. Ahmadu Bello University, Zaria. Nigeria, pp. 32-50
- Ahmed A, Adewumi J.K, Muhammed A.D.K. 1990. Irrigation water allocation and distribution. Farmer participation in irrigation developement and management. Prc. of National Workshop held at Institute for Agricultural Research, Ahmadu Bello University, Zaria, pp. 138-147
- Aremu, J.A. and Chari A.V. 1983. Irrigation and Nitrogen requirement for dry season maize (Zea mays). Final report submitted to the irrigation research committee, Institute for Agricultural Research, Ahmadu Bello University, Zaria. Nigeria, pp. 24.
- Blanney, H.F. and Moris K.V. 1942. Evaporation and consumptive use of wate: empirical formulas. Trans. Am. Gephys. Union, Vol. 23, part 1, pp. 76-83.
- Blanney, H.E. and Criddle W.D 1950. Determining water requirements in irrigated areas from climatological and irrigated data. USDA, Div. Irrig. and water conserv. pp 120.
- Booher, L.T. 1980. Surface irrigation Land and water Development Div. F.A.O, University of Calfonia Davis, pp 3-52.
- Bos, M.A. A and Nugteren J. 1982. On irrigation efficiency IILRI Publ. No 19, pp 29-60.
- Bottral, A.F. 1981. Comparative study of the management and organization of irrigation project. World Bank Staff Working paper, No 458, pp 274.
- Burman, R.D, Wixon, P.R, Writt J.J. and Pruite O . W . 1980 Water requirements. ASAE monograph, No. 3. Design and operation of farm irrigation systems. Edited by Jansen M.E. pp, 10-14.

- Chin, L.T. 1970. Management, operation and maintenance of an irrigation project. Farm management seminar, manila. Irrig. and Drain. paper, No 12 F.A.O. Rome, pp. 7-9.
- Dalhat, M.K. 1989. Evaluation of irrigation performance under high water table conditions. M.Sc. Thesis, Dept. of Agric. Eng. Ahmadu Bello University Zaria, Nigeria, pp 46-51.
- Dayaralyer, M. H.S. 1991. A review of alternative strategies for improving farmer-managed irrigation systems in Sri. Lanka. IIMI country paper, Sri, Lanka, No 7, pp. 91.
- Donen, L.D. 1971. Irrigation practice and water management. Irrig. and Drain. paper No 1, pp. 73-78.
- Doorehnbos, J and Pruitt, W.O. 1977. Guidelines for predicting crop water requirements. Irrig. and Drain. Paper No 24. F.A.O. pp. 144.
- Duru, J.O. and Yusuf, S.K. 1980. Potential of temperature-based evapotranspiration models for Northern Nigerian Agriculture A. paper present at the 14th Ann. Conf. of the Nig. Soc. Agric. Engrs. University of Ibadan, Ibadan, Nigeria.
- Duru, J.O. 1981. A simple evapotranspiration model for Northern Nigeria. A paper presented at the 5th Ann. Conf. of the Nig. Soc. Agric. Engrs, University of Ife, Ile-Ife Nigeria.
- Gabrecht, G. and Bos, M.G. 1980. Importance of water measurements in irrigation systems. Irrigation Drainage and flood control. ICID Bulletin, Vol. 29 No 1, pp. 37.
- Haskoning. 1978. Tiga Dam evaluation. An evaluation report from Haskoning Engineering consultants Nig. Ltd Vol. 1.
- Heemann, D.F. 1988. Evapotranspiration research priorities for the next decade-irrigation. Trans. ASAE. Vol. 31, No. 2, pp. 487-501.
- Holes F.L. 1984. World Bank irrigation experience. Irrigation management network paper No. 9. pp. 420-426.

- Hudsen, N.W. 1975. Field Engineering for Agricultural Development. Calrendon press. Oxford pp. 40-63.
- Hrabosky. J. 1970. Timing sequence and strategy in planning of irrigation systems. Farm water management seminar. Irrig. and Drain. paper No 12. F.A.O. pp 24-35.
- Isrealson, O.W, Hansen E.V, and Strengtham G.E. 1979. Irrigation Principles and Practice. 4th Ed. John-Weley and Sons. New York, U.S.A. pp 112-132.
- ~~James, L.G.~~ Erpenbeck, J.M. and Bessel. D.L. 1983. Estimating seasonal irrigation requirement for Washington. Trans ASAE. Vol. 25, No 5 pp 1380.
- Jansen, M.E. 1974. Consumption use of water and irrigation requirements. Report of technical committee on Irrig. and Drain. Div. pp. 88.
- Kahanjan, M.J. and Buch J.R. 1983. Optimal irrigation distribution systems with internal storage. Trans. ASAE. Vol. 26, No 3, pp 743-747.
- Kra'atz D.B. 1975. Small Hydraulic Structures. Irrig. and Drain. Paper Nos. 26/1 and 26/2 pp 406.
- Kolawole, A. 1990. Constrains for farmer participation in large-scale irrigation projects in Nigeria. A paper presented at the National Workshop on farmers' participation in irrigation Development and management, Institute for Agricultural Research, Ahmadu Bello University, Zaria. Nigeria pp 90-102.
- Kowal, J.M. and Knabe, D.T. 1972. An Agroclimatological Atlas of the Northern Nigeria with explanatory notes. Published by Ahmadu Bello University press, Samaru, Zaria. Nigeria pp 14.
- Makanjuola, F.J. and Nwa, E.U. 1985. Effects of water management on yield of sugar cane at the Bacita estate. Nigeria. Proc. 5th Agro-Asian Reg. Conf. of the ICID. pp. 138-145.
- Malysia 1984. The Kano River Project Phase II West Bank Region. A completion report by Malysia International consultants Ltd pp. 14-71.

- Martins, E.D. and Yodor R. 1987. Institutions for water management in farmer management irrigation systems. Examples from the hills of Nepal. Digana Villages. Sri. Lanka. IIMI working paper pp. 12-16
- Maurya, P.R. Ahmed, A, and Adewumi J.K. 1989. Towards farmer managed irrigation water distribution systems in Nigeria. Proc. of Intern. Workshop of the farmer managed irrigation systems Networks, Chiang Mai. IIMI, pp 237-246.
- Maurya, P.R. and Chari A.V. 1980. Wheat irrigation water requirement for Sudan savannah. Paper presented at the 7th Nigerian National Irrigation Seminar, Agricultural Extension Research and Liason Services, Ahmadu Bello University, Zaria. Nigeria.
- Maurya, P.R. and Sachan R.S. 1985. Irrigation schedulling in relation to salt build-up under varying ground-water conditions. Proc. of the 5th Afro-Asian Reg. Conf. of the ICID. Townvilla, pp 80-89.
- Melvyn, K. 1989. Surface Irrigation Systems and Practice. Canifield press, England, UK. pp 8-14
- Meriam, J.L. Sheaver M.W. and Burt C.M. 1980. Evaluation of irrigation systems and practice. Design and operation of farm irrigation systems. ASAE No 3. Edited by Jansen pp 1035.
- Micheal, A.M. 1985. Irrigation Theory and Practices. Vani Educational Books. pp 125-135.
- Muhammad, A.D.K. 1991. Water management systems performance of the Kano River Project M.Sc. Thesis, Department of Agric. Engr. Ahmadu Bello University, Zaria. Nigeria pp 106
- NEDECO, 1973. Kano River Project. Report on design of the irrigation systems. A report on the general desisgn of the West Branch Regions: by Netherlands Engineering consultants.
- NEDECO. 1974. Kano River Project area part II. Soils Min. of Agric and Nat. Res. Kano State. Nigeria.

