EVALUATION OF INTRODUCTION IN COTTON SCIENCE

By

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To my dear brother Dr. El Gerari Osman Honid
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في هذه الدراسة تم عرض المنهج الأساسي المتبوع من حيث كمية المياه في البيئة الرئيسية والصوامع الفرعية للمياه والتي تم تقيييها، بحيث تشكل سلسلة من النماذج البيئية خلالها استنشاق المياه خارج المياه يمكن أن يدخل النظر في هذه البيئة بواسطة وزارة المياه. كما تم تقييم احداث التغيرات في الفترات الزمنية بالبيئة بالإضافة إلى التأثيرات العالية والتأثيرات السلبية للنظام البيئي للمياه الممتدة. قد تؤدي هذه الدراسة إلى تحسين تفاهيم فهم شرائح مياه الصرف الصحي. 

كما أجريت تقارير عن الكبار الموجودة بالاقطارات التي قد تؤدي إلى تغييرات في البيئة. 

يرجى إجراء التحقيق ببعض الدوريات، والبحث في موضوعات متعلقة بتطبيق الدوريات، لينتج عن ذلك تحذيرات لفترة ممتدة.

يرجى إجراء التحقيق ببعض الدوريات، والبحث في موضوعات متعلقة بتطبيق الدوريات، لينتج عن ذلك تحذيرات لفترة ممتدة.
Abstract

The objective of this research was to evaluate the irrigation practice in the Gezira with respect to availability and use of irrigation water.

Discharge measurements were made by the current meter technique in the Gezira Main canal and three minor canals in the South of the scheme. Discharge measurements in the Gezira Main canal were compared with that calculated by the Ministry of Irrigation. In minor canals discharge measurements were compared with water requirement predicted from weather records, in consideration with the cropped area, type of crop and its stage of growth. The traditional inverting system made by the block inspectors was also considered.

The study revealed that there was a variation in irrigation water requirement throughout the season; generally being greater than the measured discharge in the corresponding canals and periods. Accordingly shortage of irrigation water to satisfy the crop needs was evident. The current inverting system is an ad-hoc and thus difficult to explain or relate
Fig(1.1) The Sudan Gezira board map.
Chapter (1)

Introduction

There is awareness among engineers, soil scientists, and agriculturalists of the importance of water in agricultural development and the need for its proper conservation and use. Increased world population coupled with industrial and agricultural development has increased the demand for water as a national resource. Irrigated agriculture utilizes about 80 percent of the world water supply (I.C.I.D. 1980). In arid and semi-arid regions, irrigation provides the principle source of water for agriculture; while in temperate and humid regions, irrigation may be applied to supplement rainfall.

Sudan is an agricultural country where agriculture contributes about 80 percent of the total exports of the country, about 63 percent of which comes from the irrigated sector (CSAM et al., 1972). It lies in the arid region across the middle reaches of the River Nile. The climate of the country is extreme desert in the north to semideciduous conditions north of Khartoum. South of Khartoum are the tropical savanna lands which change to tropical rain forest in the extreme south.
The annual rain varies from zero in the north to over 1000 mm in the south. The Nile and its tributaries constitute the main source of water for agricultural development in the riverian land along the Nile valley.

The distribution of the water obtained from the Nile and its tributaries is governed by the main bilateral agreements between Egypt and the Sudan namely: The 1929 and 1959 agreements. Following the 1959 agreement Egypt and the Sudan are eligible for 55.5 and 18.5 million respectively, measured at Aswan. An extra 4 million cubic meter will be added by the completion of Jangil Diverion canal presently under construction. This extra 4 million will be divided equally between the two countries.

The Gezira scheme utilizes one third of the annual allocation of the Sudan share from 1959 Nile water agreement (1350 1960) to irrigate an area of about two million feddans.

This area constituted about 13 percent of the land under cultivation and more than half of the
country's irrigated land (S.G.B., 1976). The same author revealed that the Gezira scheme produces 75 percent of the extra long staple cotton, 12 percent of rice, 15 percent of groundnuts and 25 percent of wheat of the total Sudan production.

Therefore, judicious use of irrigation water in the Gezira should consider proper assessment and measurement of existing irrigation practice as a basis for improvement of the utilization of this water. Different techniques for assessing the irrigation water requirement of field crops are available. These techniques are either used to measure or predict the crop water use. However, it is sometimes laborious and time consuming to get a field measurement of the field irrigation requirement. Accordingly prediction methods have got the advantage of being more convenient and applicable in the routine of the day-to-day water management.

The objective of this research is to evaluate the existing irrigation system in the Gezira with respect to proper utilization of water as a limiting resource.
2.1 BACKGROUND:

Gezira is the land lying between the White and Blue Nile in the centre of Sudan (Figure 2.1) the
Gezira Scheme extended over an area of about 2,000,000
hectares of plain land. It is claimed to be the largest
integration development scheme in the world and
specifically in Africa (Barnett: 1978).

Topography of the land is very flat with slope
commonly in the order of 5 cm: 1 km northwards. The
Gezira soil is deeply cracked, montmorillonitic, heavy
clay type with swelling and shrinking characteristics
(Farbrother, 1972).

Irrigation in Sudan began by pumps as a progressive
substitute for the traditional flooded irrigation in the north
of the country. Pump irrigation started in Aksaih in
1904 with small experiment for growing cotton using water
lifted from the Nile. A continuation of pump irrigation
was then considered in the Gezira area at Ummanat near
Barkat city in 1912, Bag Abdalla in 1921 and at Wad
Sina in 1923 (Gurnee et al, 1972). The experience
gained in this type of irrigation established a firm background for the large scale irrigation of Qasira (Taha, 1979).

The beginning of the gravity irrigation in the Qasira started with the construction of Samra dam in 1925 to irrigate an area of about 500,000 feddans (S.Z.A., 1982).

The water stored in the dam is diverted downstream to the fields by the action of gravity, through two main canals; one for Qasira and the other for Managil extension. Despite the initially high cost of construction of dams, canals and other structures necessary for the system, gravity irrigation systems were claimed to be the least expensive and most popular (Stegeman et al., 1980).

The design capacity of the irrigation network permits a certain crop pattern and intensity. Generally in the design of irrigation schemes the system should permit an additional 5 - 10% discharge over the design capacity (World Bank, 1980). This allowance may be for deep percolation losses, future expansion or domestic
water use. For the Gesira scheme the allowance over the
design capacity is only 2% (World Bank, 1980). This
may be due to the fact that the heavy clay soil of
Gesira has a relatively low infiltration rate, and
hence deep percolation losses can be considered negligible.
Obviously, the cropped area of an irrigated scheme
depends greatly on the maximum area that can be irrigated
by the existing canals and structures. This was neglected
during the intensification of Gesira in the early sixties
when the cropping intensity was increased from 6% to 7%
without increasing the canal capacity (IREL, 1966).
However, intensification of the crop rotation has brought
into cultivation an added 450,000 feddans of wheat and
190,000 feddan of rice. Recently, rice was abandoned
(because of the large amounts of water required, and
how productivity) there was no increase in the canal
capacity (El Obeid, 1982).

In the following sections the irrigation practice
of Gesira will be considered in terms of organization and
management. This will include the water supply and its
availability, the layout of the irrigation network and
the management of the irrigation water at the farm
level.
2.2 Irrigation water supply:

The water supply to irrigate the Gezira scheme is diverted from Sennar dam. In irrigation a dam may be constructed to perform a particular function depending on the level of the land to be irrigated relative to that of water in the river. In the case of Gezira, the topography is very flat and the level of water in Sennar dam is higher than that of the land under cultivation. Therefore, the Sennar dam is a storage reservoir where water during the rainy season is stored for use during the period of deficiency. However, according to the up-to-date view dams should not be built for irrigation alone, and as far as possible, must also serve to improve navigation facilities or creation of hydroelectric power. Accordingly, Sennar dam serves as a storage reservoir as well as a source for a hydroelectric power. The reservoir capacity is about 0.91 milliard, with an annual evaporation of 0.3 milliard, supplying water for the Gezira and Kassala main canals.

2.3 Irrigation layout:

The irrigation network of the Gezira Scheme is composed of two main canals: one irrigating the Gezira
and the other irrigating Managil extension. The main canal branched into major and minor canals and at the farm level water is distributed by Abu xx. Table 2.1 shows the number and length in km of the main, major and minor canals together with Abu xx.

Table (2.1): Number and length in km of canals

<table>
<thead>
<tr>
<th>Main Canal Branch of</th>
<th>Major Canal Minor Canal Abu xx</th>
</tr>
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<tbody>
<tr>
<td>No. Length</td>
<td>No. Length</td>
</tr>
<tr>
<td>Gesira 1 204 6 163</td>
<td>72 893</td>
</tr>
<tr>
<td>Managil 1 37 5 452</td>
<td>35 759</td>
</tr>
</tbody>
</table>

Sources: (World Bank, 1979)

Table 2.1 shows the different components of the Gesira irrigation network. It is clear from the Table that 10640 kilometers were dug to establish the network.
2.3.1 Main Canals:

Two main canals divert the water from Semna Dam to the cultivated area of the Gezira Scheme. These two canals are:

1. The Gezira Main canal with a capacity of 15.3 million cubic meter per day.
2. Manzili Main canal with a capacity of 14.7 million cubic meter per day.

The two main canals are on the west of the Blue Nile carrying irrigation water downstream 57 km to the Gezira basin (Mathew, 1974). Since the main canals are below ground level for part of their length water has to be raised by pumps in few blocks in southern regions of the scheme.

Table (2.2) shows the site of the irrigation pumps on the Gezira Main and, their location relative to the Main canal and the area served by each pump. It can be seen that the area served by pumps (i.e., 74,255 feddans) constitutes about 4% of the total area of the Gezira Scheme.
Table (2.2): Irrigation pumps on the Genira Main canal

<table>
<thead>
<tr>
<th>Site</th>
<th>Area served in feddans</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilo 11 left bank</td>
<td>20,566</td>
<td>Irrigation</td>
</tr>
<tr>
<td>Kilo 43 right bank</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>Kilo 29 left bank</td>
<td>2077</td>
<td></td>
</tr>
<tr>
<td>Kilo 41 right bank</td>
<td>45,612</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>74,255</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Genira study mission 1966.

2.3.2 Minor canals:

These are water channels off-takes from the major canals. They vary in length, width and depth relative to the watered areas, and each 5 to 10 minors constitute a block (Ministry of Irrigation, 1966).

2.3.3 Abu AL: It is a field ditch off-take from the minor canal. Its length is about 1400 meterized the
distance between one and the other is 232 meter approximately, which is equivalent to the length of
Nawashia (tenant holding). Abu xx is connected to the
minor by steel pipe of 350m in diameter commonly known
as a field outlet pipe. The discharge capacity of this
pipe is usually approximated to about 5000 m$^3$/day
(Ministry of Irrigation, 1965).

Measurement of selected field outlet pipe
discharges by Barbrather in 1974 has shown variation
from 1000 - 5000 m$^3$/day.

The scheme is divided into irrigation units of
30 feddans area called a Number, irrigated by one Abu xx.
Each Number is subdivided into nine tenant holdings
(i.e Nawashia). From Abu xx smaller irrigation channels
known as Abu vi's feed irrigation water to each Nawashia.
Even smaller channels (Badwals) finally lead the water
into the Nawashia. Each pair of Badwals is divided by
a large ridge (Tagmat). The area bounded by Badwals and
Tagmats is known as Anganal. In each Anganal the fifteenth
ridge is strengthened and built up to form Abamat
(Scott, 1967). Figure (3.1)
Fig(2.1) Typical irrigation layout at the field level showing minor canal, AbuXX, Abu VI, Godwal and Tagnat
2.6 Irrigation Water Management

Administratively the scheme is divided into 14 groups and 269 blocks. A group area ranges from 80,000 to 200,000 feddans. Water supply from the main to the minor canals is the responsibility of the Ministry of Irrigation, while that from the minor to Abu xx is the responsibility of agricultural officials of the Gezira Board (i.e. Block inspectors). Block inspectors are assisted at the field level by water-men who physically control the water supply to Abu xx’s (Abbied, 1982).

The design sheets of the Ministry of Irrigation (1965) have shown that the Gezira scheme was designed originally for continuous flow i.e. day and night flow in all minor canals, with 10 to 30 cm command at flat water level. Since it is not always possible to get this command level and impractical to irrigate by night, the night storage system was introduced. In night storage water is stored during the night in order to create enough command level for irrigation by day.
Following the intensification and diversification of the crop rotation in Osira, both the water and labour required for irrigation has increased. Accordingly, the use of night storage technique became impractical and irrigation continued, though unattended, during the night. Ultimately, the present irrigation practice in Osira is more of continuous flow than night storage system.

2.4.1 Irrigation water intake:

It is the water supply required to irrigate the cultivated area within the minor canal. The block inspector estimates the intake by assuming that each field outlet-pipe will regulate the flow of water from the minor to the xx at an approximate rate of 5000 m³/day (Farahat, 1977). Some field inspectors estimate their intakes assuming that the field outlet-pipe capacity is 4000 m³/day, while others do their own estimate relying on personal experience and judgement.

Since the intake is the responsibility of the field inspector, the usual practice is to intend more water than required, especially during the peak water...
requirement period. In addition the field inspectors have no guarantee or means of checking on the amount of water delivered in the minor canals.

The peak water requirement period may extend from September to November depending on the rainy season, during which the daily indenting is satisfied from the base flow of the Nile. After that the daily irrigation requirement is supplied from that stored in Sennar dam (World Bank 1990). Since cotton and groundnut are usually harvested by the end of November, the water stored in the dam is supposed to satisfy the irrigation requirement of cotton and wheat.

Under E.A.O project, Farbrother (1977) suggested a new system of indenting based on the advanced indent with respect to the total fields scheduled for various crops and their recommended planting dates. His system is completely independent of the actual number of the field outlet-pipes that are opened daily. This means that the calculation of the week by week changes in the indent for the whole season can be undertaken well in advance from the start of the season.
If implemented, this advance inventory has got the advantage of forward planning of irrigation relative to the other forcing operations. The preparation of this new system (i.e. advance inventory) was described in the annual reports of the Gezira research station (G.R.S., 1973). In these reports the water use rate was obtained from weather data using Penman combination equations with the appropriate crop coefficient, obtained from field experiments. Appendix I shows crop water requirement based on the average monthly data obtained from Wadmadani research station. Though the technique was proposed it has not been put to practice under field conditions. This is because of variation in planting dates and rainfall of the field inspectors and foremen to use it.