- Nugteren I. 1972. Technical aspects of water conveyance and distributions systems. Water use seminar. Damascus. Irrig. and Drain paper No 13 F.A.O. Pp 170-185.
- Nwa, E.U. and Martins B. 1982. Irrigation development in Nigeria. 4th Afro-Asian Regional conf. of the ICID Vol. No 102 pp 1-18.
- Nwa, E.U. 1980 . Cropping patterns and the environmental factors in Kano Project of Nigeria 3rd Afro-Asian Regional conf. of the ICID, Vol. No 5, pp 59-67.
- Nwa, E.U. 1991. Irrigation in Nigeria. Some contemporary issies Nig. Journ. of water Res. Vol. 1, No 1.
- Oyebode, M.A. 1989. Development of design procedures for border irrigation. M.Sc. Thesis Department of Agric. Eng. Ahmadu Bello University Zaria. Nigeria, pp 2-15
- Pradhan, P. 1989. Pattern of irrigation organisation in Nepal. A comparative study of 21 farmers manged irrigation systems. IIMI country paper-Nepal No, 1. pp 49-52.
- Saeed, M. 1986. The estimation of evapotranspiration by some equations under Hot and Arid conditions. Trans ASAE. Vol. 29 No 6, pp 343 - 438.
- Sagardos, K.A. 1970. Management, operation and maintenance of an irrigation project. Farm management seminar Manila. Irrig. and Drain paper No 2 FAO pp 342.
- Shalhvet, J. Montell. A, Bretorai. H. and Shimshi D. 1976. Irrigation of fields and chard crops under semi-arid conditions. No 1 IIIC Publ. pp. 12-16
- Sharma, M.L. 1974. Water management in unsaturated soil as influenced by gypsum. Australian Journ. of Soil Res. Vol. 10 pp 357.
- Schroab, G.O., Frever Y, R.K. Barnes, K.K. and Edminster T.W. 1966. Elementary Soil and Water Engineering 2nd Ed. John Wiley and Sons London pp. 316.

- Skogerboea, G.V. Hyat M.L. Anderson C.E. and Eagleton. K.O. 1992. Installation and field use of cut-throat flumes for water management. Water Mgt. Tech. Report. No 19. Colorado State University Fort Collins.
- Standbary, P. 1989. Land settlement for improved irrigation management. As case study of the Kwandi Oya irrigation settlement project IIMI country paper. Sri. Lanka. No 4. pp 73.
- Stern, P. 1985. Small-scale irrigation. A manual of low-cost water Technology. II/IIIC Publ. pp. 69-141.
- Thomas, W.L. 1989. Irrigation design and management for the new Orchard planting. Intern. Agric. Digest. Vol. No 2, pp. 12-21.
- Valera, A. and Desa M.N.N. 1989. Design-management interactions of Malaysia Keriar irrigation scheme IIMI country paper-Malaysia No 1 pp 64.
- Yoder, R. and Thuston, J. 1989. Design issues in farmer-managed irrigation systems. Proc. of Intern Workshop of the farmer-managed irrigation system network. Chian Mai. Thailand. IIMI. pp 310.
- Withers B. and Vipond S. 1974. Irrigation Design and Practice B.T. Basford Ltd. Pp. 45 - 148.
- Zein, A.N. 1971. Irrigation application and water distribution. Water use seminar, Damascus. Irrig. and Drain paper No 13 F.A.O., pp 142-198.
- Zimmerman, J.D. 1966. Irrigation. John-Wiley and sons. New York, USA, pp 271-306.



APPENDICIES

APPENDIX A
RECORDS OF METEOROLOGICAL DATA FOR KADAWA
(1992/93 IRRIGATION SEASON)

Table A1: NOVEMBER 1992

Date	AIR TEMPERATURE (°C)			RELATIVE HUMIDITY RH (%)	WIND (km)	EVAP. (mm)
	MAX	MIN	MEAN			
1	30	13	21.5	73	88.6	5.1
2	31	15	23	68	91.0	5.6
3	32	15	23.5	77	101.8	5.7
4	32	14	23	82	115.7	5.1
5	31	16	23.5	63	103.5	6.3
6	32	16	24	66	101.4	6.3
7	32	12	22	59	115.4	6.0
8	32	11	21.5	73	106.3	6.4
9	32	12	22	55	121.9	5.6
10	32	15	23.5	61	120.4	6.4
11	33	13	23	30	122.3	5.6
12	33	14	23.5	39	110.7	6.8
13	33	13	24	39	111.1	6.9
14	31	13	22	59	114.7	4.3
15	31	14	22.5	58	116.1	7.0
16	31	13	22	39	110.0	5.0
17	31	13	22	65	106.6	5.8
18	32	13	22.5	76	112.2	4.5
19	33	13	24	39	112.9	4.6
20	32	13	22.5	47	113.0	4.7
21	32	13	22.5	54	125.1	7.1
22	32	14	23	57	109.8	6.5
23	33	14	23.5	47	130.4	5.5
24	33	14	23.5	50	148.7	8.0
25	34	13	23.5	65	102.6	5.3
26	35	13	24	60	101.0	5.5
27	35	14	24.5	56	107.3	5.5
28	33	15	24	67	108.4	4.1
29	34	16	25	60	70.4	4.2
30	32	17	24.5	45	123.9	4.1

Table A2: DECEMBER 1992

DATE	TEMPERATURE ($^{\circ}\text{C}$)		MEAN	RH (%)	WIND (km)	EVAP. (mm)
	MAX	MIN				
1	32	14	23	59	99.8	4.1
2	32	16	24	64	120.9	5.8
3	33	13	23	64	125.0	5.7
4	33	14	23.5	52	121.0	6.2
5	31	13	22	81	131.2	5.9
6	31	14	22.5	74	120.1	5.4
7	31	13	22	74	113.6	4.6
8	28	14	21	74	89.0	5.5
9	31	14	22.5	68	87.7	5.9
10	30	13	21.5	68	112.1	5.1
11	29	15	22	47	108.2	5.1
12	25	14	19.5	48	106.8	3.0
13	27	16	21.5	91	137.5	6.4
14	26	13	19.5	43	113.2	7.8
15	28	12	20	50	103.6	6.5
16	28	11	19.5	43	137.6	7.3
17	28	13	20.5	33	130.9	7.6
18	28	13	20.5	43	135.7	7.6
19	27	12	19.5	48	144.7	5.9
20	25	12	18.5	45	126.4	5.5
21	32	12	22	64	109.6	6.5
22	31	13	23	71	126.9	5.1
23	31	13	23	65	150.0	4.9
24	31	13	22	64	185.9	6.5
25	26	11	18.5	75	205.1	7.5
26	27	11	19	80	222.2	9.0
27	22	10	16	75	198.0	8.2
28	24	12	18	79	150.7	2.0
29	23	11	17	38	144.8	8.6
30	25	10	17.5	83	155.3	8.1
31	26	9	17.5	29	206.8	13.5