The use of either of the above methods for inventing depends greatly on the decision of the field inspector as he is fully responsible within his field block. Therefore it might be misleading to say that either method is used more than the other. However, using an approximate discharge of 5,000 m³/day
for each field outlet-pipe to estimate the amount of water required in a particular minor has got more acceptance among field inspectors. This is probably because the calculations involved are simple compared with those required using the advance indexing techniques.

2.5 Discharge Measurement:

Water measurement is very important for both good water management and perfect operation of an irrigation system (Zimmeman, 1966). Good irrigation water use requires knowledge of the quantity of water available and that required to produce a crop relative to the existing soil and environmental conditions (Stegman et al., 1980).

Several methods are commonly used for measuring irrigation water supply to the farm. They can be grouped (Michael, 1973) into:

1. Volumetric Method of Water Measurement
2. Velocity-area Method
3. Measuring Structures such as weirs, flumes and flumes.
2.5.1 Volumetric method of water measurements:

Although this method is the most accurate, it is not widely used and its application is confined to discharge measurements from small streams. It is used for the calibration of the other measuring devices. In this method the flow is collected in a container of known volume for a given period of time to obtain the discharge per unit time (Michael, 1978).

2.5.2 Velocity area method:

The rate of flow passing a point in a pipe or open channel is determined by multiplying the cross-sectional area of the flow section at right angle to the direction of the flow by the average velocity (Hansen, 1962) i.e.,

$$Q = AV$$  \hspace{1cm} (2.1)

Where:

- \( Q \) = discharge per unit time
- \( A \) = area of cross-section of channel or pipe
- \( V \) = velocity of the flow

While the cross-sectional area \( A \) can be estimated or measured, the velocity of flow \( V \) is measured.
either by: (a) current meters or (b) float measurements technique.

1) CURRENT METERS:

These devices consist essentially of rotating element whose speed of rotation varies with the velocity of flow.

The current meters are usually suspended in a river or canal by a cable and hence must have empennages and weights to hold them in a fixed position in the canal (John et al., 1975).

The current meter consists essentially of a vaned wheel turned by the flowing water at a speed proportional to the water velocity. A mechanical stop-and-break attachment on the rotating spindle or of instrument trigger an electrical pulse that can be counted or recorded remotely. The velocity measured is therefore, an average over a short period of time.

Two types of current meters are commonly used in open channels:

1. The cup-type
2. The propeller type
some author stated that velocities are reduced at the banks and bed of the canal, but it must be realized that in the open flow the roughness and turbulences are of such great and irregular magnitudes that the velocity distribution cannot be placed on the precise basis which it enjoys in pipe flow. However from long experience and thousands of measurements, the United States geological survey (Stearns et al. 1960) has established certain average characteristics of velocity distribution in streams and rivers which serve as a basis for current water measurements. These characteristics of velocity distribution in a vertical section are shown in (3.2), and may be amplified by the following statements:

1. The curve may be assumed parabolic
2. The location of the maximum velocity is from 0.05 to 0.25 of the depth from the water surface (y)
3. The mean velocity occurs at approximately 0.67 below the water surface
4. The mean velocity is approximately 85 percent of the surface velocity
5. A more accurate and reliable method of obtaining the mean velocity is to take a numerical average
Fig(29) Standard velocity distribution in a vertical in open flow

\[ v_s = \frac{1}{0.85} \cdot \frac{v_{\text{max}}}{v_{\text{mean}}} \]
of the velocities at 0.2 and 0.6 below the water surface. These average values will, obviously, not apply perfectly to a particular stream or river, but numerous measurements with the current meter will tend towards accurate results since deviations from the average values will tend to compensate, thus giving a great accuracy that can be obtained from individual measurements (John et al. 1978).

The same author reported that current meter measurements for calculation of flow rate may be taken in the following manner: A reach of a river having a fairly regular cross section is selected. This cross section is measured accurately by soundings. It is then divided into vertical strips (Figure 2.3). The current meter is suspended, and velocities are measured at the two - or three - eight - beach points in each vertical strip (1, 2, 3 etc.) (Figure 2.3). From these measurements the mean velocities \( V_1, V_2, V_3 \) etc.) in each vertical section may be calculated. The mean velocity through each vertical strip is taken as the average of the mean velocities in the two verticals which bound the strip, and thus
Fig (2.3) Division of river cross section for current meter measurement.
the rate of flow \( q_{12}, q_{33}, \text{etc.} \) through the strips may be calculated from:

\[
q_{12} = b_{12} \left( \frac{y_1 + y_2}{2} \right) \left( \frac{v_1 + v_2}{2} \right)
\]

\[
q_{33} = b_{33} \left( \frac{y_3 + y_4}{2} \right) \left( \frac{v_3 + v_4}{2} \right)
\]

and the flow rate in the stream may be calculated by totaling the flow rate through the various strips.

b) **Flume measurements:**

Quick, intensive measurements of discharges are frequently made by timing the velocity of an object on the surface of the water. The observed surface velocity must be reduced, by a correction factor to get the average velocity. The correction factor is influenced by roughness, shape of channel, and depth of flow, i.e., usually in the order of 0.85 and may be as low as 0.8 and as high as 0.95. It increases as depth increases and diminishes as roughness of channel bed increases. (Johansen, 1962).
2.5.5 Measuring Structures:

In farm irrigation practices, the most commonly used devices for measuring water are orifices, weirs and flumes. In these devices the rate of flow is measured indirectly by making a reading on scale which is part of the instrument. The discharge rate can also be obtained from standard tables or calibration curves prepared specially for the instrument. All the three devices (i.e. orifices, flumes and weirs) can be made locally for farm use and give accurate results when constructed, installed and operated properly. The choice between one or the other depends on the expected flow rate and site conditions (Iseraelson, 1962 and Michael, 1976).

a) Orifices:

These are defined as openings in a plate or bulkhead the top of which is well below the stream water level. Figure (2.4) shows a typical orifice shape as used in irrigation canals. If the orifice discharges into the air, it is a free - discharge orifice, if it discharges under water, it is a submerged
Fig (2.4): The discharge of water through an orifice under head $h$. 

Source: Israelsen (1962)
orifice. Free discharge orifices require considerable head and are usually limited to special location where head loss is critical (Stegeman et al., 1980).

While submerged orifices require less head and are more commonly used in measurement of irrigation water. Orifice shapes vary widely which are either circular, sharp-edged or rectangular. One general problem of orifice is debris clogging that prevent accurate measurements. It is frequently difficult to tell if partial clogging of the orifice has occurred specially with sediments. To prevent canal overtopping, the top of the orifice wall should only extend to the maximum expected upstream water level so that it can act as emergency weir when orifice is plugged. Ismael, 1982; Michael, 1973 and A.S.A.E., 1980 reported that the head discharge relationship for a circular, sharp-edged, submerged orifice is:

\[ Q = C_d \cdot A \cdot 2gh \sqrt{h_1 - h_2} \]  

(2.4)

where:

- \( Q \) = discharge rate, \( m^3/\text{sec} \)
- \( C_d \) = discharge coefficient ranging between 0.27 and 0.61
\[ A = \text{area of orifice opening, } m^2 \]
\[ g = \text{gravitational constant, } 9.81 \text{ m/s}^2 \]
\[ h_1 - h_2 = \text{head difference across the orifice in } m \]

The structure used for the discharge regulation in the Giza main canal is a typical submerged orifice. However, the equation used by the irrigation engineers (Kamal Abd., 1983) to calculate the discharge is:

\[ Q = C_d A \sqrt{(h_1 - h_2)} \quad (4.5) \]

where:
\[ h_1 \text{ and } h_2 = \text{upstream and downstream water level across the orifice respectively} \]
\[ A = \text{the area of the orifice opening adjusted as required} \]
\[ C_d \text{ discharge coefficient assumed 0.67.} \]

The principle advantage of a submerged orifice is the small loss of head or difference in elevation of the water surface on the upstream and downstream of the orifice making it suitable for use in canals and ditches having small slope (Israelson, 1962; Michael, 1978 and Shams et al., 1980).
h) Wires.

The term weir used in measurement of water is defined as a notch in a wall built across a stream (Michael, 1973). Accurately for a rectangular weir the actual discharge can be approximated to:

\[ Q = 2.49 \sqrt{h} \]  

(2.5)

where:

- \( Q \): Discharge in \( \text{m}^3/\text{per unit time} \)
- \( h \): Head in metres.

Figure (2.5) shows a typical sectional view showing its essential components.

The advantages of a weir in discharge measurements are:

1. Accuracy
2. Simplicity
3. Ease of construction
4. Non-obstruction to flow or floating materials and durability.

Compared with orifice, weirs require a large head difference (i.e. a considerable fall of water) and therefore not suitable in canals with low slopes. In addition, depositions of sands and silts in front of the weir prevent accurate measurements (Street, 1973).
Fig. (2.5) Sectional view (vertical) of weir

Velocity head

$h = \frac{v^2}{2g}$

This space be vented at atmosphere

Channel bottom

source Michael (1978)

Horizontal line

Water surface

$2H$ min.
3) Critical-flow flumes:

They are rate meters suited for measuring irrigation water in open channels. They consist of specified construction built into the canal floor and/or sidewalls that raises the upstream flow level above that which would have existed without the construction (Iversen, 1962 and Michael, 1978). This rise must create enough fall to cause critical flow in the constructed section or float of the flume (A.S.A.E., 1960).

1.6.4 Prediction of crop water requirement from weather data:

The subject of crop water requirement which includes evaporation from land and water surfaces and transpiration from plant surfaces, commonly known as evapotranspiration, is becoming important particularly in arid and semi-arid regions.

The prediction of crop water requirement from weather data and its practical utilization in irrigation water management has received considerable attention over the past decade. The A.S.A.E (Jensen, 1974), the
FAO (Ogrenbroe and Pruitt, 1977) and A.S.O.E. (Siegman et al., 1980) have considered and advocated the use of crop water requirement predictions in the management of irrigation schemes. This is because the technique is less tedious and the results obtained can be generated from one place to another and for future use.

The A.S.O.E. (Jensen, 1974) presented an intensive review and evaluation of the methods available to predict evapotranspiration from weather records. The evaluation was done by comparing the predicted crop water requirement using each method with that obtained from lysimeter measurements covering a wide range of climatic conditions. They concluded that no method is universally applicable without regional or local calibration. However, the FAO (Ogrenbroe and Pruitt, 1977) presented guidelines and processed tables for the use of these commonly used methods; together with the weather data required in each of them. In addition, evaporation from pan (i.e. open water surface) was also included.

Table (2.3) shows these methods and the data required for them. It can be seen that measurement of
of temperature is required in three methods while sunshine hours and solar radiation measurements are required in the radiation and Penman methods only. In addition the Penman combination equation requires measurement of humidity and wind speed. In absence of direct solar radiation data, temperature records can be used to obtain solar radiation estimates. Despite the data required and the computations involved in the Penman combination equation, it proved to be the most accurate compared with other methods available for predicting crop water requirement from weather data (A.S.C.E.; Jensen, 1974 and P.A.D; Decorenza and Frueit, 1977).

Table (2.5): Weather data required for each method.

<table>
<thead>
<tr>
<th>Method</th>
<th>Temp. °C</th>
<th>Humidity</th>
<th>Wind</th>
<th>Sunshine</th>
<th>Radiation (in hr cal/cm²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blaney Criddle</td>
<td>x</td>
<td>Z</td>
<td>Z</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>Radiation</td>
<td>x</td>
<td>Z</td>
<td>Z</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Penman</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Pan evaporation</td>
<td>Z</td>
<td>Z</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

x: measured data
Z: estimated data
*: if available but not essential
2.6.1 Penman combining equation:

The first combining equation was developed by Penman in 1948 from his work in South East England (Penman, 1956). Penman regarded evaporation from soil and water surface and transpiration from plant surfaces as a combined effect of the energy balance and aerodynamic or mass transfer theories. The combining equation of Penman is basically as follows:

\[ E_o = \frac{H + E_a}{\Delta + \gamma} \]  

(2.7)

where:

- \( E_o \) = Reference evapotranspiration usually measured in mm/day.

- \( H \) = energy balance component in equivalent mm evaporated per day.

- \( E_a \) = aerodynamic component in equivalent mm evaporated per day.

- \( \Delta \) and \( \gamma \) = adjustment factors where:

  - \( \Delta \) = slope of saturation vapour pressure at near air temperature.

  - \( \gamma \) = psychrometric constant.
The Penman combination equation has been put to a rigorous assessment since its proposition. Accordingly different modifications and improvements were included into the original form of the equation. The most applied modification was the one presented by FAO (Teorell et al., 1972) as:

\[ \text{ET}_0 = C \left\{ (W/R_n + (1 - C)) f(w) (e_s - e_a) \right\} (2.8) \]

where:

- \( \text{ET}_0 \) = Reference evapotranspiration in mm/day
- \( W \) = Temperature related weighting factor
- \( R_n \) = Net radiation in cal/cm\(^2\)/day
- \( f(w) \) = Wind related function
- \( (e_s - e_a) \) = Difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in a bar
- \( C \) = Adjustment factor to compensate for the effect of day and night weather conditions obtained from tables.
2.6.2 Crop Characteristics:

The crop water requirement differ according to the prevailing weather conditions and stage of crop growth. Crops usually start with a low water use early in the season, and reaches the maximum at the attainment of maturity and then their use rate decline during the senescence phase till harvest. (Figure 2.6) Accordingly, Doorenbos and Pruitt, (1977) reported that the crop growing season can be divided into four stages as:

1. Initial stage: Germination and early growth when the soil surface is not or is hardly covered by the crop.

2. Crop development stage: From end of initial stage to attainment of effective full cover.

3. Mid season: From attainment of effective full cover to time of start of maturity.

4. Late season stage: From end of mid season stage until full maturity or harvest. The length of each growth period differ according to the kind of the crop and prevailing weather conditions.
Fig (25) Example of crop coefficient curve.
Therefore the evapotranspiration obtained from weather data need to be adjusted to the actual crop water use. This has given rise to what is known as the crop coefficient (Kc) which is usually obtained according to the stage of crop growth. The crop coefficient (Kc) is normally less than unity in the early and late growth stages and approach unity in the development phase and exceed it during the maturity phase (Stogryn et al., 1980).