Table A3 : JANUARY 1993

DATE	TEMPERATURE ($^{\circ}\text{C}$)			RH(%)	WIND (km)	EVAP. (mm)
	MAX	MIN	MEAN			
1	24	9	16.5	29	205.5	5.2
2	22	6	14	85	212.3	6.2
3	21	7	24	67	210.6	6.1
4	21	10	15.5	41	216.6	6.5
5	19	11	15	45	199.7	6.8
6	20	12	16	40	153.4	5.3
7	23	10	16.5	37	219.9	7.4
8	23	10	16.5	41	221.7	8.9
9	22	10	16	35	159.1	4.9
10	24	10	17	37	212.9	6.3
11	22	12	17	39	243.8	6.0
12	22	12	17	45	176.1	7.3
13	24	9	16.5	37	168.5	6.7
14	24	10	17	39	175.2	6.6
15	26	11	18.5	34	172.7	6.6
16	26	11	18.5	55	170.1	7.6
17	28	9	18.5	43	220.8	7.1
18	23	5	14	50	179.3	6.6
19	30	9	19.5	34	191.0	6.2
20	31	5	18	49	213.3	6.2
21	29	7	18	56	138.2	7.8
22	24	7	15.5	28	183.2	8.0
23	26	9	17.5	67	179.1	7.2
24	28	11	19.5	48	230.1	6.3
25	29	8	18.5	35	151.9	7.2
26	28	10	19	31	211.4	11.4
27	29	9	19	45	272.3	6.8
28	29	8	18.5	38	165.1	6.5
29	27	9	18	39	160.1	7.2
30	28	12	20	42	161.0	9.2
31	27	13	14	71	291.4	10.6

Table A4 FEBRUARY 1993

DATE	TEMPERATURE ($^{\circ}$ C)			RH %	WIND (km)	EVAP. (mm)
	MAX	MIN	MEAN			
1	22	14	18	33	258.4	7.3
2	22	12	17	37	263.4	7.1
3	26	12	19	35	222.7	7.7
4	26	12	19	33	223.6	8.0
5	24	12	18	35	224.9	7.0
6	25	11	18	48	170.8	6.7
7	27	12	19.5	46	143.4	7.0
8	27	15	21	47	139.9	7.4
9	28	15	21.5	41	149.8	6.4
10	28	15	21.5	90	154.8	8.9
11	28	13	20.5	38	230.0	9.0
12	28	13	20.5	43	218.2	8.6
13	27	14	20.5	31	291.6	8.6
14	25	16	20.5	33	233.4	8.0
15	26	12	19	47	181.7	8.0
16	28	11	19.5	49	154.8	8.7
17	27	13	20	49	360.7	11.4
18	24	13	18.5	66	299.6	6.8
19	27	9	18	72	281.6	8.0
20	26	15	20.5	44	256.3	8.2
21	26	14	20	44	283.6	10.0
22	29	14	21.5	40	200.8	7.3
23	28	13	20.5	49	144.8	10.3
24	31	14	22.5	49	133.2	4.8
25	33	13	23	59	109.0	8.4
26	35	14	24.5	56	121.3	8.5
27	36	16	26	50	127.5	8.8
28	35	16	25.5	51	149.1	10.0

Table A5 MARCH 1993

DATE	TEMPERATURE ($^{\circ}\text{C}$)			RH (%)	WIND (km)	EVAP. (mm)
	MAX	MIN	MEAN			
1	33	12	22.5	54	137.9	10.3
2	35	12	23.5	60	115.0	8.2
3	38	16	27	68	145.2	8.4
4	39	13	26	71	146.0	8.5
5	41	11	26	71	144.4	8.4
6	32	11	21.5	58	229.3	5.3
7	33	13	23	54	101.1	6.7
8	33	14	23.5	59	100.2	5.8
9	33	16	24.5	42	108.7	6.6
10	34	8	26	56	115.8	10.1
11	35	14	24.5	80	119.7	9.9
12	36	14	25	67	109.7	8.3
13	33	15	24	69	174.8	9.3
14	33	16	24.5	48	130.6	8.0
15	33	17	25	45	162.8	9.2
16	33	17	25	44	149.8	8.8
17	36	16	26	47	123.4	9.8
18	37	18	27.5	45	93.6	7.0
19	36	18	27	59	115.0	7.4
20	37	18	27.5	61	124.3	6.9
21	38	19	28.5	56	102.6	9.9
22	34	22	28	43	120.8	6.2
23	35	19	26	42	99.3	7.6
24	33	18	25.5	41	160.1	7.7
25	33	17	25	43	130.3	6.1
26	33	17	25.5	52	135.0	6.1
27	33	17	24	51	128.7	6.1
28	32	16	24	61	155.9	9.9
29	32	16	24	50	140.1	8.3
30	32	17	24.5	44	166.0	10.8
31	33	17	25	42	145.9	9.1

Table A6

APRIL 1993

DATE	TEMPERATURE ($^{\circ}\text{C}$)			(RH) %	WIND (km)	EVAP. (mm)
	MAX	MIN	MEAN			
1	33	17	25	63	148.4	9.1
2	34	17	25.5	61	159.4	9.1
3	36	17	26.5	48	113.4	8.7
4	36	18	27	48	116.6	8.3
5	37	17	27	47	126.4	9.3
6	36	15	25.5	48	112.5	8.8
7	37	17	27	37	135.4	10.3
8	38	18	28	39	155.0	10.2
9	39	18	28.5	45	160.1	10.8
10	37	17	27	42	161.9	10.3
11	37	16	26.5	62	131.7	10.0
12	38	17	27.6	46	106.8	10.0
13	38	16	27	51	99.8	7.9
14	39	17	28	51	126.8	10.5
15	39	19	29	46	154.2	9.4
16	39	22	30.5	49	153.1	9.3
17	36	21	28.5	46	202.1	5.3
18	36	22	29	60	144.9	6.3
19	38	24	31	51	133.7	7.7
20	39	23	31	47	129.8	9.0
21	38	24	31	43	155.7	8.6
22	37	23	30	59	195.2	6.1
23	38	24	31	65	155.5	7.0
24	39	24	31.5	57	188.7	4.5
25	39	24	31.5	46	169.7	7.6
26	39	24	31.5	64	175.4	3.0
27	39	24	31.5	62	156.2	7.0
28	39	23	31	64	177.7	3.9
29	39	24	31	53	221.2	4.0
30	35	25	30	59	250.1	3.7

Table A7

MAY 1993

DATE	TEMPERATURE ($^{\circ}\text{C}$)			(RH) (%)	WIND (km)	EVAP. (mm)
	MAX	MIN	MEAN			
1	37	23	30	76	230.2	7.7
2	38	24	31	69	216.0	7.3
3	38	22	31	74	202.8	7.9
4	36	23	29.5	71	222.6	7.1
5	34	24	29	81	309.3	8.6
6	38	22	30	60	215.3	4.6
7	32	23	27.5	64	177.9	13.0
8	33	22	27.5	76	115.7	6.5
9	34	23	28.5	78	170.6	4.8
10	35	23	29	76	259.1	9.4
11	37	23	30	76	122.9	1.7
12	33	21	27	68	149.5	5.5
13	36	21	28.5	59	157.9	7.8
14	36	21	28.5	63	180.1	7.8
15	37	21	24	80	152.6	5.9
16	37	23	30	69	150.9	7.4
17	38	24	31	67	147.8	9.2
18	38	23	30.5	71	182.9	10.6
19	38	23	30.5	62	185.0	9.6
20	38	24	31	62	180.1	8.9
21	38	24	31	70	179.7	10.5
22	37	23	30	64	186.4	7.8
23	37	24	30.5	68	146.0	6.7
24	39	23	31	63	185.3	8.7
25	39	23	31	68	223.7	10.4
26	42	24	33	63	187.9	3.3
27	41	24	32.5	60	150.9	3.3
28	39	24	31.5	73	151.5	2.9
29	38	22	30	66	205.4	3.1
30	40	24	32	75	229.8	2.9
31	39	24	31.5	64	209.6	1.1

APPENDIX B
COMPUTED VALUES OF CROP WATER REQUIREMENT
(H-E METHOD) -mm/day

Table B1

Crop: Wheat.

Date	Nov.	Dec.	Jan.	Fev.	March.	April	May
1	2	5	4	4	5	2	2
2	2	5	4	4	5	2	2
3	2	5	4	4	5	2	2
4	2	5	4	4	5	2	2
5	2	5	4	4	5	2	2
6	2	5	4	4	5	2	2
7	2	5	4	4	5	2	2
8	2	5	4	4	5	2	2
9	2	5	4	4	5	2	2
10	2	5	4	4	5	2	2
11	2	5	4	4	5	2	2
12	2	5	4	4	5	2	2
13	2	5	4	4	5	2	2
14	2	5	4	4	5	2	2
15	2	5	5	4	5	2	2
16	2	5	5	4	2	2	2
17	2	5	5	4	2	2	2
18	2	5	4	4	2	2	2
19	2	5	5	4	2	2	2
20	2	4	5	4	2	2	2
21	2	5	4	4	2	2	2
22	2	5	4	4	2	2	2
23	2	5	4	4	2	2	2
24	2	5	4	4	2	2	2
25	2	4	4	5	2	2	2
26	2	5	4	5	2	2	2
27	2	4	4	5	2	2	2
28	2	4	4		2	2	2
29	2	4	4		2	2	2
30	2	4	5		2	2	2
31		4	4		2		2

Table B2: Crop. Cowpea (Green Beans)

Month Date	Nov.	Dec.	Jan.	Feb.	March	April	May
1	4	4	3	4	5	6	6
2	5	4	3	4	5	6	6
3	5	4	3	4	5	6	6
4	5	4	3	4	6	6	6
5	5	4	3	4	6	6	6
6	5	4	3	4	6	6	6
7	4	4	3	4	6	6	5
8	4	4	3	4	6	6	5
9	4	4	3	4	6	6	5
10	5	4	3	4	6	6	5
11	5	4	3	4	6	6	5
12	5	4	3	4	6	6	5
13	5	4	3	4	6	6	5
14	4	4	3	4	6	6	5
15	5	4	4	4	6	6	5
16	4	4	4	4	6	7	5
17	4	4	4	4	6	7	6
18	5	4	3	4	6	7	6
19	5	4	4	4	6	7	6
20	5	3	4	4	6	7	6
21	5	4	3	4	6	7	6
22	5	3	3	4	6	7	6
23	5	3	3	4	6	7	6
24	5	3	3	4	6	7	6
25	5	3	3	4	6	7	6
26	5	3	3	5	6	6	6
27	5	3	3	5	6	6	6
28	5	3	3	5	6	6	6
29	5	3	3		6	6	6
30	5	3	4		6	6	6
31		3	3		6	6	6

Table B3

Crop Maize

Month Date	Nov.	Dec.	Jan.	Feb	March	April	May
1	3	3	2	6	7	4	4
2	3	3	2	6	7	4	4
3	3	3	2	6	7	4	4
4	3	3	2	6	7	4	4
5	3	3	2	6	7	4	4
6	3	3	4	6	7	4	4
7	3	3	4	6	7	4	4
8	3	3	4	6	7	4	4
9	3	3	4	6	7	4	4
10	3	3	4	6	7	4	4
11	3	3	4	6	7	4	4
12	3	3	4	6	7	4	4
13	3	3	4	6	7	4	4
14	3	3	4	6	7	4	4
15	3	3	6	6	7	4	4
16	3	3	6	6	7	4	4
17	3	3	6	6	7	4	4
18	3	3	6	6	7	4	4
19	3	3	6	6	7	4	4
20	3	3	6	6	7	4	4
21	3	2	4	6	7	4	4
22	3	3	4	6	7	4	4
23	3	3	4	6	7	4	4
24	3	3	4	6	7	4	4
25	3	2	4	6	7	4	4
26	3	3	4	7	7	4	4
27	3	2	4	7	7	4	4
28	3	2	4	7	7	4	4
29	3	2	4		7	4	4
30	3	2	6		7	4	4
31		2	4		7		4

Table B4 Crop. Tomato

Month							
Deta	Nov.	Dec.	Jan.	Feb.	March	April	May
1	3	3	5	6	4	4	4
2	4	3	5	6	4	4	4
3	4	3	5	6	4	4	4
4	4	3	5	6	4	4	4
5	4	3	5	6	4	4	4
6	4	6	5	6	4	4	4
7	3	6	5	6	4	4	4
8	3	6	5	6	4	4	4
9	3	6	5	6	4	4	4
10	4	6	5	6	4	4	4
11	4	6	5	6	4	4	4
12	4	6	5	6	4	4	4
13	4	6	5	6	4	4	4
14	3	6	5	6	4	4	4
15	4	6	6	6	4	4	4
16	3	6	6	4	4	4	4
17	3	6	6	4	4	4	4
18	4	6	5	4	4	4	4
19	4	6	6	4	4	4	4
20	4	5	6	4	4	4	4
21	4	6	5	4	4	4	4
22	4	6	5	4	4	4	4
23	4	6	5	4	4	4	4
24	4	6	5	4	4	4	4
25	4	5	5	4	4	4	4
26	4	6	5	4	4	4	4
27	4	5	5	4	4	4	4
28	4	5	5	4	4	4	4
29	4	5	5		4	4	4
30	4	5	5		4	4	4
31		5	5		4		4

APPENDIX C
COMPUTED CROP WATER REQUIREMENT (BMN METHOD) - mm/day

Table C1

MONTH: NOVEMBER 1992

DATE	WHEAT	MAIZE	TOMATO	COWPEA
1	4.0	-Do-	-Do-	3.0
2	4.1			4.0
3	3.4			3.0
4	3.0			3.0
5	4.4			4.0
6	4.0			3.2
7	4.4			4.0
8	4.0			3.0
9	5.0			4.2
10	5.0			5.0
11	7.0			6.0
12	6.1			5.4
13	6.1			5.2
14	4.4			4.0
15	5.0			4.0
16	5.0			4.0
17	5.2			5.0
18	3.4			3.0
19	6.1			5.2
20	5.4			5.0
21	5.0			4.2
22	5.0			4.2
23	6.0			5.0
24	5.3			5.0
25	4.3			4.0
26	5.0			4.1
27	5.0			4.4
28	4.2			4.0
29	5.0			4.0
30	6.0			5.0

Table C2

MONTH	DECEMBER 1992			
DATE	WHEAT	MAIZE	TOMATO	COWPEA
1	4.4	-Do-	-Do-	4.1
2	4.3			4.0
3	4.2			4.0
4	5.0			4.4
5	3.0			3.0
6	3.4			3.0
7	3.4			3.0
8	3.3			3.0
9	4.0			3.3
10	5.4			5.0
11	5.2			5.0
12	5.0			4.2
13	2.6			2.0
14	5.1			4.4
15	3.4			3.0
16	5.1			4.4
17	6.0			5.0
18	5.3			5.0
19	5.0			4.2
20	5.0			4.2
21	4.1			4.0
22	4.0			4.0
23	4.1			3.2
24	4.1			4.0
25	3.1			2.4
26	3.0			2.3
27	3.0			2.4
28	3.0			2.4
29	5.0			4.4
30	2.4			2.4
31	5.1			4.4