Table (2.4) shows crop coefficients obtained at the Gezira research station from field experiments for the crops grown in the Gezira. The crops include, cotton, pulse, wheat, groundnut and legumes. These crop coefficients were obtained for a 10-day period in the growth cycle of each crop within its growing season.
<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
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<td>0.6</td>
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<td>0.7</td>
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<td>0.7</td>
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<td>0.7</td>
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<td>0.8</td>
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<tr>
<td>1.0</td>
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</tbody>
</table>
Chapter (2)  
Materials and Methods

3.1 Introduction:

To evaluate the existing irrigation practice in the Gezira Scheme, a criteria for evaluation was adopted. It involved data on discharge measurements from irrigation canals and crop water requirement predicted with Penman combination equation using long term weather records obtained from Madani Meteorological Station. The measured discharge represented the water available for irrigation, while the crop water requirement predicted from the weather record assumed to represent the water needs of the crops. Both the water available for irrigation (discharge measurements) and the crop water requirement (predicted from weather records) were compared with those calculated with equation 2.5 and the results by the block inspectors relative to the cropped area.

This evaluation is presented in the next chapter, while the site from which data were collected and methods used in collecting them are presented below.
3.2 Site description:

Discharge measurements were made with current meters in the Gezira Main Canal and three minor canals of the Gezira irrigation network. The measurements in the Main canal were made at Kilo 77 Wad Elswa, while the minor canals were selected from Wadi Elswa block situated about 35 km south of Kassala City.

Kilo 77 Wad Elswa was selected for the discharge measurements because, it is the last station where the sediments are usually accumulated before being reported to the irrigation authorities at Sonar Dam. Minor canals from Wadi Elswa block were chosen for discharge measurements for the following reasons:

1. The block closely represents the Gezira with respect to climate, topography and soil.
2. It is close to Kilo 77 Wad Elswa (about 3 km) and thus more convenient for taking the measurements in both the Gezira Main Canal and minor canals. The discharge measurements were restricted to minor canals which irrigate fields within Wadi Elswa block only.
Plate (3.1) Vane (propeller) type current meter

Plate (3.2) The digi-counter of the current meter
A study carried out at the hydrology laboratory of Wadi Hadhrami revealed that under suitable conditions of measurements, both types gave about the same readings. In this study, differences in readings between the two types of current meters were assumed to be negligible in the context of irrigation practice of the Ozaire scheme. Measurements were made at three periods during the crop growing season, namely:

1. Following the rainy season when the irrigation water requirement is relatively low and referred to as establishment period (September - October).

2. Peak water requirement (October - November) period. Normally this period extends from mid October to end of November.

The first and second periods are during the base flow of the Nile, during which the irrigation water requirement is usually satisfied by the natural flow of the Nile.

3. Late season (December - January) period where some crops such as dura and groundnut were already
harvested. During this period the irrigation water requirement is supplied from that stored in the dam.

It has to be emphasised that whether the measurements were taken in the main or minor canals, the method of calculation of the discharge in both was the area-integration method described in section 2.5. This method was claimed to be the most accurate for the calculation of discharges (Israelson, 1962).

The procedure followed in obtaining the readings from both the main and minor canals is described in the following sections.

3.3.1 The Main Canal Measurements:

In the Main Canal a boat was used to facilitate movement from one bank to the other and to carry a winch and a metering device (Plate 3.3). The winch was used for the transfer of the propeller from one point to another during the measurement, while the metering device was used to measure the depth at which
The readings were to be taken. The propeller was kept perpendicular to the direction of the flow by a tail and a stabiliser of 25 kg weight. A plastic robe marked at 2 and 4 metres was used to determine the horizontal distance of measurement throughout the width of the main canal. Discharge forms were used for recording the number of revolutions per minute at each point of measurement. The plastic robe used to determine the distance of measurements also guided the boat from one point to the other across the main canal.

The propeller was put exactly at the surface of the water and the metering device was adjusted to the zero reading. Then the metering device was turned and the propeller sunk down until it reached the bottom of the main canal. The arrival of the propeller to the bed of the canal was detected by the degree of tension in the metallic robe of the winch. The reading at the metering device plus 15 cm (i.e. the distance between the stabilizing weight and the body of the propeller) gave the depth at the first point. This
was divided by two to determine the half depth at which the propeller must be located (\( \frac{d}{2} \)).

A mean of these one-minute readings was taken to represent the number of revolutions per minute from which revolutions per second were calculated.

From the calibration table, the velocity of flow corresponding to the number of revolutions at each location was determined. The sub-area of the channel was calculated from the measured depth and determined width. In this calculation the irrigation canal was assumed to be rectangular in shape. Using equation (2.1) the measured velocity (m/sec) was multiplied by the sub-area to give the discharge (\( m^3/sec \)). The total discharge was the summation of the discharges in all the sub-areas.

3.3.2 Measurements of the discharge in the minor canals:

The site of measurements within the minor should be at least 50 metres from the minor off-take, which was necessary for more accurate readings of the current meter (Younard, 1975).
Plate (3.3) Boat used for crossing the Cazira Main canal.

Plate (3.4) Wooden ladder to facilitate movement across the minors.
in metres per second was determined. This was multiplied by the corresponding area to obtain the discharge \( q \) at the point. The total discharge is determined by the summation of individual discharges at all points similar to that of Majnu canal.

3.4 Meteorological data:

Meteorological data were obtained from the meteorological station of Wadi Hadram research station (Appendix 3). The informations of climatological normals were monthly means of 30 years (1951 - 1980) data. The data on sunshine duration, temperature, relative humidity, and wind speed were used in Penman combination equation to calculate the reference crop evapotranspiration. The guidelines of De Penman and Peith (1977) were followed in these calculations.

3.5 Procedure of the calculation of crop water requirements:

The reference crop evapotranspiration was calculated for each month of the year (Appendix 4). The crop water requirement was the result of multiplying the reference crop evapotranspiration by the appropriate
Crop coefficient i.e:

\[ \text{CWR} = \text{ETo} \cdot Kc \]  

(3.1)

where:

\( \text{ETo} \) = Reference crop evapotranspiration in mm
\( Kc \) = Crop coefficient (Section 2.6)

This was calculated relative to the stage of growth of the crop, the growing season and the prevailing weather conditions. In this calculation the crop growing cycle was assumed to follow the recommendations of the Desira research station. The area of each crop in the three minor (i.e. Wadiatya, Ayse and Shanam) were obtained from the record of the block headquarters.

The monthly crop water requirement was obtained by multiplying the area of each crop by the crop water requirement during the particular month. The total water requirement for the minor concerned was assumed to be represented by the summation of water requirement for each crop grown in that minor, which must be available for irrigation. This was compared with the available water measured by the current gauge at that particular time.
In this chapter field measurements with current meters from the Gezira Main and minor canals are presented. These are compared with crop water requirements predicted from weather data obtained from Wad Medani meteorological station. The amount of water calculated with equation 2.5 together with that indentified by the block inspectors are also shown. From these results assessment and evaluation of irrigation in the Gezira are obtained using analytical and statistical relationships.

Despite the errors involved in estimating the crop water requirements from weather records, they are assumed to represent the crop water needs. While that measured with current meters represented the water available for irrigation in irrigation canals. These results are presented in the following sections:

4.1 Main canal results:

Table (41) shows the discharge measurement made in the Gezira Main canal using the two types
It can be seen that there is a variation in depth between points selected for taking the measurements. This variation could be attributed to silt deposition at the bed of the main canal. Nevertheless, these variations were expected and irrigation canals are less likely to be uniform in depth throughout their length. The velocity of flow and the corresponding measured discharge were almost the same in all periods except in January (Table 4.1). However, there were differences between the measured and calculated discharges at all points. The measured discharge exceeded the calculated one by about 6 to 19 percent (Table 4.1).

The measured discharge was correlated with that calculated in (Figure 6.1). The correlation coefficient and intercept of the curve are 0.92 and 3.33 respectively, indicating that equation 2.5 reasonably reflected the seasonal variation of the crop water needs.

4.2 Minor canal results

In this section the current meter measurements were compared with the crop water requirement predicted
of current meters (i.e. Currey's cup-type and Cissell's propeller-type) current meters. It also shows the depth of measurements and velocity of flow in the Giza Main canal. These were compared with the discharge calculated using (equation 2.5).

### Table 4.1: The depth (m) the mean velocity of flow (m/sec.), the measured and calculated discharge (million cubic metres) in the Giza Main canal.

<table>
<thead>
<tr>
<th>Variables</th>
<th>August (7-9th)</th>
<th>September (27-29th)</th>
<th>November (14-15th)</th>
<th>January (3-8th)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>2.3</td>
<td>2.9</td>
<td>2.6</td>
<td>2.4</td>
<td>2.55</td>
</tr>
<tr>
<td>Mean velocity</td>
<td>0.87</td>
<td>0.85</td>
<td>0.85</td>
<td>0.92</td>
<td>0.82</td>
</tr>
<tr>
<td>*Measured discharge</td>
<td>10.09</td>
<td>10.7</td>
<td>11.5</td>
<td>9.0</td>
<td>10.32</td>
</tr>
<tr>
<td>**Calculated discharge</td>
<td>9.4</td>
<td>8.7</td>
<td>9.4</td>
<td>7.7</td>
<td>8.8</td>
</tr>
</tbody>
</table>

* Measured discharge using current meter
** Calculated discharge using Equation (2.5)
presented. These are compared with crop water requirements predicted from weather data obtained from Wadi Haidari meteorological station. The amount of water calculated with equation 2.5 together with that indicated by the block inspectors are also shown.

From these results assessment and evaluation of irrigation in the Gezira are obtained using analytical and statistical relationships.

Despite the errors involved in estimating the crop water requirements from weather records, they are assumed to represent the crop water needs. While that measured with current water represented the water available for irrigation in irrigation canals. These results are presented in the following sections:

4.1 Main canal results:

Table (16) shows the discharge measurement made in the Gezira Main canal using the two types
The relation between the measured and calculated discharge using current meter and equation (2.5) respectively.
from weather data. As mentioned before, these measurements were obtained from three stations, namely: Wadailiya, Dynya, and Shenns located in the southern group of the Sudan Gezira board.

Table (4.2) shows the predicted amounts of water estimated using the prevailing weather data in the Poeman combination equation (Appendix 4) and the measured discharge using Olba current meter together with the amounts indented by the block inspectors for Wadaintaya minor.

Table 4.2: The measured, predicted and indented amounts of water in thousands cubic metres for Wadailiya minor.

<table>
<thead>
<tr>
<th></th>
<th>October (4-5th)</th>
<th>November (15-16th)</th>
<th>January (2-3rd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>26,000</td>
<td>31,000</td>
<td>27,000</td>
</tr>
<tr>
<td>Predicted</td>
<td>33,000</td>
<td>30,000</td>
<td>23,000</td>
</tr>
<tr>
<td>Indented</td>
<td>64,000</td>
<td>62,000</td>
<td>51,000</td>
</tr>
</tbody>
</table>

*Measured discharge using current meter
** Predicted discharge using Poeman combination equation
*** Indented discharge by the block inspector
It can be seen that there is a variation in both the measured and predicted amounts of water (Table 4.2). The predicted discharges were always greater than those measured except during January. It also shows that the water intended by the block inspector during January was the same as that in November. However, the predicted amount of water was relatively great in October than November period. This could be attributed to the fact that discharge measurements were taken early in October while the predictions covered the whole month during which wheat might be watered and/or planted (Table 4.2).

Table (4.3) shows the predicted amounts of water from weather records (Appendix 4) in the Penman combination equation and the measured discharge (current meter) together with the amounts intended by the block inspectors for Dywan water. Similarly, the predicted amounts of water were greater than those measured during October and November periods while the reverse was true during January. Considering the intended discharge it was greater in November than
in October and January and greatly exceeded the predicted during all periods. However, the amounts of water indented in October the same as those indented in January despite the differences in weather, type and stage of growth of the crops grown in the field (Table 4.5).

Table 4.5: The predicted, measured and indented amounts of water in thousands cubic meter for Ryuma minor canal.

(Each figure is a mean of three measurements)

<table>
<thead>
<tr>
<th></th>
<th>October (4-6th)</th>
<th>November (15-18th)</th>
<th>January (2-4th)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured discharge</td>
<td>19,000</td>
<td>22,000</td>
<td>36,000</td>
</tr>
<tr>
<td>Predicted</td>
<td>35,000</td>
<td>32,000</td>
<td>28,000</td>
</tr>
<tr>
<td>Indented</td>
<td>61,000</td>
<td>61,000</td>
<td>61,000</td>
</tr>
</tbody>
</table>

* Measured discharge using current meter
** Predicted discharge using Penman combination equation
*** Indented discharge by the block inspectors
Table (4.4) shows the predicted amounts of water using the weather records (Appendix 4) and measured discharge (using current meter) together with the amount of water indicated by the block inspectors.

Table 4.4: The measured predicted and indicated amounts of water in thousands of cubic metres for Shanen minor canal.

(Each figure is a mean of three measurements)

<table>
<thead>
<tr>
<th></th>
<th>October (4-6th)</th>
<th>November (15-16th)</th>
<th>January (3-4th)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured discharge</td>
<td>12,000</td>
<td>10,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Predicted</td>
<td>24,000</td>
<td>20,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Indicated</td>
<td>28,000</td>
<td>22,000</td>
<td>20,000</td>
</tr>
</tbody>
</table>

* Measured discharge using current meter
** Predicted using Penman combination equation
*** Indicated discharge by the block inspectors
Table (4.4) shows that the indicated discharges were the same in October and November period and exceeded the predicted and measured discharges during all periods considered (Table 4.4). The crop water requirement obtained from weather records was almost double that measured in October and November, indicating a shortage of water during those periods.
Figure (4.3) summarizes the relation between the measured and predicted discharge for the three minor and periods of measurements. They show good correlation with a correlation coefficient of 0.96 and an intercept of 3.22. The correlation coefficient of the calculated and measured discharges in the main canal Figure (4.1) was less than the correlation coefficient of the measured and predicted discharge in the minor canals Figure (4.3). While, the intercepts of the curves were nearly the same being 3.13 and 3.22 in the Main and Minor canals respectively.
Predicted discharge in thousand cubic meter/day vs. Measured discharge in thousand cubic meter/day

\[ y = 3.22 + 0.965x \]

Figure 43: The relation between the measured and predicted discharge of the three minutes considered and periods of measurement.
5.1 Criteria:

The purpose of evaluating irrigation systems was defined by Harris (1960) as:

a) To determine the efficiency of the system as it is being used.

b) To determine how effectively the system can be operated and whether it can be improved.

c) To obtain information that will assist engineers in designing other systems, and operating procedure as a basis for economic decision.