Table C3

MONTH	JANUARY 1993			
DATE	WHEAT	MAIZE	TOMATO	COWPAE
1	5.0	-Do-	-Do-	5.0
2	2.2			2.0
3	3.3			3.0
4	5.0			4.2
5	5.0			4.1
6	5.0			4.1
7	5.2			5.0
8	5.0			4.2
9	5.2			5.0
10	5.3			5.0
11	5.2			5.0
12	5.0			4.2
13	5.2			5.0
14	5.2			5.0
15	6.0			5.0
16	4.4			4.0
17	5.2			5.0
18	4.3			4.0
19	6.0			4.4
20	5.0			4.4
21	4.3			4.0
22	6.0			5.0
23	4.0			3.1
24	5.0			4.3
25	6.0			5.0
26	6.0			5.0
27	5.4			5.0
28	5.4			5.0
29	5.3			5.0
30	5.4			5.0
31	3.2			3.0

Table C4

MONTH: FEBRUARY 1993

DATE	WHEAT	MAIZE	TOMATO	COWPEA
1	5.0	-Do-	-D-	5.0
2	5.2			5.0
3	6.0			5.0
4	6.0			5.0
5	6.0			5.0
6	5.0			4.1
7	5.1			4.4
8	5.2			5.0
9	6.0			5.0
10	2.0			2.0
11	6.0			5.0
12	5.4			5.0
13	6.0			5.2
14	6.0			5.1
15	5.0			4.3
16	5.0			4.3
17	5.0			4.3
18	4.0			4.0
19	3.3			2.0
20	5.3			5.0
21	5.3			5.0
22	6.0			5.0
23	5.0			4.3
24	5.3			5.0
25	5.0			4.0
26	5.0			4.4
27	5.0			5.9
28	5.0			5.0

Table C5

MONTH: MARCH 1993.

DATE	WHEAT	MAIZE	TOMATO	COWPEA
1	1.3	3.0	4.0	5.0
2	1.3	3.0	3.3	4.3
3	1.3	3.0	3.0	4.0
4	1.1	2.1	3.0	4.0
5	1.1	2.4	3.0	4.0
6	1.2	3.0	3.0	4.3
7	1.3	3.0	4.0	5.0
8	1.3	3.0	3.3	4.3
9	2.0	4.0	4.2	6.0
10	1.4	3.1	3.0	5.0
11	1.3	2.0	2.3	3.0
12	1.2	3.0	3.0	4.0
13	1.1	2.4	3.0	4.0
14	2.0	3.3	3.9	5.1
15	2.0	4.0	4.1	5.4
16	2.0	4.0	4.2	5.4
17	2.0	4.0	4.1	5.4
18	2.0	4.0	4.0	6.0
19	1.4	3.0	4.0	5.0
20	1.4	3.0	4.0	5.0
21	2.0	3.3	4.0	5.0
22	2.0	4.0	5.0	6.0
23	2.0	4.0	4.4	6.0
24	2.0	4.0	4.4	6.0
25	2.0	4.0	4.4	6.0
26	2.0	3.3	4.0	6.0
27	2.0	3.3	4.0	6.0
28	1.3	3.0	3.3	4.3
29	2.0	3.2	4.0	5.0
30	2.0	3.2	4.4	5.4
31	2.0	4.0	4.4	5.0

APPENDIX C
COMPUTED CROP WATER REQUIREMENT (BMN METHOD) - mm/day

Table C6

MONTH: APRIL 1993

DATE	WHEAT	MAIZE	TOMOTO	COWPEA
1	1.3	3.0	3.3	4.3
2	1.3	3.0	3.4	4.4
3	2.6	4.0	4.2	5.4
4	2.0	4.0	4.2	5.4
5	2.0	4.0	4.1	5.4
6	2.0	4.0	4.2	5.4
7	2.0	4.0	5.0	6.1
8	2.0	4.0	5.0	6.2
9	2.0	4.0	5.0	6.4
10	2.0	4.0	5.0	6.0
11	1.0	3.0	5.0	5.0
12	2.0	4.0	4.4	6.0
13	2.0	3.4	4.0	5.2
14	2.0	3.4	4.1	5.4
15	2.0	4.0	4.4	6.0
16	2.0	4.0	4.4	6.0
17	2.0	4.0	4.4	6.0
18	1.4	4.0	4.0	4.9
19	2.0	4.0	4.4	5.7
20	2.0	4.0	5.0	6.0
21	2.0	4.1	5.0	6.3
22	2.0	3.3	5.0	5.0
23	1.4	3.3	4.0	4.7
24	2.0	3.4	4.1	5.4
25	2.0	2.0	5.0	6.1
26	1.4	3.0	4.0	4.8
27	2.0	3.2	4.0	4.9
28	2.0	3.2	4.0	4.9
29	2.0	3.0	4.3	5.6
30	2.0	3.3	4.0	5.0

Table C7

MONTH: MAY 1993.

DATE	WHEAT	MAIZE	TOMATO	COWPEA
1	1.1	2.5	2.9	3.8
2	1.3	2.9	3.5	4.5
3	1.2	2.6	3.1	4.1
4	1.2	2.7	3.2	3.8
5	1.0	2.1	2.5	3.3
6	1.5	3.3	3.9	5.1
7	1.4	3.0	3.5	4.6
8	1.1	2.4	2.8	3.7
9	1.1	2.3	2.7	3.4
10	1.1	2.4	2.9	3.7
11	1.1	2.5	2.9	3.8
12	1.2	2.7	3.2	4.2
13	1.5	3.3	3.8	5.0
14	1.4	3.1	3.6	4.8
15	0.9	2.0	2.4	3.1
16	1.3	2.9	3.4	4.4
17	1.7	3.0	3.6	4.7
18	1.1	2.5	2.9	3.8
19	1.5	3.3	3.8	5.0
20	1.5	3.3	3.8	5.0
21	1.3	2.9	3.4	5.0
22	1.4	3.1	3.6	4.8
23	1.3	2.9	3.4	4.5
24	1.5	3.3	3.8	5.0
25	1.3	2.9	3.4	4.5
26	1.5	3.1	4.0	5.2
27	1.6	3.5	4.1	5.4
28	1.2	2.7	3.2	4.2
29	1.7	3.0	3.6	4.7
30	1.2	2.6	3.1	4.1
31	1.5	3.2	3.8	4.9

APPENDIX D

COMPUTED VALUES OF CROP WATER REQUIREMENT (PAN METHOD)

Table D1 PLOT 1: WHEAT

S/No.	92 NOV.	92 DEC.	93 JAN.	93 FEB.	93 MARCH	93 APRIL	93 MAY
1	1.6	1.3	3.4	4.3	2.5	2.2	1.9
2	1.8	1.8	4.1	4.3	2.0	2.2	1.8
3	1.8	1.8	4.1	4.6	2.1	2.1	1.9
4	1.6	1.9	4.4	4.8	2.1	2.0	1.8
5	2.0	1.8	4.6	4.2	2.1	2.3	2.1
6	2.0	1.7	3.5	4.0	1.3	2.2	1.1
7	1.9	1.4	4.9	4.2	1.6	2.5	3.2
8	2.0	3.8	5.9	4.4	1.4	2.5	1.6
9	3.8	1.8	3.2	3.8	1.6	2.7	1.2
10	2.0	1.6	4.2	5.3	2.5	2.5	2.3
11	1.8	1.6	4.0	5.4	2.4	2.5	0.4
12	2.2	0.9	4.8	5.1	2.0	2.5	1.4
13	2.2	2.0	4.5	5.1	2.3	2.0	1.9
14	1.4	2.5	4.4	4.8	2.0	2.6	1.9
15	2.2	2.1	4.4	4.8	2.2	2.3	1.4
16	1.5	4.8	5.0	5.2	2.2	2.3	1.8
17	1.8	5.0	4.8	6.8	2.4	1.3	2.2
18	1.4	5.0	4.4	4.1	1.7	1.5	2.6
19	1.4	3.9	4.1	2.0	1.8	1.9	2.3
20	1.5	3.7	3.7	2.0	1.7	2.2	2.2
21	2.3	4.4	4.7	2.5	2.4	2.1	2.6
22	2.1	3.4	4.8	1.8	1.5	1.5	1.9
23	3.8	3.2	4.3	2.5	1.9	1.7	1.6
24	2.5	4.4	3.7	1.2	1.9	1.1	2.1
25	1.7	5.0	4.3	2.1	1.5	1.9	2.6
26	3.8	6.0	6.8	2.1	1.5	0.9	0.8
27	3.8	5.4	4.1	2.2	1.5	1.7	0.8
28	1.3	1.3	3.9	2.5	2.4	0.9	0.7
29	1.3	5.7	4.3		2.0	1.0	0.8
30	1.3	5.4	5.4		2.7	1.0	0.7
31		9.0	6.3		2.2	0.9	0.3