However, it is hardly possible to evaluate a large scheme as Giza. Nevertheless, whatever minor improvement has been introduced into the system, the benefit will certainly be economically encouraging. In this study a criterion for evaluating how effective the system is operating in order to forward suggestion for improvement was adopted. This was mainly comparing measurements of discharge in irrigation canals with those obtained from calculation methods or predictive
techniques. A similar procedure was followed by Badra (1977) when comparing current meter measurements with equation for calculating the mean stream velocity or the cumulative flow over a period of time. His study was to develop a measuring device to determine the discharge from the minor canal to Abu XX.

5.2 Main Canal results:

The control of water was carried out in Gezira scheme by racks and weir gates and movable coirs and pipes of different sizes. With racks and weir gates, control is usually based on individual gauge-discharge curves of the downstream water level or formulating a constant obtained from current meter measured discharge (Matthew, 1972).

As seen in Table (4.1), the measured discharge was always greater than that calculated by equation (3.5). Accepting the errors encountered in the current meter measurements, there is an indication that the water available for irrigation was underestimated. This implied that excess water may be discharged at the
time when not required in the field, which could be a direct reason for the breakage of the irrigation canal observed in recent years. This underestimation of irrigation water is obviously a drawback of the equation used in these calculations. However in the equation used (i.e equation 2.5) certain parameters were underestimated. These parameters included: acceleration due to gravity and the secondary flow. Although it might not be possible to incorporate these parameters, their effect could be covered for in choosing the appropriate coefficient within or even above the range reported by Israelson (1962) and Venard (1975). The range suggested by the authors was 0.8 to 0.9 while that used in equation (2.5) was 0.87.

The regression line and the co-relation coefficient shown in figure 4.1 indicated that the measured and calculated discharges were in close agreement. Accordingly the irrigation water management within the main canal can be considered satisfactory. Similar remarks were made by Farbrother and Adam (1977).
5.3 Minor canal and meteorological results:

The estimation of the crop water requirement from weather data and its practical utilization in the irrigation water management is becoming increasingly important, particularly in arid and semi-arid irrigated areas of the world (Jensen, 1974; Seegman et al, 1980). This is probably because the technique is relatively easy to obtain and can be generated from one locality to another and over time. Accordingly in large schemes, like Gezira, the use of weather-based techniques as a tool in water management practice has got a great potential.

A study on evaluating the accuracy of sixteen weather-based methods for estimating crop water requirement by comparing their estimate with lysimeter data covering a wide range of climatic conditions was conducted by Jensen (1974). He concluded that the range of accuracy varied from 23 percent to 53 percent for all the methods with the combination equation giving the least error and the best line of fit. The
version of combination equations used in this study was that reported by the FAO (Doorenbos and Pruitt, 1977) and ASAE (Stegman et al., 1980). However the Peauser type combination equation is a data demanding and requires great computation and skill end this often claimed as a disadvantage in using it. With advent of computers, its application has been not more than a routine, when used in appropriate computer program (Siddiq, 1982).

The weather data (Appendix 4) and the crop data (Table 2.3) used in the combination equation to predict the crop water requirement were obtained from the Gezira research station and thus assumed to represent the conditions over the Gezira scheme.

The predicted water requirement was greater than that measured during October and November and less than it in January period (Table 4.2 - 4.4). While October and November were peak water requirements periods, the January period was a late season stage. During peak water requirements cotton, groundnut and
dust were under irrigation, while wheat was pre-watered in early October and planted by mid October. On the other hand, in January there was only cotton and wheat to be irrigated and thus water in irrigation canals was greater than required. As reported in the Newsletter of International Irrigation Centre (1980) increasing the cropping intensity increases water demand during the peak month of October and November which approaches the system capacity limit of 32 million cubic meters per day.

It has been reported by Fetterman (1978) that despite of rapid intensification of agricultural system from 45 percent to 76 percent cropping intensity, the overall efficiency of water use still appears to be as good or even better than 87 percent. This doesn’t mean that irrigation was properly applied because there is a seasonal variation in the availability and use of water (Table 4.2 - 4.4). Carr (1986) stated that efficient irrigation depends on applying the right amount of water at the right time as uniformly as possible across the field.
5.4 Water Irrigation.

Discharge from the optimum water holding capacity of Cezara soil is around 960 m³/hectare (Farbrother 1974). If the figure in the field-outlet pipe of 5000 m³/day was accurate and 37.5 hectare block takes an average irrigation interval of 12 days, then the water supplied by each field outlet pipe within this interval would be 60,000 m³. Since the water holding capacity of the Cezara soil is about 960 m³/hectare the water requirement for a block of 37.5 hectare would only be 38,000 m³. Indicating an excess watering of about 22,000 m³ (i.e. 40 percent) which is either lost by evaporation or deep percolation. However, deep percolation losses under Cezara clay is practically negligible (Farbrother, 1974). Therefore the assumption that each field outlet pipe should supply 5000 m³ per day lead to overwatering of field crops. Fortunately measurements of discharges from selected field outlet pipes by Farbrother (1974) have shown variation from 1000 – 8000 m³ per day. In
action the water indented was always greater than that measured or predicted and thus not satisfied by the irrigation authorities. Accordingly, the present water indenting policy should be improved on basis of more rational and scientific techniques.
This research investigated the current irrigation practice in the Gezira with the object of assessing it relative to modern water management techniques. This involved comparing the existing irrigation practice with discharge measurements from irrigation canals and crop water requirement estimated from weather records. The technique used by the Ministry of Irrigation for calculating the discharge in the main canals together with that used by the field inspectors in the minor canals were also evaluated. Obviously, the art of irrigation or the experience and judgment of the farmer cannot be replaced but merely supplemented by modern techniques and technology.

This study revealed that the irrigation practice in Gezira can be improved through:

1. Improving the system of water delivering into the irrigation canals.
2. Adjusting the crop rotation relative to the water available for irrigation.
3.1 Improving the Collection of Water Indicating into the Irrigation Canals:

The existing indicating system depends greatly on the experience and judgment of the block inspectors. Estimation of crop water requirement from weather records and its incorporation in the day-to-day water management in the Gezira scheme was advocated few years ago (Farbrother, 1977). So far it has not been used and it is high time to consider its application to schedule the irrigation of field crops. However, proper timing of agricultural operations in the field including dates of sowing and harvesting are equally important to consider for efficient water management.

The coefficient of 0.87 used in equation 2.5 to calculate the discharge in the Gezira main canal should be increased within or above the range suggested by Israelson (1983).

5.2 Adjusting the Crop Rotation Relative to the Water Available for Irrigation:

As mentioned before the peak water requirement in the Gezira scheme occurs during October and November.
months. This coincided with the development phase of cotton and groundnut which were at an increasing water use rate and the planting of wheat. To alleviate the stress on these crops the crop rotation or the agricultural operations need to be adjusted.

However, there was an excess water during January. This excess water should either be discharged in the Nile downstream or used to irrigate new crops such as fodder or vegetables.

5.3 Suggestions for further investigation:

The practice of irrigation in the Gezira scheme is large to be evaluated in a single research project. While this study indicated the problem and initiated the research in this field, other parts of the problem should be investigated by further research there are:

1. Efficiency of irrigation in the Gezira which should include both the conveyance and application efficiencies on the farm.
2. The practice of irrigation on the farm and uniformity of water application through identifying the length of run and width of individual watered units within the same field.