Table D2

PLOT 2: COWPEA

S/No.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY
1	3.4	2.8	3.4	4.8	6.8	5.4	4.6
2	3.7	3.9	4.1	4.8	5.4	5.4	4.3
3	3.8	3.8	4.1	5.1	5.6	5.2	4.7
4	3.4	4.1	4.4	5.3	5.7	4.9	4.3
5	4.2	3.9	4.6	4.7	5.4	5.5	5.1
6	4.2	3.6	3.5	4.5	3.5	5.3	2.7
7	4.0	3.0	4.9	4.7	4.5	6.1	7.7
8	4.3	3.7	5.9	4.9	3.9	6.0	3.9
9	3.7	3.9	3.2	4.3	4.4	6.5	2.9
10	4.3	3.4	4.2	5.9	6.7	6.1	5.6
11	3.7	3.4	4.0	6.0	6.6	6.0	1.0
12	4.6	2.0	4.8	5.7	5.5	6.0	3.3
13	4.6	4.3	4.5	5.7	6.2	4.7	4.7
14	2.9	5.2	4.4	5.3	5.3	5.6	4.7
15	4.7	4.4	4.4	5.3	6.1	5.5	3.5
16	3.2	4.8	5.0	5.8	5.9	3.1	4.4
17	3.9	5.0	4.8	7.6	6.6	3.7	5.4
18	3.0	5.0	4.4	4.6	4.7	4.6	6.3
19	3.0	3.9	4.1	5.3	4.9	5.4	5.7
20	3.1	3.7	4.1	5.4	4.6	5.0	5.3
21	4.8	5.1	5.2	6.7	6.6	3.7	6.3
22	4.4	3.4	5.3	4.8	4.1	3.7	4.7
23	3.7	3.2	4.8	6.8	5.0	4.2	4.0
24	5.3	4.4	4.2	3.2	5.1	2.7	5.2
25	3.5	5.0	4.8	5.6	4.1	4.5	6.2
26	3.7	6.0	7.6	5.7	4.1	2.1	2.0
27	3.7	5.4	4.6	5.9	4.1	4.2	2.0
28	2.8	1.3	4.4	6.7	6.6	2.3	1.7
29	2.8	5.7	4.8		5.5	2.4	1.9
30	2.8	5.4	6.1		7.2	2.2	1.7
31		9.0	7.0		6.1		0.7

Table D3 PLOT 3: MAIZE

S/No.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY
1	4.0	3.2	4.0	5.6	7.9	3.5	3.0
2	4.3	4.5	4.7	5.5	6.3	3.5	2.8
3	4.4	4.4	4.7	5.9	7.5	3.4	3.0
4	4.0	4.7	5.1	6.2	6.6	3.2	2.8
5	4.8	4.5	5.3	5.4	7.5	3.6	3.3
6	4.8	4.2	4.1	5.2	4.1	3.4	1.8
7	4.6	3.5	5.7	5.4	5.2	4.0	5.0
8	5.0	4.3	6.8	5.7	4.5	3.9	2.5
9	4.3	4.5	3.7	5.0	5.1	4.2	2.0
10	5.0	4.0	4.8	6.8	7.8	4.0	3.6
11	4.3	4.0	4.6	6.9	7.6	3.9	0.7
12	5.3	5.0	5.2	6.6	6.4	3.9	2.1
13	5.3	5.0	5.2	6.6	7.2	3.0	3.0
14	3.3	6.1	5.1	6.2	6.2	4.1	3.0
15	5.4	5.1	5.1	6.2	7.0	3.6	2.3
16	3.7	5.6	5.8	6.7	7.8	3.6	2.9
17	4.5	5.8	5.5	8.8	7.6	2.0	3.5
18	3.5	5.8	5.1	5.3	5.4	3.0	4.1
19	3.5	4.5	4.7	6.2	5.7	3.5	3.7
20	3.6	4.3	4.7	6.3	5.3	3.2	3.4
21	5.5	5.1	6.1	7.7	7.6	2.4	4.1
22	5.1	4.0	6.2	5.6	4.7	2.4	3.0
23	4.3	3.7	5.5	7.9	5.8	2.7	2.6
24	6.2	5.1	4.8	3.7	5.9	1.8	3.4
25	4.1	5.8	5.5	6.5	4.7	2.9	4.0
26	4.3	6.9	8.8	6.6	4.7	1.4	1.3
27	4.3	6.3	5.3	6.8	4.7	2.7	1.3
28	3.2	1.5	5.1	7.7	7.6	1.5	1.1
29	3.2	6.6	5.5		6.4	1.5	1.2
30	3.2	6.3	7.0		8.4	1.4	1.1
31		10.5	8.1		7.0		0.4

Table D4

PLOT5: TOMATO

S/No.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY
1	4.0	3.2	4.0	5.6	7.9	3.8	3.2
2	4.3	4.5	4.7	5.5	6.3	3.8	3.1
3	4.4	4.4	4.7	5.9	7.5	3.7	3.3
4	4.0	4.7	5.1	6.2	6.6	3.5	3.0
5	4.8	4.5	5.3	5.4	7.5	3.9	3.6
6	4.8	4.2	4.1	5.2	4.1	3.7	1.9
7	4.6	3.5	5.7	5.4	5.2	4.3	5.5
8	5.0	4.3	6.8	5.7	4.5	4.3	2.8
9	4.3	4.5	3.7	5.0	5.1	4.6	2.0
10	5.0	4.0	4.8	6.8	7.8	4.3	4.0
11	4.3	4.0	4.6	6.9	7.6	4.2	0.7
12	5.3	2.3	5.6	6.6	6.4	4.2	2.3
13	5.3	5.0	5.2	6.6	7.2	3.3	3.3
14	3.3	6.1	5.1	6.2	6.2	4.4	3.3
15	5.4	5.1	5.1	6.2	7.0	4.0	2.5
16	3.7	5.6	5.8	6.7	6.8	3.9	3.1
17	4.5	5.8	5.5	8.8	7.6	2.2	4.4
18	3.5	5.8	5.1	5.3	5.4	2.6	4.4
19	3.5	4.5	4.7	6.2	5.7	3.2	4.0
20	3.6	4.3	4.7	6.3	5.3	3.8	3.7
21	5.5	5.1	6.1	7.7	7.6	3.5	4.4
22	5.1	4.0	6.2	5.6	4.7	2.9	3.3
23	4.3	3.7	5.5	7.9	5.8	2.9	2.8
24	6.2	5.1	4.8	3.7	5.9	1.9	3.7
25	4.1	5.8	5.5	6.5	4.7	3.2	4.4
26	4.3	6.9	8.8	6.6	4.7	1.5	1.4
27	4.3	6.3	5.3	6.8	4.7	2.9	1.4
28	3.2	1.5	5.1	7.7	7.6	1.6	1.2
29	3.2	6.6	5.5		6.4	1.7	1.3
30	3.2	6.3	7.0		8.4	1.6	1.2
31		10.5	8.1		7.0		0.5

APPENDIX E

RECORDS OF DISCHARGES, VOLUME AND APPLIED DEPTH TO VARIOUS FARM UNITS (PLOTS)

Table E1: Discharge Volume and Applied Depth to Farm Unit. F4
 Crop: Wheat
 Area. 1.0 ha

Date	Time used To Irrigate T (min)	up str. Height ha cm	Disch. Q (m ³ /s) x10 ⁻⁴	Vol. Appld. QT (m ³)	Depth Appld. d (mm)	Calculated crop water Requirement (CWR).		
						mm/day	HE	BMN Pan
26-11-92	159	3.8	3.9	3.721	12.40	-	-	-
7-12-92	149	4.5	5.0	4.700	15.67	45	52	16
18-12-92	120	3.5	3.4	2.448	8.16	55	44	26
29-12-92	97	4.8	5.5	3.201	10.67	50	48	41
12-1-93	92	4.3	4.7	2.594	8.65	56	63	61
21-1-93	83	4.5	5.0	2.490	8.30	41	45	40
9-2-93	79	5.3	6.4	3.034	10.11	77	98	82
19-2-93	80	4.0	4.2	2.016	6.72	40	53	49
1-3-93	78	3.8	3.9	1.825	6.80	55	49	23
Total			42.0	26.029	86.76	383	451	338
Average			4.7	2.892	9.64	48	56	42
Standard Error			0.8	0.770	2.57	10	14	18

Table E2: Discharge, Volume and Applied Depth to Farm Unit - F6

Crop: Maize Area: D & ha.								
Date	Time used to Irrigate	Up str. Height ha	Disch. Q (m ³ /s)	vol. Appld. QT (m ³)	Depth Appld. d mm	Calculated Crop Water Requirement (CWR)		
	T (min)	cm	x10 ⁻⁴			mm/day HE	BMN	Pan
26-11-92	29	3.5	3.4	0.5916	7.89	-	-	-
7-12-92	27	3.5	3.4	0.5508	7.34	36	52	47
18-12-92	26	3.3	3.1	0.4836	6.45	33	49	52
29-12-92	22	4.0	4.2	0.5544	7.39	28	42	54
12-1-93	19	3.5	3.4	0.3876	5.19	42	63	76
21-1-93	16	3.5	3.4	0.3264	4.35	36	49	47
9-2-93	17	4.0	4.2	0.4284	5.71	96	98	112
19-2-93	16	3.5	3.4	0.3264	4.35	60	47	66
1-3-93	16	3.5	3.4	0.3264	4.35	64	50	74
Total			31.9	3.9756	53.02	395	451	528
Average			3.5	0.4417	5.89	49	56	66
Standard Error			0.33	0.10	1.38	20	14	18

Table E3: Discharge, Volume and Applied Depth to Farm unit - F7

Crop: Wheat

Area: 3 ha

Date	Time used to Irrigate T (min)	Up strm. Height ha (cm)	Disch. Q (m ³ /s) x10 ⁻⁴	Vol. Appld. Qt (m ³)	Depth Appld. d (mm)	Calculated Daily crop Water Requirement (CWR) mm/day		
						HE	BMN	Pan
26-11-92	38	2.5	2.1	0.4788	1.60	-	-	-
7-12-92	30	4.0	4.2	0.7560	2.52	45	52	16
18-12-92	25	3.8	3.9	0.5850	1.95	55	94	26
29-12-92	35	3.5	3.4	0.7140	2.38	50	45	41
12-1-93	20	4.5	5.6	0.6000	2.60	56	63	61
21-1-93	35	3.8	3.9	0.8150	2.73	41	45	40
9-2-93	25	3.3	3.1	0.4650	1.55	77	98	82
19-2-93	30	3.3	3.1	0.5580	1.86	40	53	49
1-3-93	28	2.8	2.8	0.4200	1.40	55	49	23
Total			31.5	5.3958	17.99	383	451	338
Average			3.5	0.5995	2.0	48	56	42
Standard Error			0.83	0.12	0.41	10	14	13

Table E4: Discharge, Volume and Applied to Farm unit - F8

Crop: Maize

Area: 0.12 ha

Date	Time used to Irrigate T (min)	Up strm Height ha (cm)	Disch. Q (m ³ /s) x10 ⁻⁴	Vol. Appld. QT (m ³)	Depth Appld. d (mm)	Calculated Daily Crop Water Requirement		
						(CWR) HE	BMN	Pan
26-11-92	26	1.5	0.96	0.1498	2.0	-	-	-
9-12-92	23	2.0	1.5	0.2070	2.76	27	59	56
16-12-92	20	3.0	2.7	0.3240	4.32	21	31	32
22-12-92	19	5.0	5.9	0.6726	8.97	17	29	30
28-12-92	28	2.0	1.5	0.2526	3.36	28	19	29
4-1-93	18	3.0	2.7	0.2916	3.89	16	28	42
10-1-93	18	4.0	4.0	0.4536	6.05	22	30	30
15-1-93	22	1.5	4.2	0.1267	1.69	32	26	26
21-1-93	16	5.0	5.9	0.5664	7.55	32	29	32
26-1-93	17	2.0	1.5	0.1530	2.04	20	25	31
1-2-93	15	3.0	2.7	0.2930	3.24	28	30	37
6-2-93	17	2.0	1.5	0.1530	2.04	30	27	28
13-2-93	14	4.0	4.2	0.4284	5.71	42	35	43
20-2-93	17	2.0	1.5	0.1530	2.04	42	33	46
27-2-93	14	5.0	5.9	0.4956	6.61	38	31	45
1-3-93	15	4.5	5.0	0.4500	6.00	14	14	16
11-3-93	16	3.0	2.7	0.2592	3.45	70	27	62
16-3-93	15	5.0	5.9	0.5310	7.08	35	15	23
21-3-93	16	4.0	4.2	0.4032	5.38	35	17	32
26-3-93	14	5.0	5.9	0.4956	6.61	35	21	26
1-4-93	13	4.5	5.0	0.3900	5.20	39	16	38
Total			71.32	7.1987	95.99	623	540	701
Average			3.40	0.3272	4.57	31	27	35
Standard Error			1.76	0.15	1.97	9	7	9

Table E5: Discharge, Volume and Applied Depth to Farm Unit-F9

Crop: Wheat

Area: 1.0 ha

Date	Time used to Irrigate T (min)	Up-Strm. Height ha (cm)	Disch. Q (m/s) x10-4	Vol. Appld. QT (m3)	Depth Appld. d (mm)	Calculated Daily crop Water Requirement (CWR) mm/day.		
						HE	BMN	Pan
26-11-92	35	2.5	2.1	0.4410	1.47	-	-	-
7-12-92	45	3.0	2.7	0.7290	2.43	45	52	16
18-12-92	35	3.5	3.4	0.7140	2.38	55	44	26
21-12-92	38	2.5	2.1	0.4788	1.60	50	48	41
12-1-93	25	2.2	1.7	0.2550	6.85	56	63	61
21-1-93	35	3.0	2.7	0.5670	1.89	41	46	40
9-2-93	25	3.0	2.7	0.4050	1.35	77	98	82
19-2-93	26	3.5	3.4	0.5304	1.77	40	53	49
1-3-93	25	3.5	2.7	0.4050	1.35	55	49	23
Total			23.5	4.5252	15.09	383	451	338
Average			2.6	0.5028	1.68	48	56	42
Standard Error			0.48	0.13	0.98	10	13	18