3. Proper allocation of water between competing crops on the same field. This might involve crop yield models describing the watering regime of individual crops leading to identifying the production per unit of land or water used.
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Appendix

Appendix No. 1

Crop Water Requirement
Indenting in the desire.

Table of Crop-Water-Requirement
(Prepared under FAP/DFE Project:
(Per brother) 6/CUB/OLP)
The water requirements, from planting to harvest, of a number of irrigated crops, when grown to good standards of husbandry in the Gising area. - In cubic metres per feddan per day, averaged over 10/11 day periods, ($\frac{1}{2}$ months), for the year of average weather.

(4.2 cubic metres per feddan = 1 mm)
Since the rapid intensification and diversification of the rotations, the Management of the Gable Gereya Board has come to recognize the increasingly urgent need to improve the standards of 'Indenting' for water supplies in the Gereya and Magall.

Now, under the terms of FAO Technical Co-operation project 6/128/01 N, the new "Crop-Water-Requirement" (CWR) method of Indenting is being introduced to the commercial areas, after the initial field trials had proved satisfactory.

CWR Indenting calls for two basic inputs:

(a) The total soddas actually planted, (or expected to be planted), by the tenants on any individual Minor Canal, covering each cropping component of the rotation by successive 10/11 day periods.

(b) The mean water requirement in cubic metres per soddam per day, for each crop over its normal length of season, in years of average climatic conditions.
These Tables of "Crop-Water-Requirement" provide all that is necessary under (b) above. They have been extracted from various papers and annual Reports published at the Gezira Research Station over recent years; and are brought together here with acknowledgments to the Director-General of the Agricultural Research Corporation. The author is grateful to him for his permission to circulate these Tables as a 'working paper' under this FAO Project.
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**Cotton**

Acala Cotton

A medium-staple variety.

**Crop-Harvest**

Standards of

Crop-Harvest Day.

(For current commercial standards, see page 4.)

**Crop-Water-Requirements**

Inches per period per day.
Actually planted in these periods

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Dec 1-10 21.3 25.8 28.2 28.4 28.2
11-20 17.0 20.9 25.3 27.2 27.5
21-31 15.6 17.2 21.1 25.2 27.5

Jan 1-10 16.2 15.7 17.3 21.2 25.4
11-20 18.3 16.4 26.0 17.6 21.6
21-31 22.7 20.0 17.6 17.1 16.9

Feb 1-10 28.9 24.2 21.5 18.8 18.3
11-20 28.6 28.6 25.7 25.7 25.0
21-30 29.3 29.3 29.8 29.8 26.6

Mar 1-10 31.1 31.1 31.1 31.1 31.1
11-20 31.9 31.9 31.9 31.9 31.9
21-31 33.2 32.2 33.2 33.2 33.2

CROP-WATER-REQUIRE EARM COTTON
MEETING PER MONDAY PER DAY.
Actually planted in these periods
Month  Jun  Jul  Aug  Sep  Oct  Nov  Dec
  Jun  1-10   PD
  "     11-20   20.2  PD
  "     21-30   38.5  19.3  PD
  Jul  1-10   21.1  18.9  19.8  PD
  "     11-20   22.6  19.6  17.8  16.6  PD
  "     21-31   33.9  20.9  18.1  18.3  15.4
  Aug  1-10   26.0  22.3  19.9  16.9  15.2
  "     11-20   27.6  24.6  21.5  19.6  18.1
  "     21-31   31.2  28.6  25.6  21.5  18.8
  Sep  1-10   31.5  31.2  28.9  26.9  22.3
  "     11-20   31.0  31.9  31.6  29.3  26.4
  "     21-30   29.9  31.0  31.1  31.3  29.3
  Oct  1-10   25.4  29.5  30.6  31.3  31.2
  "     11-20   22.2  24.6  28.1  29.6  30.5
  "     21-31   18.6  21.5  23.5  27.7  28.8
  Nov  1-10   19.6  17.9  20.8  23.1  26.6
  "     11-20   15.1  17.6  20.2  22.4
  "     21-30   14.6  16.6  19.5
  Dec  1-10   14.1  14.2
  "     11-20   13.6

Jelkford
MEAN MAX
& all long-term spreading varieties.
CROP-AREA
RECOMMENDED
IN
QUICK MOWING
PER FRIDAY
PER DAY.

Arbitrary dates of "water-stop", according to SOE administrative circular.

GRS research now recommends "Rich broadcasting" after 150 days
(Ref: Dr. R. Lembag)
Actually planted in these periods

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Water may be withheld over the last 10 days, without significant loss of yield.
## Crop-Water Requirements

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In calculating the Crop-Water Requirements of the wheat crop, it is particularly important to adhere strictly to the rule that "planting-date" refers to the date at which the '1st. Watering', or 'germination-watering', was completed.

The actual sowing, or drilling, of the seed, precedes the '1st. Water' in the case of sowing "on-the-dry", but follows into the soil soon as soon as the surface dries out sufficiently to take the tractor and drill. In both methods of planting, the cubic metres required for the '1st. Water' are almost identical.
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In calculating the crop-water-requirements of the wheat crop, it is particularly important to adhere strictly to the rule that "planting-date" refers to the date at which the 'last watering', or germination water, was completed.

The cubic metres required for 'last watering' are almost identical, irrespective of whether given immediately after sowing, or immediately before sowing (i.e. 'Tahdihal').
## Appendix 2

**MINISTRY OF IRRIGATION & H.E.S.**
**HILL WATER DEPARTMENT**
**HYDROLOGICAL SECTION**
**DISCHARGE FORM - PAGE 1**

**STATION: T.M.C**
**RIVER: K.77**
**DATE: 27.9.1960**
**DISCHARGE No: 1**
**TYPE OF CURRENT METER: SIRA**

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Summary of discharge observation:

Total discharge: 112.49

Mean velocity = \[
\frac{\text{total discharge}}{\text{total area}} = \frac{112.49}{0.20} = 562.45 \ m^2/\text{day}
\]

Max. depth = 3.25
D.S = 11.36
D.S = 7.98
Discharge = 8.308
### Appendix 4:

Area in feddums, water requirements in cubic meters for cotton, groundnut and water in Wadalatya, Pyura and Soman minors of Wadalatya block.

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*Grand Total of the mines*

| | 297,750 | 357,740 | 347,703 | 377,153 | 317,007 |

**Irrigation efficiency**

156,29
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<td>C.W.R.</td>
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<td>7883</td>
<td>10632</td>
<td>6432</td>
<td>6488</td>
<td>5775</td>
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<td>4- Wheat 227</td>
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<tr>
<td>( K_c )</td>
<td>0.93</td>
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<tr>
<td>C.W.R.</td>
<td>5402</td>
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<tr>
<td>Total C.W.R.</td>
<td>9682</td>
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<tr>
<td>GCWS Y.R. of the minor</td>
<td>10066</td>
<td>12431</td>
<td>3893</td>
<td>19740</td>
<td>15514</td>
<td>19326</td>
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<tr>
<td>( E_{irr} ) \times 100</td>
<td>12835</td>
<td>15725</td>
<td>24249</td>
<td>21153</td>
<td>19638</td>
<td>19606</td>
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</tbody>
</table>

**Notes:**
- \( E_{irr} \): Reference crop evapotranspiration in mm
- \( K_c \): Crop coefficient
- C.W.R.: Crop water requirement