TABLE 2
Mean daily global radiation in 10 day periods at the 20 reference stations in cal cm⁻² day⁻¹

Station	Latitude	Lokoja	Makurdi	Ilorin	Ibi	Mokwa	Bida	Minna	Jos	Yola	Yelwa	Kaduna	Bauchi	Samaru	Potiskum	Maiduguri	Gusau	Kano	Nguru	Sokoto	Katuna
Jan 1-10	7°48'	425	441	417	413	452	419	417	453	448	440	440	481	453	474	476	476	454	446	432	424
Jan 11-20	7°48'	386	417	379	386	406	445	415	483	498	461	453	481	446	454	446	468	425	418	418	418
Jan 21-31	7°48'	386	392	376	376	406	460	415	476	460	453	438	477	423	444	454	461	425	418	418	418
Feb 1-10	7°44'	449	466	441	471	454	504	476	533	512	485	500	522	493	497	505	533	481	490	459	512
Feb 11-20	7°44'	474	474	433	499	487	439	484	508	520	467	508	531	509	497	505	511	465	498	467	522
Feb 21-28	7°44'	474	491	474	516	496	438	508	533	520	467	508	531	509	497	505	511	465	498	467	522
Mar 1-10	7°44'	457	448	448	501	471	384	480	515	498	471	489	507	512	503	529	503	503	525	499	517
Mar 11-20	7°44'	431	422	439	445	471	393	480	480	463	498	489	484	506	477	511	477	494	473	508	482
Mar 21-31	7°44'	422	466	448	492	471	402	471	454	489	480	489	479	489	477	485	468	494	473	456	482
Apr 1-10	7°44'	445	454	454	463	492	402	502	475	475	480	480	457	484	484	502	431	484	520	520	448
Apr 11-20	7°44'	428	410	401	437	448	396	439	422	439	395	448	423	484	457	511	395	502	484	520	448
Apr 21-30	7°44'	445	463	428	472	448	314	457	395	457	422	448	463	475	484	475	368	493	466	457	475
May 1-10	7°44'	445	463	428	472	448	314	457	395	457	422	448	463	475	484	475	368	493	466	457	475
May 11-20	7°44'	419	428	419	436	475	290	469	469	434	401	460	427	481	472	490	410	499	502	484	448
May 21-31	7°44'	428	445	428	463	488	299	469	469	434	401	460	427	481	472	490	410	499	502	484	448
Jun 1-10	7°44'	419	428	419	436	475	290	469	469	434	401	460	427	481	472	490	410	499	502	484	448
Jun 11-20	7°44'	419	428	419	436	475	290	469	469	434	401	460	427	481	472	490	410	499	502	484	448
Jun 21-30	7°44'	419	428	419	436	475	290	469	469	434	401	460	427	481	472	490	410	499	502	484	448
Jul 1-10	7°44'	402	393	393	410	416	251	393	402	402	369	419	431	439	460	460	381	496	487	497	424
Jul 11-20	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Jul 21-31	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Aug 1-10	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Aug 11-20	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Aug 21-31	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Sep 1-10	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Sep 11-20	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Sep 21-30	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Oct 1-10	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Oct 11-20	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Oct 21-31	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Nov 1-10	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Nov 11-20	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Nov 21-30	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Dec 1-10	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Dec 11-20	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424
Dec 21-31	7°44'	368	359	359	376	407	260	375	367	412	378	410	431	439	460	460	381	496	487	497	424

Table G1 — Crop Coefficients (Kc) for various crops and their growing periods

Crop	Relative Humidity more than 70% (humid)		Relative Humidity less than 20% (arid)		Growing Period Days
	Mid- Season	Final Growth	Mid- Season	Final Growth	
Barley, Wheat	1.1	0.25	1.2	0.2	120-165
Green Beans	0.95	0.85	1.0	0.9	75-90
Maize	1.1	0.55	1.2	0.6	80-110
Millet	1.05	0.3	1.15	0.25	105-140
Sorghum	1.05	0.5	1.15	0.55	120-130
Cotton	1.1	0.65	1.2	0.65	180-195
Tomatoes	1.1	0.6	1.2	0.65	135-180
Cabbage	1.0	0.85	1.1	0.95	80-95
Cauliflower					

APPENDIX H
Table H.1 Radiation Ratios for the EBM Evapotranspiration Model (Dunn 1984)

Lat. N.	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
04°00'	.0819	.0770	.0806	.0853	.0851	.0799	.0832	.0859	.0852	.0866	.0802	.0803
04°30'	.0816	.0775	.0886	.0855	.0855	.0803	.0836	.0862	.0852	.0863	.0798	.0797
05°00'	.0812	.0773	.0886	.0857	.0859	.0808	.0841	.0865	.0852	.0861	.0794	.0792
05°30'	.0807	.0771	.0885	.0859	.0863	.0813	.0845	.0868	.0853	.0859	.0790	.0787
06°00'	.0803	.0768	.0885	.0861	.0866	.0818	.0850	.0871	.0853	.0857	.0786	.0782
06°30'	.0799	.0765	.0885	.0863	.0870	.0822	.0854	.0874	.0854	.0855	.0782	.0777
07°00'	.0794	.0763	.0884	.0865	.0874	.0872	.0859	.0877	.0854	.0853	.0778	.0772
07°30'	.0790	.0760	.0884	.0867	.0877	.0832	.0863	.0879	.0851	.0852	.0775	.0767
08°00'	.0785	.0753	.0883	.0869	.0881	.0836	.0867	.0882	.0855	.0850	.0771	.0762
08°30'	.0781	.0755	.0883	.0870	.0885	.0841	.0872	.0885	.0855	.0848	.0767	.0758
09°00'	.0777	.0753	.0882	.0872	.0889	.0845	.0876	.0888	.0855	.0846	.0764	.0753
09°30'	.0772	.0750	.0882	.0874	.0892	.0850	.0880	.0891	.0856	.0844	.0760	.0748
10°00'	.0768	.0743	.0881	.0875	.0896	.0854	.0885	.0894	.0856	.0842	.0757	.0744
10°30'	.0764	.0745	.0881	.0877	.0900	.0859	.0889	.0897	.0857	.0840	.0753	.0739
11°00'	.0759	.0742	.0880	.0879	.0904	.0864	.0894	.0900	.0857	.0838	.0749	.0734
11°30'	.0755	.0740	.0879	.0881	.0908	.0868	.0898	.0903	.0857	.0836	.0746	.0729
12°00'	.0751	.0737	.0878	.0882	.0912	.0873	.0903	.0906	.0850	.0835	.0742	.0724
12°30'	.0746	.0734	.0878	.0884	.0916	.0878	.0907	.0909	.0858	.0832	.0738	.0719
13°00'	.0742	.0732	.0877	.0886	.0919	.0883	.0912	.0912	.0859	.0830	.0734	.0714
13°30'	.0737	.0729	.0877	.0888	.0923	.0887	.0916	.0915	.0859	.0828	.0731	.0709
14°00'	.0733	.0726	.0876	.0890	.0927	.0892	.0921	.0918	.0850	.0826	.0727	.0704